IWA Water Reuse 2018

IWA Regional Conference on Opportunities for Water Reuse in Southeast Asia

ABSTRACT & PROCEEDING BOOK

October 30 – November 2, 2018

Phuket, Thailand

Organized by

Welcome Message from Chair

Dear Colleagues and Friends,

On behalf of the IWA Water Reuse Specialist Group Management Committee and the local organizing and program committees, it is my great pleasure to welcome you all to the 2018 IWA Regional Conference on Opportunities for Water Reuse in Southeast Asia in Phuket, Thailand. This is the first time an event of the Water Reuse Specialist Group takes place in Thailand underscoring the growing interest in water reclamation and reuse as an alternative water supply in Southeast Asia.

For this conference, we received a solid number of abstract submissions, which allowed us to assemble an exciting technical program that will feature some recent international developments and trends in embracing and further growing water reclamation and reuse but also technical advancements regarding treatment and water quality monitoring as well as lessons learned from regional water reuse projects. We are also fortunate to be in a great location to enjoy the spirit of Thailand.

Water reuse has come a long way in the last couple of decades. While water scarcity continuous to be a key driver for water reuse in many regions of the world that lack sufficent freshwater supplies, climate change impacts, rising energy prices, the need to mitigate greenhouse gas emissions, requirements for environmental restoration, the paradigm shift to resource recovery, or achieving the targets of the 2030 Sustainable Development Goals are other key factors that have resulted in adopting water reuse as an increasingly important component of sustainable water resource management worldwide.

This regional conference in the field of water reuse will feature many innovative projects and approaches offering many opportunities for water reuse applications in Southeast Asia. The conference will provide a platform to share and discuss the most recent experiences and advances in water reuse management, resource recovery and the role of water reuse in mitigating climate change impacts.

Finally, I'd like to thank our local host and sponsors on behalf of the WRSG Management Committee for working effortless and very professionally in preparing for this exciting event!

Enjoy the conference and networking with colleagues and friends!

Jörg E. Drewes

Chair, IWA Water Reuse Specialist Group

Welcome Message from Local Chair

Dear Participant,

I want to extend to you a warm welcome to the 2018 IWA Regional Conference on Opportunities for Water Reuse in Southeast Asia in Patong, Thailand. Our conference is meeting on the beautiful island of Phuket, the tourism destination consistently ranked in the top ten worldwide. This is the first time that the IWA International Conference on Water Reclamation and Reuse is being held in this region.

This regional IWA Water Reuse conference in Phuket focuses on opportunities for meeting the many challenges associated with the current rapid development in Southeast Asia. In addition, the conference features prominent experts in critical subjects, such as megacities and rural regions, high-tech and low-tech solutions, water reclamation, water reuse, distributed water treatment systems, water and tourism, and water reuse policy within cultures of Southeast Asia.

I encourage you to use this opportunity to expand your professional network and trust that you will participate fully in order to realize a beneficial experience. Our local team and I want to thank you very much for giving us the opportunity and the pleasure to prepare this conference venue at Patong, Phuket, Thailand. Now, we are ready to greet you with famous Thai hospitality.

Please do not forget to enjoy the gorgeous sites in Phuket during your attendance this year and please come back to Thailand again in the future.

Pongsak (Lek) Noophan, Ph.D.
Local Chair, Organizing Committee,
IWA Regional Conference on Opportunities
for Water Reuse in Southeast Asia in Phuket, Thailand.

Welcome Message from Local Co-Chair

Dear attendee of the conference,

It is a great pleasure and honor to welcome you to the conference at Phuket of this 2018 Regional IWA International Conference on Opportunities for Water Reuse in Southeast Asia. The Expert Centre of Innovative Materials at Thailand Institute of Scientific and Technological Research is very proud to organize the first IWA International Conference on Water Reclamation and Reuse in Thailand.

Water reuse has been becoming increasingly important around the world as the expansion of urban society, the growth of population and industry. Therefore to provide the adequate water supply, it's essential to have appropriate technologies to treat and recycle water. This regional conference will lead to the exchange of knowledge, technology learning, and networking. I believe that the management and new technology of water reuse can be the solution of water shortage in Southeast Asia.

In addition to the technical program, participants will also have the opportunity to explore the city of Phuket which has many of interests such as beautiful beaches, delicious food, local culture and traditions. The social program will also be set for participants to experience the beauty and attractions of the city to make this conference fulfill with both outstanding technology and good memorial to the venue.

I would like to thank conference committees for their respective contributions and also thank for all the sponsors of the conference. Finally, I wish you all have a nice time and enjoy staying in Phuket at the IWA 2018 regional conference.

Siriporn Larpkiattaworn, Ph.D

Local Co-Chair, Organizing Committee,
IWA Regional Conference on Opportunities
for Water Reuse in Southeast Asia in Phuket, Thailand.

Organizing Committee

Pongsak (Lek) Noophan, Ph.D.	Department of Environmental Engineering, Faculty of Engineering, Kasetsart University, Thailand
Siriporn Larpkiattaworn, Ph.D.	Thailand Institute of Scientific and Technological Research (TISTR), Ministry of Science and Technology, Thailand
Shane A. Snyder, Ph.D.	Department of Chemical and Environmental Engineering, University of Arizona, USA
Kwang-Ho Choo, Ph.D.	Division of Environment Engineering, Director of advanced Institute of Water Industry, Kyungpook National University, Republic of Korea
Olivier Lefebvre, Ph.D.	Department of Civil and Environmental Engineering, National University of Singapore, Singapore

Program Committee

Jörg E. Drewes, Dr.-Ing.	Technical University of Munich (TUM), Germany
Shane A. Snyder, Ph.D.	University of Arizona, USA
Kwang-Ho Choo, Ph.D.	Kyungpook National University, Korea
Olivier Lefebvre, Ph.D.	National University of Singapore, Singapore
Siriporn Larpkiattaworn, Ph.D.	Thailand Institute of Scientific and Technological Research (TISTR), Thailand
Jonathan Clement	Global Technology Leader, Nanostone, the Netherlands
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Chongrak Polprasert, Ph.D.	Thammasat University, Thailand
Thumrongrut Mungcharoen, Ph.D.	Chairman of Energy and Environment Cluster, National Science and Technology Development Agency, Thailand
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Satoshi Okabe, Ph.D.	Hokkaido University, Japan
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Sanya Sirivithayapakorn, Ph.D.	Kasetsart University, Thailand
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Siwaruk Chotiwan, Ph.D.	Thailand Institute of Scientific and Technological Research (TISTR), Thailand

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Jörg E. Drewes, Dr.-Ing.	Technical University of Munich (TUM), Germany
Chongrak Polprasert, Ph.D.	Thammasat University, Thailand
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Stuart Khan, Ph.D.	University of New South Wales, Australia
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Olivier Lefebvre, Ph.D.	National University of Singapore, Singapore
Chalermraj Wantawin, Ph.D.	Kasetsart University, Thailand
Pongsak (Lek) Noophan, Ph.D.	Kasetsart University, Thailand (secretary of scientific committee)

Local Organizing Committee

Chongrak Wachrinrat, Ph.D.	Acting President, Kasetsart University, Thailand
Peerayuth Charnsethikul, Ph.D.	Dean of Faculty of Engineering, Kasetsart University, Thailand
Wirach Chantra	Acting Governor, Thailand Institute of Scientific and Technological Research (TISTR), Ministry of Science and Technology, Thailand
Aparat Mahakhant, Ph.D.	Deputy Governor Research & Development for Sustainable Development, Thailand Institute of Scientific and Technological Research (TISTR), Ministry of Science and Technology, Thailand

Keynote Speakers

Professor Jörg E. Drewes, Ph.D.

Chair IWA Water Reuse Specialist Group, Chair Professor of Urban Water Systems Engineering at the Technical University of Munich, Germany

Professor Shane A Snyder, Ph.D.

Nanyang Technological University, Singapore, University of Arizona, USA

Mr. Moh Tiing Liang

Deputy Director for International Relations & Capability, IDDPUB, Singapore's National Water Agency

Dr. Wijarn Simachaya

Director General of Pollution Control Department, Ministry of Natural Resources and Environment, Thailand

Professor Chongrak Polprasert, Ph.D.

Thammasat University, Thailand

Professor Jeyong Yoon, Ph.D.

Seoul National University College of Engineering, Korea

Invited Speakers

Professor Kwang-Ho Choo, Ph.D.

Director of Advanced Institute of Water Industry, Kyungpook National University, Korea

Dr. Keith A. Maruya, Ph.D.

Head of SCCWRP's Chemistry Department and an Environmental Scientist, South California Coastal Water Research Project Authority, USA

Associate Professor Rachnarin Nitisoravut, Ph.D.

Thammasat University, Thailand

Professor Stuart Khan, Ph.D.

University of New South Wales, Australia

Program at a glance

TIME	OCT 30, 2018 (TUE)	OCT 31, 2018 (WED)	NOV 01, 2018 (THU)	NOV 02, 2018 (FRI)
08:30	Registration	Registration	Registration	Registration
09:00	Workshop Sessions	Opening Ceremony Keynote Sessions	Keynote Sessions	Keynote Sessions Oral Sessions
10:00	Networking Break	Networking Break	Networking Break	Networking Break
	Workshops Sessions	Keynote Sessions	Poster Sessions	Oral Sessions
11:00			Oral Sessions	Closing Ceremony
12:00	Lunch	Lunch	Lunch	Lunch
13:00	Workshops Sessions	Invited Speaker Oral Sessions	Invited Speaker Oral Sessions	Technical Tour
14:00	Networking Break	Networking Break	Networking Break	
15:00	Workshops Sessions	Invited Speaker Oral Sessions	Invited Speaker Oral Sessions	
16:00				
17:00	Welcome Reception	Phuket Night Tour	Banquet Dinner	
18:00				
19:00				
20:00				
21:00				

Daily Program

TUESDAY, OCTOBER 30, 2018

08:30 - 17:00	**Registration Open** Room: Orchid Grand Ballroom (2nd floor)
09:00 - 10:00	**Workshop Session I:** Water reuse professionals development and integration ***Assoc. Prof. Olivier Lefebvre, Dr. Orlando Garcia Rodriguez and Dr. Hugo Olvera Vargas****, Ph.D., National University of Singapore* ***(Singapore)*** Room: Bu-Nga (3rd floor)
10:00 - 10:30	**Networking Break** (3rd floor)
10:30 - 12:00	**Workshop Session I:** Water reuse professionals development and integration (Continued) ***Assoc. Prof. Olivier Lefebvre, Dr. Orlando Garcia Rodriguez and Dr. Hugo Olvera Vargas****, Ph.D., National University of Singapore* ***(Singapore)*** Room: Bu-Nga (3rd floor)
12:00 - 13:00	**Lunch** Room: Sunset (1st floor)
13:00 - 14:30	**Workshop Session II**: Membrane reactors for water and wastewater engineering ***Professor Kwang-Ho Choo****, Ph.D., Director of Advanced Institute of Water Industry, Kyungpook National University* ***(Korea)*** Room: Bu-Nga (3rd floor)
14:30 - 15:00	**Networking Break** (3rd floor)
15:00 - 17:00	**Workshop Session II**: Membrane reactors for water and wastewater engineering (Continued) ***Professor Kwang-Ho Choo****, Ph.D., Director of Advanced Institute of Water Industry, Kyungpook National University* ***(Korea)*** Room: Bu-Nga (3rd floor)
17:30 - 20:00	**Welcome Reception** Location: Sky Pool (3rd floor)

WEDNESDAY, OCTOBER 31, 2018

08:30 - 17:00	**Registration Open** Room: Orchid Grand Ballroom (2nd floor)	
09:00 - 09:15	**Opening Ceremony** Room: Orchid Grand Ballroom (2nd floor)	
09:15 - 10:25	**Opening Keynote Session**	
	1st keynote (09:15 - 09:50)	Current and future of water reclamation and reuse ***Professor Jörg E. Drewes****, Ph.D., Chair IWA Water Reuse Specialist Group, Chair Professor of Urban Water Systems Engineering at the Technical University of Munich* ***(Germany)***

	2nd keynote (09:50 – 10:25)	Water reclamation and reuse in Asia ***Professor Shane A Snyder***, *Ph.D., Nanyang Technological University* ***(Singapore)***		
10:25 - 10:40	**Networking Break** (2nd floor)			
10:40 - 11:50	**Keynote Session**			
	3rd keynote (10:40 – 11:15)	Water reclamation and reuse in Singapore ***Mr. Ong Key Wee,*** *Chief Engineer of Water Supply (Plants) Department of PUB* ***(Singapore)***		
	4th keynote (11:15 – 11:50)	Water reclamation and reuse in Thailand ***Dr. Wijarn Simachaya***, *Director General of Pollution Control Department, Ministry of Natural Resources and Environment* ***(Thailand)***		
11:50 -12:00	**Panel Discussion**			
12:00 - 13:00	**Lunch** Room: Bua Laung (1st floor)			
13:00 - 13:30	**1st Invited speaker:** Quorum quenching bacterial sheets for effective biofouling control in membrane bioreactors ***Professor Kwang-Ho Choo***, *Ph.D., Director of Advanced Institute of Water Industry, Kyungpook National University* ***(Korea)*** Room: Orchid Grand Ballroom (2nd floor)			
Technical Sessions	***Room: Dalah II (3rd floor)*** **A-I: Membrane Technologies (Part I)**		***Room: Dalah III (3rd floor)*** **B-I: Advanced Treatment Technologies**	
Moderator	**Professor Kwang-Ho Choo/ Dr. Siriporn Larpkiattaworn**		**Professor Michael A. Urynowicz/ Dr. Somchai Dararat**	
13:30 - 14:30	WR-A01 (13:30 – 13:50)	Development of an electrode-assisted membrane bioreactor (e-MBRs) for water reuse: anode respiration on the membrane fouling ***Satoshi Okabe****, K. Terada, S. Ishizaki.* ***(Japan)***	WR-B01 (13:30 – 13:50)	Degradation of ibuprofen through the continuous adsorption and regeneration of activated carbon using electrochemical technologies ***Orlando García-Rodríguez,*** *R.R. Chua, A. Villotb, C. Gérente, Y. Andrès, Y. L. Fang, H. Jiangyong, O. Lefebvre.* ***(Singapore)***
	WR-A02 (13:50 – 14:10)	Stand-alone and hybrid membrane processes for reclamation and reuse of domestic wastewater ***Sarper Sarp (UK)***	WR-B02 (13:50 – 14:10)	Removal of perfluorooctanoic acid (PFOA) from wastewater by electrocoagulation process *M.-K. Kim,* ***Kyung-Duk Zoh (Korea)***
	WR-A03 (14:10 – 14:30)	New membrane integrated processes for the reuse of high salinity wastewater *J. Kim, J. Kim,* ***Seungkwan (SK) Hong*** ***(Korea)***	WR-B03 (14:10 – 14:30)	Electrochemical detection of low and ultra-low concentrations of heavy metals in natural waters *G. Lisak, J. Boback,* ***Ge Liya (Singapore)***

14:30 - 14:40	**Networking Break** (2nd floor)			
14:40 - 15:20	WR-A04 (14:40 – 15:00)	Development chitosan forward osmosis membrane for desalination of sea water ***Saiful****, A. Afriyanti, Marlina, M. Ramli, N. Mahmud* ***(Indonesia)***	WR-B04 (14:40 – 15:00)	Use of leachate of saline-alkali land for oleaginous microalga growth and lipid accumulation *Y. He,* ***Yu Hong,*** *Y. Liu* ***(China)***
	WR-A05 (15:00 – 15:20)	Energy consumption in baffled membrane bioreactor (B-MBR) ***Taro Miyoshi****, T.P. Nguyen, T. Tsumuraya, K. Kimura, Y. Watanabe* ***(Japan)***	WR-B05 (15:00 – 15:20)	Electro-Fenton treatment of pharmaceutical pollutants at near-neutral pH using tripolyphosphate ***Hugo Olvera-Vargas****, V. Wee Yong Han, O. Lefebvre* ***(Singapore)***
15:20 - 15:50	**2nd Invited speaker:** Staged development of a bioscreening toolbox for recycled and ambient water monitoring and assessment ***Dr. Keith A. Maruya,*** *Ph.D., Head of SCCWRP's Chemistry Department and an Environmental Scientist, South California Coastal Water Research Project Authority* ***(USA)*** Room: Orchid Grand Ballroom (2nd floor)			
Technical Sessions	***Room: Dalah II (3rd floor)*** **A-II: Membrane Technologies (Part II)**		***Room: Dalah III (3rd floor)*** **B-II: Sustainable Technology and Management**	
Moderator	**Dr. Keith A. Maruya/ Assoc. Prof. Sanya Sirivithayapakorn**		**Professor Satoshi Okabe/ Assist. Prof. Suchart Leungprasert**	
15:50 – 17:30	WR-A06 (15:50 – 16:10)	Simultaneous removal of DOM and nitrate from sewage treatment plant effluent by a photocatalytic membrane *H. Xu,* ***Yang Li****, M. Ding, W.C., K. Wang, C. Lu* ***(China)***	WR-B06 (15:50 – 16:10)	Demanding a change from wastewater treatment to resources recovery and zero liquid discharge in China – how have the government and industrial sectors reacted? ***Daniel M. Cheng****, V.C. Li* ***(Hong Kong)***
	WR-A07 (16:10 – 16:30)	A membrane-aerated biofilm reactor for efficient single-stage nitrogen removal and mitigation of nitrous oxide emission: Proof-of-concept from biofilm depth profile analysis ***Akihiko Terada****, C.T. Kinh, .T Suenaga, T. Hori, S. Riya, M. Hosomi* ***(Japan)***	WR-B07 (16:10 – 16:30)	Evaluation of micro pollutant removal in aquaculture wastewater treatment process using dynamic light scattering technique ***Fatehah Mohd Omar****, F. Rakbi* ***(Malaysia)***

	WR-A08 (16:30 – 16:50)	Direct filtration of treated wastewater using gravity-driven membrane system with periodic manual cleaning as appropriate water reuse technology for developing countries: a real-scale experiment ***JongChan Yi***, *J. Lee, H Kim, P.-K. Park, S.H. Noh* ***(Korea)***	WR-B08 (16:30 – 16:50)	Water reuse eco-toilets for tourism challenges and sustainable development: from conceptual evolvement to reality advancement *D.M. Cheng and* ***Victor C. Li*** ***(Hong Kong)***
	WR-A09 (16:50 – 17:10)	Woven fiber microfiltration (WFMF) and ultraviolet (UV-C) light emitting diodes for water reuse in low- to middle-income countries ***Sara Beck****, H. Nguyen, P. Suwan, E. Ovie, T. Rathnayeke, T. Koottatep* ***(Switzerland)***	WR-B09 (16:50 – 17:10)	Synergistic opportunities to utilize impaired waters in coastal regions ***Andrea Achilli****, K.T. Sanders, A.E. Childress* ***(USA)***
17:30 - 21:30	**Phuket Night Tour**			

THURSDAY, NOVEMBER 01, 2018

08:30 - 17:00	**Registration Open** Room: Orchid Grand Ballroom (2nd floor)		
09:00 - 10:10	**Keynote Session**		
	1st keynote (09:00 - 09:35)	Sustainable wastewater management technology for tourism in Southeast Asian countries with emphasis on pharmaceutical residues ***Professor Chongrak Polprasert,*** *Ph.D., Thammasat University* ***(Thailand)***	
	2nd keynote (09:35 – 10:10)	The principle and application of CDI technology for the purpose of water reuse ***Professor Jeyong Yoon,*** *Ph.D., Seoul National University College of Engineering* ***(Korea)***	
10:10 - 10:25	**Networking Break** (2nd floor)		
10:25 – 11:00	**Poster Sessions** Location: The front of Orchid Grand ballroom (2nd floor)		
Technical Sessions	***Room: Dalah II (3rd floor)*** **A-III: Innovation Monitoring**		***Room: Dalah III (3rd floor)*** **B-III: Water Reuse Planning Costs and Economics**
Moderator	**Assoc. Prof. Olivier Lefebvre/** **Assoc. Prof. Sanya Sirivithayapakorn**		**Professor Chi-Wang Li/** **Assist. Prof. Cheema Soralump**

11:00 – 12:00	WR-A10 (11:00 – 11:20)	Evaluating techniques to measure water quality parameters from direct potable water reuse facilities: from TOC to high resolution mass spectrometry ***Christiane Hoppe-Jones***, *S. Beitel, K. Daniels, I. Lopez, M. Park, S.A. Snyder* ***(USA)***	WR-B10 (11:00 – 11:20)	Reduction of CO_2 emissions in sewage treatment systems by removing oil and fat from wastewater and using it for power generation ***Tomohiro Okadera***, *M. Fujii, K. Syutsubo.* ***(Japan)***
	WR-A11 (11:20 – 11:40)	Identification of environmental contaminants by applying LC-QQQ, LC-QTOF and RT prediction: a cost-efficient method ***Han Yuan***, *J.J. Yang, E.R. Wanjaya, M.L. Fang* ***(Singapore)***	WR-B11 (11:20 – 11:40)	Comparative environmental impacts and economic benefits of different wastewater management for cassava-based ethanol production in Thailand ***Rutjaya Prateep Na Talang***, *S. Sirivithayapakorn* ***(Thailand)***
	WR-A12 (11:40 – 12:00)	Prediction of the attenuation of trace organic compounds (TOrCs) by ozone oxidation using an on-line fluorescence sensor ***Minkyu Park***, *K.D. Daniels, S.A. Snyder* ***(USA)***	WR-B12 (11:40 – 12:00)	Estimating coastal water quality in Danang Bay, Vietnam: models and parameter assessment *D.T.M. Le , N. K. Dang, K.T.P. Ho,* ***Long Ta Bui (Viet Nam)***
12:00 – 13:00	**Lunch** Room: Bua Laung (1st floor)			
13:00 – 13:30	**1st Invited speaker:** Plant microbial fuel cell: A waste-to-energy technology for possible water reclamation ***Assoc. Prof. Rachnarin Nitisoravut,*** *Ph.D., Thammasat University* ***(Thailand)*** Room: Orchid Grand Ballroom (2nd floor))			
Technical Sessions	***Room: Dalah II (3rd floor)*** **A-IV: Innovation Technologies and Options for Water Reuse**		***Room: Dalah III (3rd floor)*** **B-IV: High Tech and Low Tech Solutions (Part I)**	
Moderator	**Professor Chi-Wang Li/ Assoc. Prof. Dr. Rachnarin Nitisoravut**		**Professor Akihiko Terada/ Assoc. Prof. Pongsak Noophan/ Assist. Prof. Suchart Leungprasert**	
13:30 - 14:30	WR-A13 (13:30 – 13:50)	Entrapped mixed microbial cell (EMMC) technology for effective biological wastewater treatment/reuse ***Ping-Yi Yang***, *C. Song, J. L. Irvine, and C. F. Lin* ***(USA)***	WR-B13 (13:30 – 13:45)	Replacement/precipitation reaction for zinc removal using electrogenerated iron ***Natacha Martin,*** *V. Ya, C.-W. Lia* ***(Taiwan)***
	WR-A14 (13:50 – 14:10)	Operation assessment of a water reclamation plant by water quality analysis coupled with fluorescence excitation-emission matrix and high performance size exclusion chromatography ***Wan-Ru Chen***, *S.-Y. Liou* ***(Taiwan)***	WR-B14 (13:45 – 14:00)	Impact of flow rate on adsorption column capacities of different pore size distribution on activated carbons ***Naphat Kumjiam,*** *M. Thanuttamavong* ***(Thailand)***

	WR-A15 (14:10 – 14:30)	Options for water re-use from decentralized wastewater treatment systems ***Michael A. Urynowicz* (USA)**	WR-B15 (14:00 – 14:15)	High capacity adsorbents for trace Cr(VI) removal from drinking water ***Renuka Verma**, S. Sarkar **(India)***
			WR-B16 (14:15 – 14:30)	Electro-stimulated reutilization of volatile fatty acids for bio-alcohols production by mixed cultures under different organic loads. ***José Gavilanes**, C. Nagendranatha Reddy, B. Min **(Korea)***
14:30 - 14:40	**Networking Break** (2nd floor)			
14:40 – 15:20	WR-A16 (14:40 – 15:00)	Biological pre-treatment of river water slightly contaminated by ammonia for use as a drinking water source *Y.-J. Wu, Y.-W. Liu, H.H. Cheng, C.-W. Ke, C.-H. Chang, L.-M. Whang, **Tsair-Fuh Lin (Taiwan)***	WR-B17 (14:30 – 14:55)	Evaluation of nitrification and denitrification performance of down-flow hanging sponge system for high-strength domestic wastewater treatment ***Sirikes Thonglee**, W. Yoochatchavalb, T. Danshita, T. Yumaguchi, T. Okadera, Y. Ebie, K. Syutsubo **(Thailand)***
	WR-A17 (15:00 – 15:20)	Application of in vitro bioassays to assess water reuse plants around the world ***Shawn Beitel**, K. Daniels, C. Hoppe-Jones, I. Lopez, M. Park, S. Snyder **(USA)***	WR-B18 (14:55 – 15:10)	A novel high-pressure electrocoagulation system for dyeing wastewater treatment ***Vinh Ya**, K.H. Choo, N.C. Le, C.-W. Li **(Viet Nam)***
15:20 – 15:50	**2nd Invited speaker:** Recent development, experiences and research toward potable reuse in Australian cities ***Professor Stuart Khan**, Ph.D., University of New South Wales **(Australia)*** Room: Orchid Grand Ballroom (2nd floor)			
Technical Sessions	***Room: Dalah II (3rd floor)*** **A-V: South East-Asia Megacities and Rural Regions**		***Room: Dalah III (3rd floor)*** **B-V: High Tech and Low Tech Solutions (Part II)**	
Moderator	**Professor Stuart Khan/ Assoc. Prof. Dr. Pongsak Noophan**		**Professor Chi-Wang Li/ Assist. Prof. Cheema Soralump**	
15:50 - 17:10	WR-A18 (15:50 – 16:10)	Temporal variability of faecal contamination from on-site sanitation systems in the groundwater of northern Thailand ***ChongJoon Chuah**, A.D. Zieglerb **(Singapore)***	WR-B19 (15:50 – 16:05)	Evaluate of the biodegradability on high carbohydrate wastewater treated by fungal ***Watcharapol Wonglertarak**, S. Dararat, B. Wichitsathian **(Thailand)***

	WR-A19 (16:10 – 16:30)	Application of analytic hierarchy process (AHP) for the assessment of water reclamation alternative *Y. Jareeya, **Oranee Rungrueang**, W. Watcharapol, W. Boonchai **(Thailand)***	WR-B20 (16:05 – 16:20)	Characterization of dissolved effluent organic matter (EfOM) from municipal waste water treatment plant as a function of color ***Ashraful Islam**, G.X. Sun, M. Yang, Y. Zhang **(China)***
	WR-A20 (16:30 – 16:50)	Water reclamation and reuse from centralized and decentralized wastewater treatment plants in Thailand ***Pongsak (Lek) Noophan**, S. Phanwilai, S. Chayawanich, S. Vongsasomand, C.Wantawin. **(Thailand)***	WR-B21 (16:20 – 16:35)	Investigation on recovery of anammox-enriched culture on attached growth after two starvation conditions (warm and cold temperatures) ***Jarawee Kaewyai**, C. Wantawin, P. L. Noophan **(Thailand)***
	WR-A21 (16:50 – 17:10)	Water-reuse concepts for industrial parks in water-stressed regions in South-East-Asia ***Sonja Bauer**, J. Behnisch, A. Dell, V.A. Nguyenc, M. Engelhart, H.J. Linke, M. Wagner. **(Germany)***	WR-B22 (16:35 – 16:50)	Optimization of metal oxide composite electrocatalysts for anodic degradation of hazardous water micropollutants: Catalytic activity and durability ***Hyeona Park**, N. Mameda, H.-J. Park, K.-H Choo **(Korea)***
			WR-B23 (16:50 – 17:05)	The intergration of hydroponics into a brewery effluent treatment system ***Richard Taylor**, C. Jones **(South Africa)***
18:00 - 21:00	**Banquet Dinner** Location: Hotel Lawn (1st floor)			

FRIDAY, NOVEMBER 02, 2018

08:30 - 17:00	**Registration Open** Room: Orchid Grand Ballroom (2nd floor)	
09:00 - 10:00	**Keynote Session**	
	1st keynote (09:00 – 10:00)	Emerging contaminants from water reclamation and reuse ***Professor Shane A Snyder**, University of Arizona, **(USA)***
10:00 - 10:15	**Networking Break** (2nd floor)	
Technical Sessions	***Room: Orchid Grand Ballroom (2nd floor)*** **A-VI: Technologies for Water Reuse in Europe and Asia**	
Moderator	**Professor Jörg E. Drewes/ Assist. Prof. Mongkol Damrongsri**	

10:15 - 11:35	WR-A22 (10:15 – 10:35)	Introducing sequential managed aquifer recharge technology (SMART) for enhanced removal of trace organic compounds and pathogens during water reclamation ***Jörg E. Drewes****, S. Karakurt, V. Zhitenva, K. Hellauer, U. Hübner* ***(Germany)***
	WR-A23 (10:35 – 10:55)	Wastewater Reuse in Turkey: From Present Status to Future Potential ***Bilgehan Nas****, S. Doğan, A. Aygün, S. Uyanik , K. B. Nas, S. Turgut, M. Cop, T. Dolu* ***(Turkey)***
	WR-A24 (10:55 – 11:15)	Fertilizer effect of rice cultivation by reusing water treated with sewage of small region rural village in Japan ***Hitoshi Ogawa (Japan)***
	WR-A25 (11:15 – 11:35)	Application of membrane technology in water reuse in China *J. Wang,* ***Heng Liang****, W. Gong, G. Li, S.A. Snyder.* ***(China)***
11:35 - 12:00	**Closing ceremony**	
12:00 - 13:00	**Lunch** Room: Bua Laung (1st floor)	
13:00 - 17:00	**Technical Tour**	

Poster Presentations

WR_P01	Computer surge modeling and proof of design of your reuse water system ***Frank Knowles Smith, III*** ***(USA)***
WR_P02	Fabrication of ultrafiltration PLA hollow fiber membrane for Surface water treatment applications ***Arisa Jaiyu***, *Siwaruk Chotiwan, Worawat Wattabathana, Kanungnuch Keawsupsak, Julaluk Pannoi, Borwon Narupai, Passakorn Sueprasit* ***(Thailand)***
WR_P03	Quantification of ammonium oxidizing bacteria (AOB) from full scale of BNR WWTPs for possible water reclamation in Bangkok and Phuket provinces ***Sirinan Chayawanich***, *P. Prachakittikul, P.L. Noophan* ***(Thailand)***
WR_P04	IOT based Real time monitoring of water levels in tanks using machine learning with android application *J. Gautam,* ***Gurulingappa M. Patil***, *A. Gupta, A. Agrawal, S. Shah, S. Mittal* ***(India)***
WR_P05	Impact of weather variables on urban water consumption at multiple temporal scales: the case of Bangkok, Thailand ***Chinnapan Makpiboon***, *A. Pornprommin, S. Lipiwattanakarn* ***(Thailand)***
WR_P06	Quantification of nitrite oxidizing bacteria (NOB) from full scales of BNR WWTPs for possible water reclamation in Bangkok and Samut Prakan provinces ***Sorada Vongsasom,*** *P. Prachakittikul, P.L. Noophan* ***(Thailand)***
WR_P07	Variation of fluorotelomer alcohols and perfluoroalkyl carboxylic acids in municipal wastewater treatment plants over a period between 2013 and 2016 ***Chunmeng Ma***, *H.R. Chen, Y. Zhang , M. Yang* ***(China)***
WR_P08	Comparison of natural dyes removal by coagulation process with different coagulants *J. Yimrattanabavorn,* ***Tharika Kaenjun***, *W. Wonglertarak, B. Wichitsathian* ***(Thailand)***
WR_P09	Addressing governance issues in sanitation through IoT based platform ***Rathin Biswas***, *K. Arya* ***(India)***
WR_P10	Contamination and risk assessment of PFOA, PFOS and other Per- and Polyfluoroalkyl substances in tap water and drinking water in Bangkok, Thailand *W. Tabtong,* ***Suratsawadee Sukeesan***, *N. Boontanon, S.K. Boontanon* ***(Thailand)***
WR_P11	Anaerobic Reactor in order to use for water reclamation (case study on development of high quality biogas technology) *S. Dararat,* ***Pattcharee Jaiaun***, *N. Traiyawong, K. Charoenpornpithak, N. Klaijieama* ***(Thailand)***
WR_P12	Direct production of reusable water using sequencing batch reactors – floating micro-filter membrane process ***Minsoo Kim***, *G. Kim, H. Kim* ***(Korea)***
WR_P13	Polysulfone membrane to treat wastewater on effect study of plasma treatment time for improvement of surface hydrophilicity ***Soraya Ruangdit,*** *T. Chittrakarn, S. Sirijarukul, C. Kaew-on, C. Yuenyao, Y. Tirawanichakul.* ***(Thailand)***
WR_P14	Experimental study for greywater treatment using Greenwall concept ***Shrijith Nair,*** *T.D. Nalamutt* ***(India)***
WR_P15	**MPPE Separation of organics from water** ***Bjorn de Theije,*** *M. Poonpipat* ***(Netherlands)***

Conference General Information

About the Conference

Name	IWA Water Reuse 2018 IWA Regional Conference on Opportunities for Water Reuse in Southeast Asia
Date	October 30 (Tue) – November 2 (Fri), 2018/ 4 days
Venue	Phuket Graceland Resort and Spa, Phuket, Thailand
Organizers	Department of Environmental Engineering, Faculty of Engineering, Kasetsart University,Thailand
	The Expert Centre of Innovative Materials, Thailand Institute of Scientific and Technological Research (TISTR), Ministry of Science and Technology, Thailand.
Theme	Opportunities for Water Reuse in Southeast Asia

Registration

Location	The foyer in front of Orchid grand Ballroom, 2nd Floor	
Date and Time	October 30 (Tue) – November 1 (Thu), 2018 November 2 (Fri), 2018	08:30 – 17:00 08:30 – 11:00

Exhibitions

Location	The foyer in front of Orchid grand Ballroom, 2nd Floor

Internet Access

WiFi is available throughout the conference venue.

Lunch, Networking Break and Welcome Reception

October 30 (Tue), 2018	Lunch is served in the Sunset restaurant on the 1st floor. Networking or coffee break is served in the front of Bu-Nga room on the 3rd floor.
October 31 (Wed) – November 2 (Fri), 2018	Lunch is served in the Bua Laung restaurant on the 1st floor. Networking or coffee break is served in the front of Orchid grand Ballroom on the 2nd floor.
October 31 (Wed), 2018	Welcome reception is served in the Sky Pool on the 3rd floor.

Lunch and Welcome reception Coupons are going to be distributed for all Conference participants. In order to access the restaurant, the coupon is required.

Banquet Dinner

November 1 (Thu), 2018	Banquet dinner is served at the Hotel Lawn

Banquet dinner ticket is given to our conference participants (Optional) at the registration desk with your name badge. The ticket is required to access this event.

Technical Tour

Place	Full Scale Wastewater Treatment Plant at Phuket City Municipality	
Date and Time	November 2 (Fri), 2018	13:00 – 17:00

Conference Rooms and Exhibition Floor Plan

ABSTRACT

Content

Section A-III: Innovation Monitoring

Section A-IV: Innovation Technologies and Options for Water Reuse

Section A-V: South East-Asia Megacities and Rural Regions

Section A-VI: Technologies for Water Reuse in Europe and Asia

Section B-I: Advanced Treatment Technologies

Section B-II: Sustainable Technology and Management

Section B-III: Water Reuse Planning Costs and Economics

Section B-IV: High Tech and Low Tech Solutions (Part I)

Section B-V: High Tech and Low Tech Solutions (Part II)

Poster Presentations

WR-I01

Quorum quenching bacterial sheets for effective biofouling control in membrane bioreactors

Tahir Iqbal[a], Kibaek Lee[b] and Kwang-Ho Choo[b,*]

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Abstract

One of the most important factors causing membrane fouling in membrane bioreactors (MBRs) is biofouling, which results from the extensive growth of microorganisms at the membrane surface (Guo et al. 2015). Microbial communications using signal molecules, known as quorum sensing, facilitate such microbial behaviors. In recent years, quorum quenching (QQ) technology that can interfere with microbial communication has been developed and demonstrated for biofouling control in MBRs treating synthetic and municipal wastewater (Lee et al. 2018). Particularly, bacterial QQ has more attraction to practical applications because use of QQ bacteria confined or entrapped in polymeric media is sustainable and cost-effective that of QQ enzymes (Oh et al. 2012, Weerasekara et al. 2014, 2016). Various QQ media have been prepared and tested with respect to biofouling control and it was found that the thinner media, the better in QQ efficacy (Lee et al. 2016). This is because mass transfer at the media surface plays an important role in effective biofouling mitigation. Physical effects (e.g., bombardment of media onto the membrane surface) were found to be important in reducing membrane fouling in flat sheet membranes, but not always. The efficacies were affected by the shape of membrane modules and became insignificant for hollow fiber modules. Some of the media may get trapped inside the densely aligned hollow fiber bundles nullifying the physical cleaning effect. Therefore, this study employed fixed flat sheets entrapping QQ bacteria for effective biofouling control in MBRs (Figure 1a). The efficacy of QQ sheets was investigated with different QQ bacterial doses during the treatment of synthetic and real municipal wastewaters. The maximal QQ bacteria dose to a reactor was estimated to be ~250 mg BH4/L considering the stability of QQ sheets (max. ~20 mg BH4/ml of sheet volume) and the allowable amount of sheets in the MBR (max. ~1.25% of the reactor volume). Figure 1b shows the QQ activity as a function of BH4 dose up to 250 mg/L. It seems that there were three phases in the variation of QQ activity: (1) lag phase (0-50 mg/L), (2) exponential increase phase (50-100 mg/L), and (3) linear increase phase (>100 mg/L). In this study, three QQ doses (50, 75, and 100 mg BH4/L), which are the lowest, middle, and highest doses of the exponential increase phase, respectively, were selected to investigate the biofouling control efficacy in MBRs. It was found that the more QQ bacteria the greater in biofouling control. Fouling mitigation was more pronounced when the feed was switched from synthetic to real municipal wastewater because the latter contained inferior organics and nutrients. It is expected that greater QQ doses up to 250 mg/L may achieve further fouling delays, but holistic approaches for QQ optimization are needed, considering the economics.

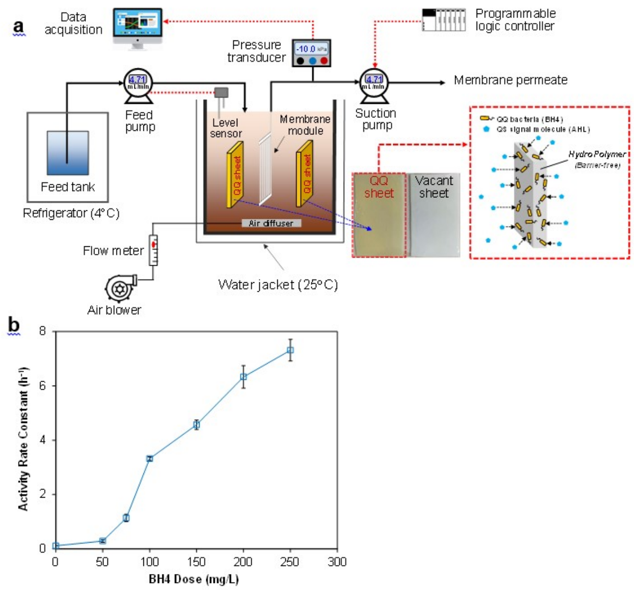

Figure 1 (a) A schematic diagram of the laboratory-scale MBR operated with QQ sheets (b) Variations of QQ activity rate constant as a function of BH4 dose.

Keywords: Membrane bioreactor, Quorum quenching, Sheet, Biofouling, Effective dose

WR-I02

Staged Development of a Bioscreening Toolbox for Recycled and Ambient Water Monitoring and Assessment

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Abstract

Our reliance on conventional analytical chemistry to monitor for known and unknown chemicals, including transformation products, present in ambient and recycled water is rapidly becoming antiquated. In addition to a lack of sustained relevance, chemical-specific monitoring does little to address the occurrence and potential impacts of complex mixtures. In vitro bioassays (IVBs) include engineered cell lines that respond to chemicals by initiating a molecular event (e.g. gene expression) and that in some cases serves as a precursor to an adverse outcome. Because their specificity is pre-engineered, IVBs can be used to screen for a wide variety of chemicals extracted from water samples, with the added benefit that specific IVB responses represent integrated measures of bioactivity for chemicals exhibiting a common mode of action. Thus, these bioanalytical tools can screen for known and unknown chemicals alike, supplementing existing targeted chemical analysis in monitoring frameworks by broadening the universe of bioactive chemicals addressed while providing a more directed assessment of water quality.
Dozens of IVBs have been developed to screen chemicals for various modes of bioactivity; however, relatively few have been applied to or adapted for water quality applications. Among endpoints that have been applied to screen water quality, most have not yet been fully optimized, standardized and validated for widespread use by the water quality community (**Table 1**). To improve the efficacy of IVB screening tools, we seek to identify a suite of endpoints that are relevant to ecological and human health, and to build standardized protocols for these endpoints, creating a "bioscreening toolbox" with performance-based quality assurance/quality control (QA/QC) criteria that are appropriate for a variety of aqueous matrices in bench-, pilot- and full-scale investigations. A five-stage development sequence is proposed to ensure IVB measurements are relevant, robust and comparable among studies.
A panel of experts recently recommended two IVBs – the estrogen receptor alpha (ER-□) and aryl hydrocarbon receptor (AhR) – for screening of recycled water quality in California (USA). These assays have undergone optimization, standardization and validation over the past several years (He et al. 2013; Escher et al. 2014; Mehinto et al. 2015; Kunz et al. 2017) and are now being applied to assess product water quality and unit process treatment efficacy in pilot scale studies (Carollo 2017). Our next steps will include 1) identification and optimization of new IVB endpoints for relevant modes of action; 2) standardization and validation of endpoints that have been successfully optimized for water quality monitoring; and 3) guidance on appropriate applications and interpretation of bioscreening monitoring results.

Table 1 Candidate in vitro bioassays (IVBs) that screen for chemicals by mode of biological action.

Endpoint Activity	Relevant CECs	Adverse effect	Development Stage[a]
I. Endocrine disrupting chemicals (EDCs)			
Estrogen receptor (ER)	estradiol, bisphenol A, nonylphenol	Feminization, impaired reproduction, cancer	4
Anti-estrogen receptor (ER-)	synthetic pyrethroids	Disrupted reproductive development, impaired reproduction	2
Anti-androgen receptor (AR-)	musks, phthalates, pesticides	Androgen insensitivity, impaired reproduction, cancer	2
Glucocorticoid receptor (GR)	anti-inflammatory steroids	Development, immune diseases, diabetes	3
Progesterone receptor (PR)	progestins	Cancer, hormone resistance syndrome, impaired reproduction	2
II. Carcinogenic chemicals			
Aryl hydrocarbon receptor (AhR)	dioxin-like chemicals, polycyclic aromatic hydrocarbons, pesticides	Cancer, impaired reproduction, Development	3
Tumor suppressor protein Response Element (p53RE)	DNA alkylating agents, oxidants, PAH metabolites	Oxidative stress, tissue and DNA damage, cancer	1
III. Immunosuppressants, neurotoxins and other chemicals of concern			
Thyroid hormone receptor (TR)	pesticides, bisphenol A, flame retardants	Impaired metabolism, auto-immune diseases	1
Peroxisome proliferator activated receptor (PPAR)	pharmaceuticals, phthalates	Metabolic disorders, impaired immune function, cancer	1
Acetylcholine receptor (AChE)	neonicotinoid and other neurotoxic pesticides	Neurotoxicity, behavior	1

Stage 1 (exploratory): is endpoint amenable to screening of water quality?
Stage 2 (optimization): is performance consistent with monitoring goals?
Stage 3 (standardization): can standard operating procedures (SOPs) and thresholds be developed?
Stage 4 (pilot evaluation): does it provide value in practice?
Stage 5 (implementation): can it be certified as a standard method and run by commercial labs?

Keywords: water quality; monitoring; in vitro bioassays

WR-I03

Plant Microbial Fuel Cell: A Waste-to-Energy Technology for Possible Water Reclamation

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Abstract

A concept of waste-to-energy has brought about a bio-system named microbial fuel cell (MFC) as an alternative technology possibly for a mission in Mars by NASA. This, thereby, allows waste to be utilized in-situ possibly for reuse and generated electricity for power. Overtime, descendants of MFC has been developed based upon configurations, structures, and purposes. A plant microbial fuel cell (PMFC) is an extended version of MFC that exercises the unique plant-microbe relationship at the rhizosphere of a plant and converts solar energy to electricity. In this presentation, an evolution of research in this topic at Sirindhorn International Institute of Technology, Thammasat University, Thailand through subsequent research by generations of graduate students will be shared. Three main paradigms in PMFC will be pointed out including plant rhizodeposition and photosynthetic activity, role of soil microbes driven by physiochemical and biological characteristics, and lastly engineering aspects involved in design an efficient configuration of PMFC.

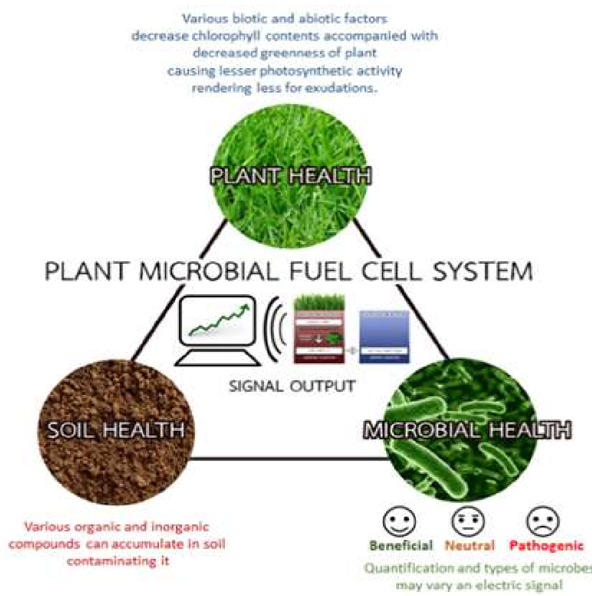

Figure 1 Trio for assessments in PMFC (Regmi et al., 2018)

Keywords: PMFC; Rhizodeposition; Waste-to-Energy

WR-I04

Recent development, experiences and research toward potable reuse in Australian cities

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Abstract

Australia has played an important role in the development of potable reuse internationally. Most significantly, Australia was the first country to develop national water quality guidelines specifically for this purpose. This has recently been followed up with the development of detailed protocols for the validation of treatment performance for a number of key advanced water treatment processes. Nonetheless, the successes of potable reuse projects, which have been proposed for development in Australia, have been variable.

An important groundwater replenishment project is now operational in Perth, Western Australia. However, what was to be a similarly important reservoir-augmentation project in South East Queensland is currently idle. A smaller scheme in Sydney, New South Wales, produces highly treated reclaimed water for river-flow augmentation upstream of a drinking water offtake. Each of these projects has contributed to technical skills and provided important research opportunities.

Despite a potentially long lead time, and following current trends from California and South Africa, there is growing discussion among Australian water utilities and academia; regarding the likelihood of future 'direct potable' reuse (DPR) projects in Australia (Khan, 2011; Law, 2016). It is possible that smaller, regional towns and cities may be the early adopters of DPR in Australia, most driven by a lack of alternatives, with long distances inland precluding seawater desalination.

During 2017, an online survey, conducted at a water industry workshop, asked participants to provide their opinion on the likelihood of large Australian cities (population >100,000) developing new planned potable reuse projects in the next 20 years (to 2037). The same question was then asked regarding small Australian cities (population <100,000). The responses to these two questions are presented in figure 1. With 28 responses, none of participants rated the likelihood as "very unlikely" in either case. A minority selected "unlikely" for large cities (14%) and small cities (21%), with the remainder selecting either "likely" or "very likely" for both sizes of cities.

The workshop participants were also asked whether direct potable reuse, specifically, should be considered as a realistic water supply strategy in Australia within the next 20 years. None of the 28 respondents selected "No, DPR is not a realistic or suitable option of Australian cities within that timeframe". However 4% (1 respondent) answered "Yes, it doesn't hurt to consider it, but DPR is unlikely to be favourable in any circumstances". In contrast, 39% answered "Yes, there may be some advantages of DPR in some circumstances" and 57% answered "Yes, there are clear advantages of DPR in some circumstances".

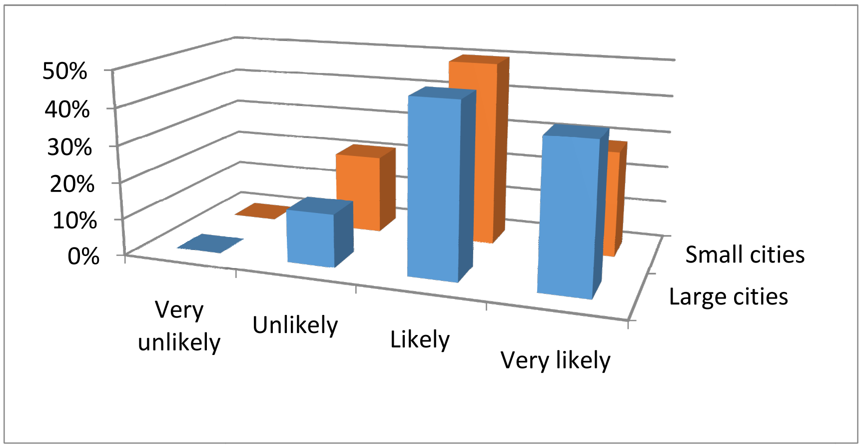

Figure 1 Workshop participants' opinions on the likelihood of large (>100,000) and small (<100,000) Australian cities developing new planned potable reuse projects in the next 20 years (n=28).

Unfortunately, during the current, but inevitably temporary period of few urban water shortages, national policy priorities have turned away from urban water planning (Radcliffe, 2015). Intergovernmental and statutory institutional structures, such as the National Water Commission have been abolished. Water policy complacency is evident and reform impetus is at risk of being lost (Infrastructure Australia, 2017). Water research funds are also reducing with the loss of a number of major water funding bodies, including the Australian Centre of Excellence for Water Recycling (Burgess *et al.*, 2015; Radcliffe, 2015). However, recent analysis has indicated that Australian governments have much to learn from decisions to build very large potable reuse and desalination plants, particularly around timing and scale (Horne, 2016). It is anticipated that future water reuse decisions (in both private and public sectors) will be taken with a much greater commercial focus (Horne, 2016).

Keywords: potable reuse, Australia, guidelines.

WR-A01

Development of an Electrode-Assisted Membrane Bioreactor (e-MBRs) for Water Reuse: Anode Respiration on the Membrane Fouling

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Abstract

To further reduce membrane bioreactor (MBR) energy consumption, we constructed electrode-assisted membrane bioreactors (e-MBRs), in which aeration is omitted and instead solid anode electrode is installed as alternative electron acceptor. The reactor performance (e.g., COD removal and membrane permeability) was monitored. The newly constructed e-MBR could achieve comparable COD removal rate (about 70 %) to the conventional MBR despite of no aeration. Membrane fouling of e-MBR was significantly mitigated due to less production of soluble microbial products especially biopolymer. These data clearly demonstrate that e-MBR is a promising water reclamation technology with a minimum energy consumption.

Keywords: electrode-assisted membrane bioreactor (e-MBR); anode respiration; membrane fouling; biopolymer production

WR-A02

Stand-Alone and Hybrid Membrane Processes for Reclamation and Reuse of Domestic Wastewater

Sarper Sarp[a]

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Abstract

MBR processes have relatively small footprints, reduced sludge productions, and higher removal rates for certain pharmaceuticals, when compared to conventional activated sludge (CAS) processes (Snyder et al. 2007; Sipma et al. 2010). However, MBR effluent water quality, when domestic wastewater is used as raw water, is not sufficient to be considered for reclamation purposes. Therefore, sequential systems, such as Membrane bio-reactor (MBR) and reverse osmosis (RO), have been tried and reported to be effective for wastewater reclamation (Tam et al. 2007; Dialynas et al. 2008). However high fouling potential of the RO membranes in these sequential systems is one of the major problems. Effluent organic matter (EfOM) contributes significantly to membrane fouling which causes a major economic issue for MBR-RO systems. NF systems, on the other hand, can also be considered as a more economical and relatively lower fouling potential candidate to RO systems.

In our previous studies, we have applied advanced oxidation processes (AOP) to the MBR effluents, prior to the membrane filtration, in order to reduce the fouling potential and to increase the removal rates for personal care products and pharmaceuticals (PPCPs). We have investigated the removal of the natural and effluent organic matters (NOM and EfOM), toxic anions, and micropollutants by MBR, AOP, and membrane processes, individually and in combinations.

The flux decline was decreased from 29% to 15% when 9 mg/L of ozone was used, the same decline was also observed when 6 mg/L ozone and hydrogen peroxide (1/1 ozone/peroxide molar ratio) were used. A further decrease in flux decline was observed when pH was adjusted to 9.00 (29% to 9%) prior to the ozone/peroxide oxidation. In most cases, the increase in the ozone dose, the addition of hydrogen peroxide and the adjustment of the pH level also led to an increase in the removal of pharmaceuticals. Iopromide, TCEP and Naproxen were found to be more resistant to the oxidation when pH was increased.

NF membranes also provided high removal efficiencies in terms of toxic anions, and the UF membrane provided relatively high removal efficiencies for anions (except for nitrate) and the relatively hydrophobic micropollutant, oxybenzone.

Keywords: Pharmaceuticals and personal care products (PPCPs), toxic anions, fouling potential, advanced oxidation processes (AOPs), membrane processes, nanofiltration (NF), reverse osmosis (RO), ultrafiltration (UF)

WR-A03

New membrane integrated processes for the reuse of high salinity wastewater

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Abstract

Osmotically-enhanced dewatering (OED) and membrane distillation crystallization (MDC) processes were investigated for the enhancement of water recovery from shale gas produced water (SGPW). Through utilizing draw solution of which osmotic pressure is lower than feed solution, OED can extract water across a semi-permeable membrane at lower hydraulic pressure than osmotic pressure of the feed. For water reuse from higher concentration of SGPW, MDC process was employed. By integrating with crystallization, scalant loading in membrane distillation (MD) stage was reduced properly and thus wetting and fouling were mitigated effectively

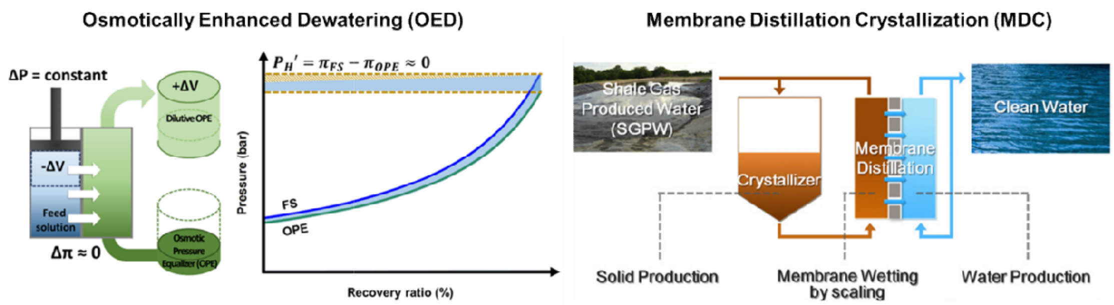

Figure 1 The conceptual design of the OED and MDC processes for water reuse from SGPW.

The most obvious advantage of OED process is to produce more water flux when the low hydraulic pressure applied (Kim et al., 2017). For the reason, reusing the produced water through OED process becomes more attractive. In this study, the performance of OED using shale gas produced water (SGPW) was assessed to verify its feasibility as a newly developed reusing process. The shale gas produced water samples were provided from Sichuan region in China, and pre-treated by UF membrane with a pore size of 100 kDa. The initial concentrations of SGPW and draw solution are 28 and 25g/L TDS, respectively. As shown in Fig. 2, the feed concentration gradually increased as the draw concentration increased. At the end of the experiments, the concentration of SGPW increased up to 85 g/L TDS, which accounts for 67 % of water recovery. Moreover, the measured water fluxes were in good agreement with prediction, which means that there were no fouling and no scaling during the experiments. Thus, the OED process can be potentially one of the most promising alternatives for reusing.

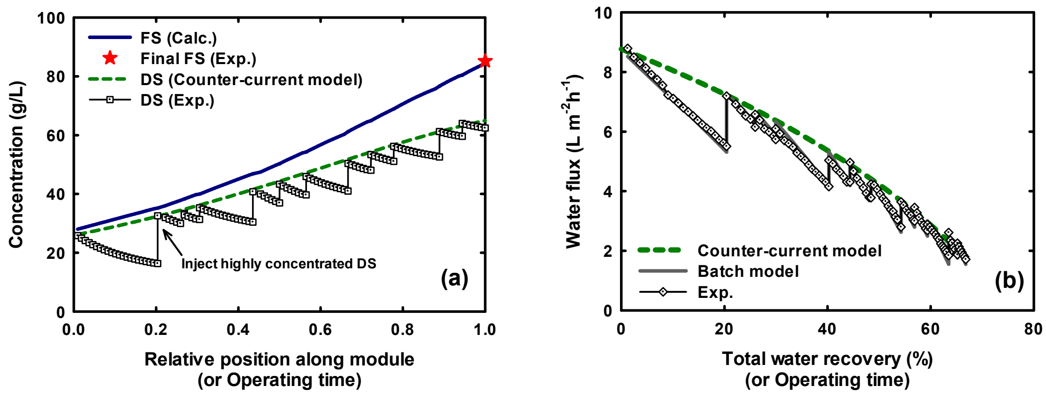

Figure 2 (a) Modeled and experimental concentration profiles as a function of time, and (b) water flux as a function of water recovery for the SGPW dewatering experiment.

Osmotically-enhanced dewatering (OED) is a process that can be used for desalination and reusing of high salinity wastewater. In OED, instead of using hydraulic pressure only to create the driving force for water transport through the membrane in the RO process, the OED process utilizes draw solution that flows along the permeate side of the membrane. Draw solution has lower osmotic pressure than that of feed water, resulting in lowering osmotic gradient between feed and draw solution. Thus, water can transport across the membrane at lower hydraulic pressure than osmotic pressure of feed water. This approach can improve the water recovery by increasing concentration of draw solution as the feed water is concentrated.

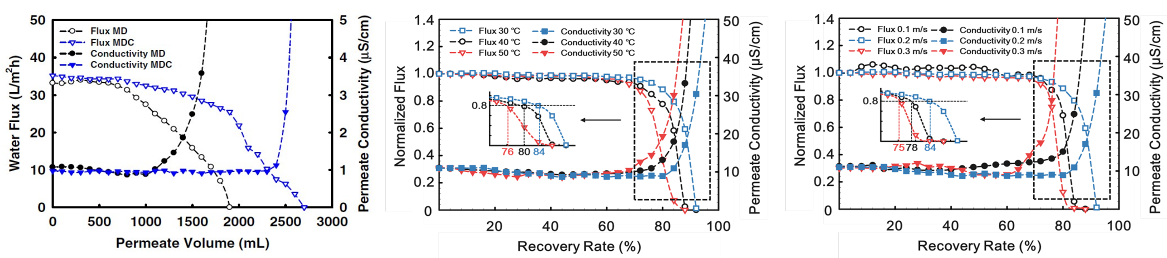

Figure 3 Water flux and permeate conductivity during the MDC process under various feed CFV and T_{Cr} operating conditions.

To mitigate inorganic scaling, MDC process was evaluated under the same operating conditions in terms of temperature, cross-flow velocity. As shown in Fig. 3, during the MDC operation the water flux decline and the conductivity increase were substantially delayed compared to the single MD process. Due to the reduction of SGPW ionic concentration by forced crystallization in the crystallizer, the inorganic scalant loading of the MDC system could be decreased to such an extent that the MDC process could continue for much longer without membrane wetting or inorganic scaling. This allowed the total recovery of the MDC process to increase by 62.5%, or be twice that of the single MD process, while still retaining proper permeate water quality. Furthermore, the water productivity of MDC process from SGPW was evaluated by optimizing the main operating parameters. Maximum recovery rate was 84% under 0.2 m/s of feed CFV and 30 °C of T_{Cr} conditions. (Kim et al., 2017, Kim et al., 2018)

Keywords: Osmotically-enhanced dewatering (OED); Membrane distillation crystallization (MDC); High water recovery; Shale gas produced water (SGPW)

WR-A04

Development Chitosan Forward Osmosis Membrane for Desalination of Sea Water

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[b]*Department of Mechanical Engineering, Faculty of Engineering, Syiah Kuala University*

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Abstract

The survival of humankind depends on the availability of sufficient clean water in the earth. Although most of the Earth's surface is covered with water, a billion people worldwide do not have access to adequate drinking water and more than 2 billion people is suffer to access clean water, especially drinking water. The need for clean water will continue to increase in the future as the growth of the world population, climate change and water pollution by industrial and household waste and future indicators shows increasing scarcity of water worldwide (Chung, Zhang et al. 2012). Besides, some parts of the world prone to natural disasters also face the clean water crisis, especially in the emergency response period after the natural disaster. In an emergency after a natural disaster the availability of clean water and drinking water is much more difficult. Sea and brackish water desalination is the most fast and easy to meet growing water needs. Forward osmosis is recognized as one of the membrane-based desalination process and a promising alternative to reverse osmosis as a lower cost and more environmentally friendly desalination technology(Shafer et al., 2015).

A chitosan-based forward osmosis (FO) membrane has been prepared in this study for sea water desalination. The FO membrane was casted by phase inversion method. The membrane posses asymmetric structure with 33,67 % of porosity and 15,76 % of a swelling degree. The chitosan membrane have the tensile strength of 28,83 kgf / mm^2 and elongation equal to 7,16%. Chitosan FO membrane were tested using fructose, sucrose, and mixture of fructose and sucrose as the draw solution to extract water from a brackish water feed solution. An increase in draw solution concentration lead to an increase in water flux. For all three draw solutions, the order of water flux is sucrose >fructose > mixture of sucrose and fructose, at the same of flow rate. High product water quality was obtained for all draw solutions. The product of water quality has been met to indonesian government regulation of drinking water quality. Chitosan forward osmosis membrane can be an alternative method for production drinking water from sea water.

Keywords: forward osmosis membrane, chitosan, desalination, sea water, drinking water

WR-A05

Energy consumption in baffled membrane bioreactor (B-MBR)

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Abstract

Membrane bioreactor (MBR) is a powerful tool for water reclamation and reuse though high energy consumption is a big obstacle for its wide-spread application. In Southeast Asia, MBRs in which both nitrification and denitrification can be promoted (e.g., modified Ludzack–Ettinger (MLE) configuration) are thought to be required to avoid unfavourable decrease in pH caused by the formation of nitrate as a result of nitrification. In MLE-MBR, recirculation pump and mixer in the anoxic tank account for certain fractions of energy consumption. On this basis, we developed a baffled membrane bioreactor (B-MBR), which does not require recirculation pump and mixer in the anoxic tank for promoting nitrification and denitrification (Kimura et al., 2008). In the B-MBR, baffles are inserted in an MBR tank and water level is appropriately controlled. B-MBR is capable of promoting both nitrification and denitrification in a single reaction tank without stopping membrane filtration. In this study, we investigated the energy consumption of B-MBR treating municipal wastewater.

We continuously operated a pilot-scale B-MBR in an existing wastewater treatment facility in Sapporo, Japan using the influent of primary clarifier of the facility as a feed water. The B-MBR had an effective volume of 3.7 m^3. Membrane elements comprised of hollow-fiber polytetrafluoroethylene (PTFE) membrane (Sumitomo Electric Industries, LTD., Osaka, Japan) with a nominal pore size of 0.2 μm and an effective fiber length of 0.8 m were used in this experiment. The hydraulic retention time (HRT) was 5.9 h. The mixed liquor suspended solid (MLSS) concentration was in the rage of 11,000-14,000 mg/L. The highest and lowest water levels were selected so that the operating time per cycle became approximately 19 min. The recirculation of the mixed liquor suspension took place for approximately 9 min in one operation cycle. Intermittent membrane filtration (9 min filtration and 1 min relaxation) was performed. Membrane flux (defined as net flux) was set at 0.5 m^3/m^2/day. The membrane aeration was controlled so that the specific air demand per membrane surface area (SAD_m) became 0.30 m^3/m^2/hr. A maintenance cleaning with chemically enhanced backwashing (once per week with 500 ppm NaClO and 0.02% NaOH solution and every alternative week with 0.2% H_2SO_4 solution) was also performed.

Excellent removals of biochemical oxygen demand (BOD), total nitrogen (T-N), and total phosphorus (T-P) were seen in the pilot-scale B-MBR (Table 1). Small amount of ammonium-nitrogen (NH_4^+-N) was detected in the treated water. This insufficient nitrification may be attributed to the low water temperature of the bioreactor (around 13°C). During the continuous operation for one month, the increase in transmembrane pressure was marginal (within the range of 11-16 kPa), suggesting that B-MBRs can be stably operated under the operating conditions adopted in this experiment. On this basis, we estimated the energy consumption in a hypothetical full-scale B-MBR (dairy maximum and average capacities of 14,000 and 10,000 m^3/day, respectively) operated with comparable operating conditions adopted in the pilot-scale experiment.

Table 1 Raw wastewater and treated water qualities during the pilot-scale experiment (n = 8).

	BOD (mg/L)	T-N (mg/L)	NH_4^+-N (mg/L)	T-P (mg/L)
Raw wastewater	176.0 ± 43.5	29.3 ± 2.4	15.5 ± 1.9	3.0 ± 0.3
Treated water	1.8 ± 1.0	3.3 ± 1.3	2.0 ± 1.3	0.2 ± 0.1

Values are given ± standard deviation.

The specifications adopted in the estimation are listed in Table 2. In a full-scale B-MBR, a membrane element with an effective membrane fiber length (vertical length) of 3 m is used. Assuming that increase in vertical length of membrane fiber does not affect the demand on membrane aeration, the air-flow rate adopted in the pilot-scale experiment corresponds to the SAD_m of 0.08 m^3/m^2/hr in a full-scale B-MBR. Other specifications (e.g., oxygen

transfer efficiencies) were set at the same values to our previous work (Miyoshi et al., 2018). The result of the estimation suggests that the specific energy consumption in entire B-MBR system (including fine screen) is 0.231 kWh/m^3, which is substantially lower than typical values for MBRs (0.4 kWh/m^3). Applying B-MBR in wastewater reclamation and reuse system is thought to contribute for reducing overall operating cost through the reduction in energy consumption.

Table 2 Specifications used in estimation of energy consumption.

Item	Value	Basis
Minimum temperature	25°C	Assumption on wastewater in Southeast Asia region
Net flux	0.5 m^3/m^2/day	Operating condition adopted in pilot-scale experiment
SAD_m	0.08 m^3/m^2/hr	Effective membrane fiber length of 3 m
DO concentration	1.5 mg/L	Average concentration in interior zone of baffles
MLSS concentration	10,000 mg/L	
BOD (wastewater)	50 mg/L	Assumption on wastewater in Southeast Asia region
SS (wastewater)	40 mg/L	Assumption on wastewater in Southeast Asia region
T-N (wastewater)	15 mg/L	Assumption on wastewater in Southeast Asia region
BOD (treated water)	5 mg/L	
SS (treated water)	N.D.	
T-N (treated water)	5 mg/L	

Keywords: Baffled membrane bioreactor; nitrogen removal, energy-saving

WR-A06

Simultaneous removal of DOM and nitrate from sewage treatment plant effluent by a photocatalytic membrane

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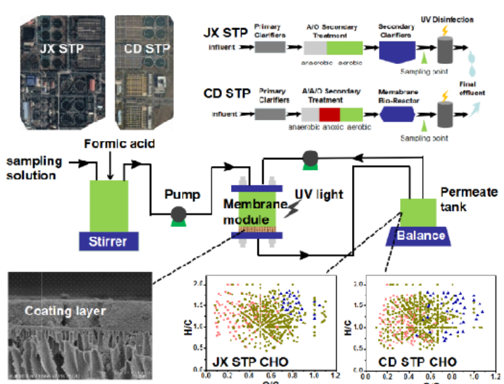
Abstract

The reuse of the sewage treatment plant(STP) effluent may be limited due to the dissolved organic matter(DOM) and nitrate. Herein, we reported a nonlinear optical(NLO) material membrane for simultaneous removal of DOM and nitrate from sewage treatment plant effluent. The effluent samples obtained from two different secondary treatment processes(A/O and A^2/O+MBR) were filtered by the UV lamp irradiated membrane. With the moderate addition of the formic acid(FA) and fewer operation cycles, the removal efficiency of DOC could even be over 50% and the nitrate reached 70%, meanwhile the residual FA was not much of an environment risk. Moreover, via the analysis of Fourier transform-ion cyclotron resonance mass spectrometry(FT-ICR-MS), we found that the molecular transformation in different STP effluent samples displayed a high consistency with the addition of FA. Unsaturated CHO, CHON and CHOS lignins or aromatic structure like substances were more likely to be removed as the increasing of FA concentration, and consistent alterations of molecular average carbon oxidation state and double bond equivalent could be observed. Compared to CHO compounds, CHON and CHOS compositions were more easily consumed by the photocatalytic denitrification. In general, the evident removal of DOM and nitrate from different STP effluent via a photocatalytic membrane provides a useful approach for the advanced treatment of secondary effluent that may be applicable to other photocatalytic membrane or system.



This graphic can be used as a summary for the reuse of the sewage treatment plant(STP) effluent in this report.

Keywords: effluent; Nonlinear optical material membrane; DOM; Nitrate; FT-ICR-MS

WR-A07

A membrane-aerated biofilm reactor for efficient single-stage nitrogen removal and mitigation of nitrous oxide emission: Proof-of-concept from biofilm depth profile analysis

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Abstract

Nitrogen removal from municipal and industrial wastewater treatment facilities always demands small-footprint and cost-effectiveness in a biological treatment unit. Given that aeration accounts for approximately 50% of operational expenditure in a municipal wastewater treatment facility, of importance is reduction in aeration cost for cost-effective biological nitrogen removal. Currently, a membrane-aerated biofilm reactor (MABR) has been paid attention in that aeration efficiency is much higher [e.g. 10 kg-O_2/kWh (Syron et al. 2015)] than a conventional aeration. An MABR consists of a gas-permeable membrane and biofilm grown onto the membrane. This “reactive surface” (Nerenberg, 2016) accomplishes direct oxygen entry to the biofilm in a bubbleless manner, resulting in high oxygen utilization efficiency for nitrification (Brindle et al. 1998). Furthermore, a counter-current substrate diffusion geometry, where oxygen is supplied from the biofilm interior, provides a clear zonation for oxidation and reduction within biofilm depth, allowing for achievement of simultaneous nitrification and denitrification, and partial nitrification and anammox. In addition to the achievement of effective single-stage nitrogen removal, the counter-current substrate diffusion geometry may mitigate emission of nitrous oxide (N_2O), a strong greenhouse and ozone-depleting gas produced during biological nitrogen removal. This benefit likely stems from the direction of oxygen entry, avoiding its consumption coupling with an electron donor supplied from the biofilm exterior. This unique biofilm geometry ensures a sufficient electron donor supply for denitrification including N_2O reduction to N_2, eventually mitigating N_2O emission. We herewith hypothesized that an MABR biofilm for simultaneous nitrification and denitrification accelerates N_2O reduction to N_2 gas, resulting in mitigation of N_2O emission. To this end, this study investigated nitrogen removal performances of and N_2O emissions from an MABR and conventional biofilm reactor (CBR) for simultaneous nitrification and denitrification. Especially, N_2O depth profiles and microbial community compositions within the biofilms were performed in a comparative manner.

Laboratory-scale biofilm reactors employing counter-current (MABR) and co-current substrate supply (CBR) geometries were constructed. Each reactor consisted of a liquid compartment, where biofilm was grown for nitrogen removal from a synthetic wastewater and gas compartment with the details described elsewhere (Kinh et al. 2017). The two reactors had the same dimension and liquid volume (200 mL) but oxygen entry directions were opposite between MABR (from the biofilm bottom) and CBR (from the biofilm top). The reactors continuously received a synthetic medium mainly consisting of sodium acetate (200 mg-C/L) and ammonium (200 mg-N/L). An oxygen loading rate was identical between an MABR and CBR. Water qualities [total dissolved organic carbon (DOC), total nitrogen (T-N), NH_4^+, NO_2^-, and NO_3^-] and N_2O were measured to compare the reactor performances. Dissolved oxygen (DO) and N_2O concentration profiles within biofilm depth in an MABR and CBR were measured by microelectrodes (Unisense, Aarhus, Denmark). Microbial community compositions in a whole biofilm and sectioned biofilms attained by cryosection (Terada et al., 2010) were analysed by 16S rRNA gene amplicon sequencing according to the previous work (Kinh et al., 2017). A predictive metagenomics approach PICRUSt was employed to identify N_2O-reducing bacteria from 16S rRNA data and a reference genome database (Langille et al., 2013).

Throughout three-month reactor operation, an MABR employing a counter-current substrate diffusion biofilm geometry, where air is supplied from the biofilm bottom, displayed a better nitrogen removal performance than a CBR, indicating a superiority of an MABR. Dissolved N_2O concentration in the bulk liquid at the steady-state reactor performance was two orders of magnitude lower in an MABR than in a CBR. These measurements provide that an MABR emits far less N_2O with better nitrogen removal. Thicknesses of matured biofilms in an MABR and

CBR were above 1400 μm. N_2O depth profiles in an MABR demonstrated that N_2O concentration was the highest at the biofilm bottom and steeply decreased at DO concentration of below 0.5 mg/L, suggesting that N_2O consumption occurs in a deeper region of the biofilm in an MABR. The predominant order in both biofilms was consistently Rhodocyclales, which increased its abundance after one month operation. A predictive metagenomics approach suggests that species in the order Rhodocyclaces harbour a functional gene encoding N_2O reductase, indicating that they were predominant N_2O reducers in both MABR and CBR. Spatial distribution of these species within the biofilms were relatively homogeneous in both reactors, alluding that their activities substantially differed in biofilm depth of an MABR and CBR.

Keywords: Biological nitrogen removal; Membrane-aerated biofilm reactor; Nitrous oxide

WR-A08

Direct filtration of treated wastewater using gravity-driven membrane system with periodic manual cleaning as appropriate water reuse technology for developing countries: a real-scale experiment

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Abstract

A filtration system for treated wastewater equipped with a gravity-driven micro-filter membrane (GDMFM) module was developed as an appropriate water reuse technology for developing countries (e.g., countries in sub-Saharan Africa). The module was designed to ensure that it can be easily cleaned manually even by an unskilled operator. Furthermore, it can be cleaned automatically by feeding water flow. Direct filtration of treated wastewater using a real-scale MF membrane module (membrane area: 1.2 m^2; nominal pore size: 0.157 μm) was carried out to evaluate the performance of the GDMFM system and the applicability of the system in developing countries.

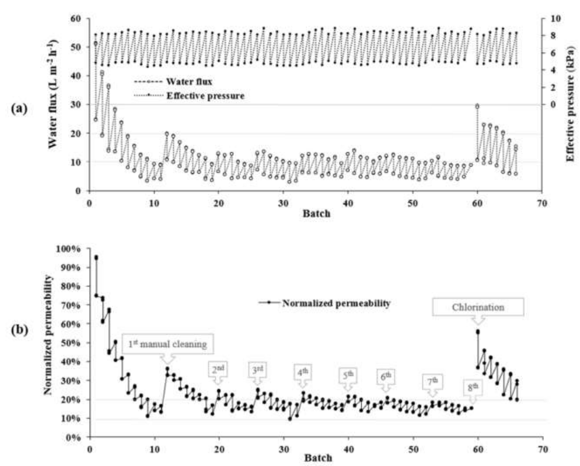

Figure 1. (a) Profiles of water flux and effective pressure, and (b) variation of normalized permeability over batch runs. A total of 8 manual cleanings performed; one chlorination performed right after the 8^{th} manual cleaning.

Relatively long-term filtration could be conducted by using the module only with weekly manual-cleaning maintenance. Over three months, 66 batches of filtration were completed and approximately 10,900 L of treated wastewater could be filtered. The flux of the module was stable in the range of 4–13 L m^{-2} h^{-1} after 19th batch operation. The permeability of the module was recovered by 3.2% owing to the cleaning effect of feed water flow (so called feed-induced cleaning) in every batch. Cake removal and water flux recovery via manual cleaning was clearly observed. The manual cleaning was effective, so the flux could be significantly increased as shown in Fig. 1(a). The permeability of the module repeatedly increased by approximately 10% owing to the manual cleaning. However, the increase of permeability was gradually reduced, which was mainly caused by the fouling portion which was not removed by the physical manual cleaning. Chlorination using chlorine tablets was carried out right after the 8^{th} manual cleaning to evaluate the impacts of simple disinfection and preservation method on the performance of the GDMFM system as shown in Fig. 1(b). The result showed that chlorination could be applied as an additional cleaning method in the GDMFM system to improve the water quality of the filtrate. There was no failure in the integrity of the module during the entire filtration process. *Escherichia coli* and heterotrophic bacteria were not detected in the filtered water at all. The GDMFM system produced 165 L of filtered water per module per day for three months. Considering the cost of system and the life expectancy of the module, each household in sub-Saharan Africa can be served with safe drinking water at a cost of 10–23 US dollars per year.

Keywords: Drinking water treatment; gravity-driven membrane; manual cleaning

WR-A09

Woven Fiber Microfiltration (WFMF) and Ultraviolet (UV-C) Light Emitting Diodes for Water Reuse in Low- to Middle-Income Countries

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Abstract

The global population is expected to rise to approximately 8.3 billion people by 2030, reflecting an unprecedented 25% growth in just over two decades. By 2025, an estimated 1.7 billion people will not have access to enough water to satisfy their basic human needs. Since a majority of population growth occurs in areas that lack centralized water supply and sanitation systems, this research focuses on a decentralized water treatment process. The research is needs-based and problem-driven, targeted at developing and evaluating water reuse technology for addressing water scarcity and contamination in low- to middle-income countries.

A progression of three Master's Thesis projects, involving students from Vietnam, Thailand, Nigeria, and Sri Lanka, the research investigated the application of a polyester, woven-fiber microfilter (WFMF) as pretreatment for ultraviolet (UV) disinfection with UV light emitting diodes (LEDs) with the ultimate goal of wastewater reuse for agriculture in low- to middle-income countries.

The first stage of the research, conducted at the Asian Institute of Technology (AIT) north of Bangkok, Thailand evaluated options for pretreating domestic wastewater to an appropriate quality for disinfection by UV-C LED irradiation using woven-fiber microfiltration. Domestic wastewater from a primary sedimentation tank and effluent from a conventional septic tank were pumped through a submerged woven-fiber microfilter to decrease the suspended solids content and lower turbidity to appropriate levels for UV disinfection. The two permeates were pumped through flow-through UV reactors manufactured in-house, encased in stainless steel, including a UV-C LED reactor emitting at 280 nm as well as a LP UV reactor for comparison. For permeate with a minimum UV transmittance of 40%, the UV-C LED operating at 10 mL/min and the LP UV flow-through reactor at 1.5 L/min inactivated MS2 coliphage, a common surrogate for enteric viruses, by 3.5-log and 7-log respectively.

A follow-up study evaluated less expensive pre-treatment options as well as the operation and maintenance of a commercially-available UV-C LED reactor. Domestic wastewater continuously flowed through a tube settler and sand filter before flowing through a UV-C LED reactor emitting at 280 nm. For pre-treated wastewater at a UV transmittance of 70%, a flow rate of 30 mL/min achieved 3.7-log reduction of MS2. Fouling of the reactor by UV-induced organic calcium, magnesium, phosphorus, and iron complexes decreased the disinfection efficacy by approximately 1-log reduction of MS2 after 8 days. The fouling layers were reversible and removed with four hours of citric acid exposure.

Whereas the previous two studies used a peristaltic pump to pump water through the system, a subsequent study at the Swiss Federal Institute of Aquatic Science and Technology (Eawag) is currently evaluating the woven-fiber microfilter as a gravity-driven membrane. Engineers are determining the efficacy of the woven fiber material at removing suspended solids, lowering turbidity, and increasing UV-transmittance. The material's suitability as a gravity-driven membrane will be assessed and the biofilm formation on the membrane surface will be characterized. As before, the permeate will be pumped through a UV-LED reactor emitting at 280 nm to inactivate the remaining bacterial and viral pathogens or indicators. The combination of an inexpensive woven-fiber material in series with UV-C LED technology is a promising option for treating wastewater for agricultural reuse.

This presentation will present the results from all three studies

Keywords: Wastewater Reuse for Agriculture; Woven Fiber Microfilter, UV-C Light Emitting Diodes

WR-A10

Evaluating techniques to measure water quality parameters from direct potable water reuse facilities: from TOC to high resolution mass spectrometry

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Abstract

With growing demands and stresses on drinking water sources especially in arid and semi-arid regions, augmenting potable water supplies with reclaimed water is increasingly of interest. The goal for potable reuse facilities is to produce "safe water", however, regulatory agencies mainly focus on bulk organic parameter to assess the water quality. Monitoring compounds of emerging concern (CECs) will give further insides into the removal efficiencies of the advanced treatment trains at water reuse facilities. However, due to the large number of chemicals present in wastewater effluents, it is not feasible to test for all of them. Non-targeted analysis (NTA) is a valuable tool to evaluate removal efficiencies of unknown/unidentified compounds in water reuse applications.
The goal of this research is to compare different methods to characterize organic matter, CECs, and other water quality parameters and to evaluate their suitability in water reuse applications. Samples from five water reuse facilities around the United States and the world were collected. At each site, samples from different treatment stages, as well as the drinking water source were collected and compared to the effluent of the water reuse facilities. The treatment trains ranged from Microfiltration(MF)-Reverse Osmosis (RO)-UV Advanced Oxidation Process (UV-aOP), UVAOP-Biological Activated Carbon (BAC)-Granular Activated Carbon (GAC) to BAC-Ozone. Samples were analysed for bulk organic parameters (TOC, UV, Fluorescence), CECs, and NTA using liquid chromatography quadrupole time-of-flight mass spectrometry (LC-qTOF). The results of this study provide a comprehensive view and comparison of different water quality parameters in water reuse applications.
Removal of bulk organic parameters was site specific. TOC removal was usually greater than 95%, 57%, 60% for RO-based, UVAOP-BAC, and BAC-Ozone treatment trains, respectively. Common CECs that occurred at high frequencies and concentrations at most wastewater effluents were acesulfame, sucralose, iopamidol, iohexol, and carbamazepine. Most water reuse treatment trains removed more than 95% of the CECs detected in wastewater effluents. NTA analysis was used to compare samples after each treatment step. Correlation coefficients below 0.3 were calculated between the wastewater effluents and the effluent after advanced treatment, indicating weak to no linear relationships between the samples. Further information on the removal and formation of compounds after each treatment step were also evaluated.

Keywords: Water reuse; NOM; non-targeted analysis

WR-A11

Identification of environmental contaminants by applying LC-QQQ, LC-QTOF and RT prediction: a cost-efficient method

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Abstract

The presence of organic contaminants in the environment has become a great concern around the world. Many studies have been reported on identification and quantification of environmental contaminants, among which liquid chromatography-tandem mass spectrometry (LC-MS/MS) has greatly been used. Most of the reported methods employ standards for confirmation of the analytes and development of analytical methods. However, such standards are often costly yet not always available. Though MS2 is not always accessible, multiple reaction monitoring (MRM) transitions of environmental contaminants are widely reported in scientific literatures or commercial database (e.g., Pesticide Dynamic MRM Compound Database). In this study, we aim to identify environmental pollutants and/or their transformation products by applying Agilent LC- triple quadrupole (QQQ), LC- quadrupole time of flight (QTOF) and retention time (RT) prediction even without possessing standards. The combination of those methods can utilize both the sensitivity of LC-QQQ and high resolution (i.e., highly accurate mass) of LC-QTOF. To test this hypothesis, a small library of selected contaminants is measured in both synthetic and real water samples. MRM parameters including collision energy and fragmentor voltage were optimized using a single sample running. Peak match between MRM QQQ and QTOF can rule out some isobaric candidates. Furthermore, with additional filter from RT prediction we can identify compounds with a high confidence level without the purchase of authentic standards.

Keywords: environmental contaminants; standards; LC-QQQ; LC-QTOF; RT prediction

WR-A12

Prediction of the attenuation of trace organic compounds (TOrCs) by ozone oxidation using an on-line fluorescence sensor

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Abstract

Water reuse technologies have increasingly become mature and many regions of the world currently implement potable water reuse. Compared to indirect potable reuse (IRP) that includes environmental buffers such as groundwater aquifer, direct potable reuse (DPR) has benefits such as lower implementation cost and reduced carbon footprint (Paranychianakis et al. 2014). However, substantially lower retention time requires infallible monitoring of treatment efficacy to secure produced water quality.

There are numerous on-line sensors commercially available and they have been proven to be reliable particularly for the measurement of bulk water qualities such as conductivity, turbidity, pH, etc. However, it is challenging to monitor trace organic compounds (TOrCs) such as pharmaceuticals, personal care products, industrial compounds, and steroid hormones because their environmentally relevant concentrations are very low (e.g., ng/L levels). Liquid- or gas-chromatography with tandem mass spectrometry is the predominant analytical techniques for the analysis of TOrCs, but requires extensive sample preparation such as solid phase extraction, and long analysis time, therefore not suitable for on-line analysis of TOrCs. In order to on-line monitor fate of TOrCs throughout reuse treatment processes, monitoring of fluorescence as a surrogate can be a viable option. Fluorescence spectroscopy requires minimal sample preparation, and short analysis time, factors that enable on-line analyses.

Wastewater effluents—primary water sources for water reuse—contain fluorophores and emit fluorescence when absorbing light. Since the fate of fluorophores throughout physical and chemical processes behaves similarly with TOrCs, fluorescence has widely been studied as a surrogate for the monitoring of TOrC attenuation in various advanced treatment processes such as activated carbon adsorption (Anumol et al. 2015), ozone oxidation (Park et al. 2017), and UV/advanced oxidation process (UV/AOP) (Yu et al. 2015). However, a few studies demonstrated the application of on-line sensors to predict the TOrC abatement in water reuse (Chys et al. 2018).

Therefore, the aim of this study is to demonstrate fluorescence surrogate for the monitoring of TOrC abatement in a pilot-scale ozone oxidation system. To this end, commercial on-line fluorescence sensor (YSI fDOM sensor, Xylem brand) that measures fluorescence at humic substance-like matter continuously monitored the fluorescence of both influent and effluent of the ozone system by alternating the streams every five minutes so that percent attenuation can be calculated. We developed a fluorescence surrogate model previously (Park et al. 2017) and employed it for the prediction of TOrCs. Thirty-three TOrCs were measured over a week and their concentration data were input for the surrogate model. Figure 1 shows the comparison of observed and predicted values of diclofenac attenuation. Relatively high R^2 value (i.e., 0.73) indicates that diclofenac attenuation can be successfully predicted with the on-line fluorescence sensor. Other TOrCs also exhibited good prediction such as carbamazepine (R^2=0.75), diltiazem (R^2=0.81), and trimethoprim (R^2=0.67). While longer demonstration of on-line sensor and application of surrogate model to various water qualities are necessary to verify the robustness of on-line surrogate prediction of TOrCs, this study sheds light on the feasibility of on-line prediction of TOrCs.

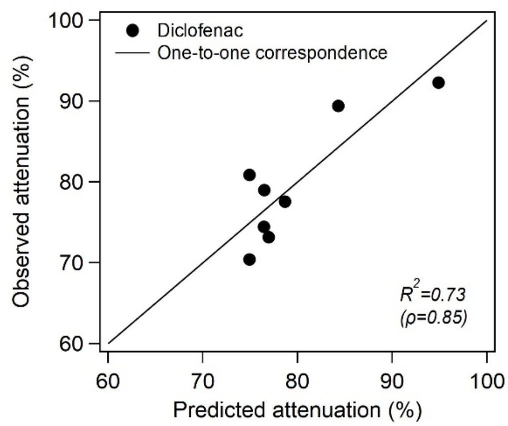

Figure 1 The comparison of observed attenuation of diclofenac with the attenuation predicted by the surrogate model with the on-line data. ρ indicates the Pearson linearity coefficient.

Keywords: Ozone; Trace Organic Compounds (TOrCs); Surrogate

WR-A13

Entrapped Mixed Microbial Cell (EMMC) Technology for Effective Biological Wastewater Treatment/Reuse

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Abstract

Two biological wastewater treatment processes, activated sludge and biofilm, have been applied in practice for years. Advantages and disadvantages of practicing these two processes have been widely reported. To overcome and improve these operational and maintenance weaknesses, alterations and modifications of these processes have been developed.

Among these developments, the EMMC (Entrapped Mixed Microbial Cell) technology is a modified biofilm (an attached growth) and activated sludge (suspended growth) process. The microbial cells are entrapped in polymers that prevent the washout of biomass, and maintain high solid retention time (SRT). This technology has been investigated for various types of wastewaters for years.

In a laboratory study, a simulated domestic sewage (soluble COD of 190-220 mg/L) was investigated at hydraulic retention time (HRT) of 3 to 6 hours. Cellulose acetate (CA) and cellulose triacetate (CTA) were used as gel polymers. The complete procedures for making the carriers are presented in Figure 1.1. Continuous and intermittent aeration were operated to evaluate the impact of the removal of carbon and nitrogen. More than 95% COD and NH_4-N removal; and 50% total nitrogen removal were achieved under the operating conditions of continuous aeration at HRT of 6 hours.

For the application of real domestic sewage, it was previously reported that high removal efficacy of carbon and nitrogen still can be achieved as presented in Table 1.1. In general, the challenge of convectional biological wastewater treatment processes used today include the design and operation of an effective retention of mixed microbial cells within the reactor. Previous studies were also successful in minimizing effluent discharge of total suspended solids (TSS) concentration for both synthetic and actual wastewaters as shown in Table 1.2.

The EMMC technology (a modified biofilm and activated sludge process) apparently can effectively hold the biomass in the reactor, and provides the effective removal of organics and nitrogen with minimal TSS effluent discharge. EMMC should be considered a potential alternative for conventional biological wastewater treatment and reuse; especially applied to regions with limited land requirements to build or improve existing infrastructure.

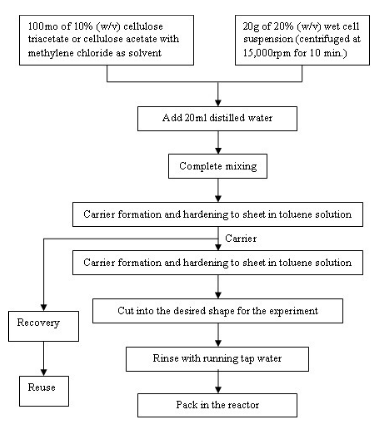

Figure 1.1 Preparation Schematic Sequences of CA and CTA

Table 1.1 Case studies of the application of EMMC technology for actual domestic sewage (pilot plant)

Packing ratio, %	34
Pilot scale, Liter	100.0
HRT, hours (total volume)	6
Aeration	Continuous
- SCOD removal efficiency, %	69±9
- TKN removal efficiency, %	97±1
- TN removal efficiency, %	79±5

Table 1.2 Effluent TSS concentration in the various sources of wastewater

Source	Influent TSS Concentration mg/L	Effluent TSS Concentration mg/L
Synthetic Wastewater (Kim and Yang, 2004 and 2005; Yang et al 1997, Yang et al 2002a, Yang and Myint, 2003)	≈ 0	< 30
Actual Domestic Sewage (Yang et al 2002b)	40—60	40—70
Actual Swine Wastewater (Yang et al 1997b)	200—400	300—400

Keywords: Modified biofilm/suspended culture process, Entrapped Mixed Microbial Cell; Minimize sludge production

WR-A14

Operation Assessment of a Water Reclamation Plant by Water Quality Analysis Coupled with Fluorescence Excitation-Emission Matrix and High Performance Size Exclusion Chromatography

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Abstract

Water scarcity is now a critical issue all around the world. The needs for water reclamation and reuse have become more and more prevalent in recent decades. Optimizing the operations and maintenance of water reclamation systems is critical for reducing operation costs and enhancing reclaimed water quality. In this study, a performance assessment was carried out on a semiconductor wastewater reclamation plant located in southern Taiwan by analyzing the water quality in all treatment facilities including pH adjustment tank, bio-activated carbon (BAC) filtration, multilayer microfiltration (MMF), ultrafiltration (UF) and reverse osmosis (RO). Water samples were collected every week from April 2015 to January 2016 and the obtained water quality was used to evaluate the pollutant removal efficiency in each unit as well as in the whole plant.

It was observed that during the first half of the sampling period (April 2015 to June 2015), BAC unit achieved high total organic carbon (TOC) removal efficacy (up to 66.1%). However, in the second half of the sampling period (October 2015 to January 2016), the TOC removal by BAC significantly decreased to 6.3% and the TOC residue in reclaimed water exceeded 1 mg C/L which was the regulated standard for reuse. The characteristics and molecular compositions of dissolved organic matters were analyzed using fluorescence excitation-emission matrix (FEEM) and high performance size exclusion chromatography (HPSEC) in order to elucidate the cause of bad reclaimed water. Figure 1a showed the organic species in pH adjustment tank (*i.e.* the raw water of the plant) were mainly small aromatic proteins in the first-half period. After treated by BAC, the main species were converted to larger proteins (Figure 1b). The results suggested that the microorganisms can utilize organic matters and transformed smaller aromatic proteins to larger molecules which facilitated organic matter removal in the subsequent membrane units, especially RO.

Compared to the first-half period, BAC unit was not capable of transforming organic substances in the second period and nitrification was dramatically enhanced. The deterioration of BAC function may be the major factor leading to the bad reclaimed water quality. Bad performance of BAC was attributed to sludge aging problem. Longer water retention time is a beneficial operation condition for nitrifying bacteria but was not profitable for heterotrophic bacteria. A suggestion to discharge sludge was provided to the operation team for urgent improvement. Results from this study also suggested MMF and UF had minor contribution of pollutant removal and over 95% of contaminants were removed by RO. Frequent backwash and replacement of RO membrane were suggested for future maintenance. The water quality analysis showed high consistency with FEEM and HPSEC results. This study demonstrated that the combination of these three techniques could be an efficient and comprehensive approach for the evaluation of treatment performances and organic fouling problems in wastewater treatment processes.

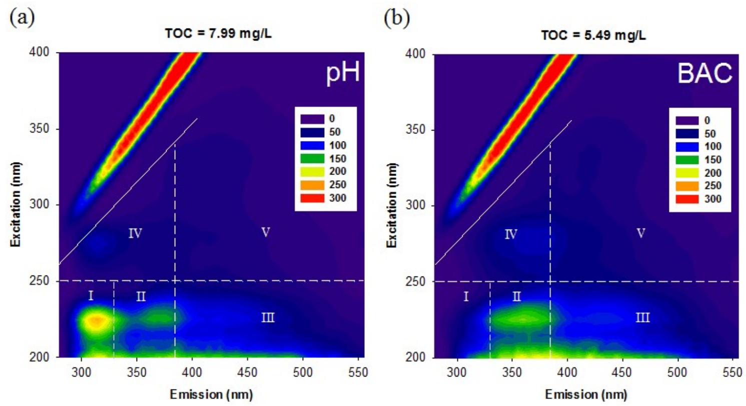

Figure 1 FEEM of each unit (samples collected on 4/23/2015); (a) pH adjustment tank, (b) BAC.

Keywords: FEEM; HPSEC; bio-activated carbon

WR-A15

Options for Water Re-use from Decentralized Wastewater Treatment Systems

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Abstract

Decentralized wastewater treatment systems can present a risk to human health and the environment by releasing highly soluble nitrate–nitrogen into the groundwater.
A research and demonstration study undertaken in Black River Falls, Wisconsin, evaluated several promising biofilter technologies for on-site nitrogen removal (Urynowicz, et. al). Duplicate recirculating sand filter-upflow anaerobic systems were used to treat septic tank effluent from a correctional institution. The system configurations produced treated wastewater with a total nitrogen concentration of 15.2 to 18.2 mg/L, representing 63.0 to 72.0% nitrogen removal, respectively. The differences between the two systems appear to have been the result of process configuration changes made over the duration of the study. This paper evaluates the nitrogen removal performance of the recirculating sand filter-upflow anaerobic systems and the effect of operational and environmental factors, including the recirculation ratio, BOD_5/NO_3^-, and temperature. Option for water re-use of the treated effluent are also discussed.

Table 1 Source Tank Effluent

Parameter	Mean	High	Low
Five-day biochemical oxygen demand (mg/L)	213.0	382.0	90.0
pH	6.9	7.8	6.5
Alkalinity as $CaCO_3$ (mg/L)	234.0	315.0	108.0
Total suspended solids (mg/L)	46.0	236.0	11.0
Total dissolved solids (mg/L)	350.0	652.0	202.0
Total nitrogen (mg/L)	50.0	65.0	35.0
Total Kjeldahl nitrogen (mg/L)	50.0	66.0	35.0
Ammonia-nitrogen (mg/L)	40.0	56.0	24.0
Nitrate-nitrogen (mg/L)	0.5	2.0	0
Total phosphorous (mg/L)	8.0	12.0	5.0

Table 2 Treatment System Effluent

Parameter	System 1			System 2		
	Mean	High	Low	Mean	High	Low
Five-day biochemical oxygen demand (mg/L)	4.0	19.0	1.0	9.0	52.0	1.0
pH	7.0	7.6	5.6	6.9	7.6	6.2
Alkalinity as $CaCO_3$ (mg/L)	91.0	205.0	32.0	115.0	280.0	44.0
Total suspended solids (mg/L)	8.0	84.0	0	9.0	125.0	0
Total dissolved solids (mg/L)	314.0	523.0	33.0	330.0	620.0	181.0
Total nitrogen (mg/L)	15.2	30.0	6.0	18.2	33.0	6.0
Total Kjeldahl nitrogen (mg/L)	4.5	25.0	0	7.1	28.0	0
Ammonia-nitrogen (mg/L)	2.0	18.0	0	4.4	24.0	0
Nitrate-nitrogen (mg/L)	10.7	22.0	2.0	11.0	30.0	1.0
Total phosphorous (mg/L)	7	11.0	2.2	7.0	14.0	2.5

Keywords: Wastewater Treatment; Decentralized; Water Re-use

WR-A16

Biological pre-treatment of river water slightly contaminated by ammonia for use as a drinking water source

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Abstract

Public water supply in south Taiwan strongly relied on a major surface water source, Kaoping River. However, water quality and quantity of the river was influenced by extremely high turbidity, in many cases up to 20,000 NTU, in rainy seasons, and low flow in dry seasons, posing a high risk to public water supplies in the area. To secure water supply during the episodes relevant to high turbidity and low flow conditions, an alternative source water, Dong-Gan (DG) River, with stable surface flow and low turbidity, was proposed to be used. Because DG river is polluted by the wastewater from swine farms, ammonia in the river is relatively high and therefore need to be treated.
A 2 m^3 pilot-scale biological pre-treatment process was applied in this study to exam the capability and efficiency of ammonia removal in the contaminated river water. The biological pre-treatment process applied porous polyurethanes carriers (BioNET) (Chang et al., 1999) for microorganisms, including heterotrophs and nitrifiers, to grow on and retain in the bioreactor. Three different hydraulic retention times (HRTs), 1.33, 0.81, and 0.5 hours, were examined in this study. Detailed operational conditions and performance were listed in Table 1. Ammonia monooxygenase subunit A (amoA) gene of ammonia oxidizing archaea and bacteria (AOA and AOB) and 16S rRNA gene of total bacteria were quantified using real time quantification polymerase chain reaction (qPCR).

Table 1 Operational condition and performance of each test run in this study.

	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6
Influent flow rate (CMD)	36	59	96.5			
Hydraulic retention time (hour)	1.33	0.8	0.5			
Average ammonia concentration in raw water (mg-N/L)	5.46	7.38	5.45	2.05	3.05	4.3
Average addition of ammonia concentration (mg-N/L)	—	—	—	1.47	6.42	6.05
Average ammonia concentration in influent (mg-N/L)	5.46	7.38	5.45	3.52	9.47	10.35
Average ammonia concentration in effluent (mg-N/L)	0.22	0.47	1.2	0.32	1.76	1.63
Average removal efficiency (%)	96	93	78	91	81	84
Average removal rate (kg-N/m^3/day)	0.09	0.2	0.21	0.15	0.37	0.42

Contaminated river water was directly used as raw water for the BioNET process. The ammonia concentration in the river water increased from below 1 mgN/L (August/September) to 8-9 mgN/L (April/May). Under HRT 0.5 hours, average ammonia removal efficiency and rate could reach 84% and 0.42 kg-N/m^3/day, respectively. The quantification results showed that AOB abundance was 2-3 orders of magnitude higher than that of AOA. The ratio of AOB over total bacteria was varied within 0.1% to 8.6%. Besides, AOB abundance higher than 1.5×10^8 copy/BioNET provides nitrification removal efficiency more than 70% (Figure 1). Furthermore, after applying recycle of the effluent, total inorganic nitrogen loss was observed, indicating the occurrence of denitrification and

the potential of total nitrogen removal in the BioNET process. Our results suggested promising strategy of removing ammonia from slightly polluted river water using BioNET.

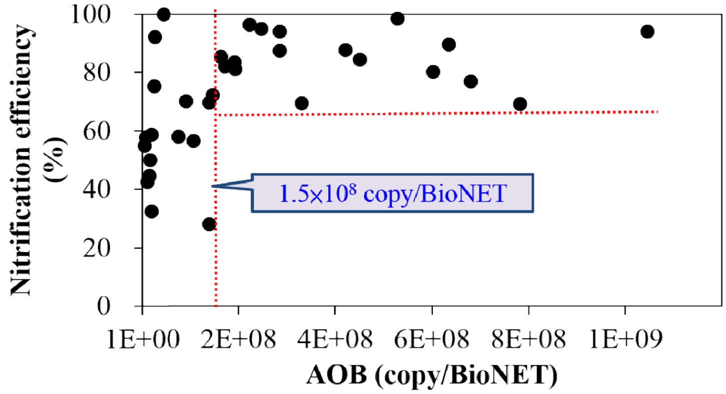

Figure 1 Relationship between nitrification efficiency and abundance of AOB on BioNET

Keywords: biological pre-treatment; nitrification; denitrification

WR-A17

Application of *in vitro* bioassays to assess water reuse plants around the world

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Abstract

Receptor mediated cellular bioassays are becoming increasingly popular to screen surface waters and water from reuse applications for chemicals of emerging concern (CECs), including pharmaceuticals, personal care products, steroid hormones, and endocrine disrupting chemicals. Although analytical chemical analysis continues to be the leading method to monitor specific compounds within these waters, not all compounds can be tested easily, nor does this application provide information interactions with biological systems. Cellular bioassays have the ability to assess the effect of the mixture of all compounds extracted from an environmental sample has on receptors or pathways of interest. This enables one to identify if there are compounds present that could impact certain biological systems. The aim of this research was to use *in vitro* bioassays to assess the ability of different water reuse facilities to remove biologically active CECs. Water samples were and continue to be collected from a total of 5 different water reuse facilities located across the continental United States, Singapore and Namibia. Secondary wastewater effluent (WWE) along with water samples after different stages of additional treatment were collected. Water samples were filtered and extracted using solid-phase extraction, with the extracts then tested using 5 different bioassays that investigate interaction with the estrogen receptor (ER), glucocorticoid receptor (GR), arylhydrocarbon receptor (AhR), p53 pathway, and general cytotoxicity. Although different treatment trains are employed at the different locations, similar trends existed for the removal of compounds interacting with the endpoints investigated. Firstly, there was no general cytotoxicity or interaction with the p53 pathway observed in any of the extracts, however, interaction with the ER, GR and AhR were found. Microfiltration was not found to be effective at removing compounds interacting with the ER, GR and AhR when detected in the WWE. Biological-activated carbon was effective at removing compounds found to interact with the ER and GR. Ozone treatment was effective at removing compounds found to interact with the ER. Finally, reverse osmosis was found to be effective at removing compounds that interact with the ER, GR and AhR. Although the treatment trains differed among sites, many implement multiple types of treatment that when used together were effective at removing the biologically active compounds that interact with the ER, GR and AhR to limits below detection. This research is ongoing, looking at these facilities over time while also testing samples using targeted and non-targeted analytical methods to gain a comprehensive view of the removal of contaminants by water reuse technologies.

Keywords: bioassay; in vitro; water reuse

WR-A18

Temporal Variability of Faecal Contamination from On-Site Sanitation Systems in the Groundwater of Northern Thailand

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Abstract

We investigated the impacts of on-site sanitation systems to local groundwater. In this year-long study, we monitored the response of faecal contamination levels to hydroclimatological factors including rainfall and groundwater table. Concentration of faecal indicators—*E. coli* (ESC), *Enterococcus* (ENT), nitrate—in thirteen pairs of shallow and deep wells were determined every 7–14 days. All samples from shallow wells were tested positive for faecal contamination (ESC and ENT > 1 MPN/100 mL) but concentration varies. A maximum of 24,000 MPN/100 mL were recorded in some shallow wells. Water from deep wells showed lower susceptibility to contamination with only 4 and 23% of samples tested positive for ESC and ENT, respectively. Concentrations of ESC and ENT were lower too, with a maximum of 5 MPN/100 mL and 28 MPN/100 mL, respectively. Fluctuation in contamination among the wells was described by four archetypal responses to hydroclimatological forcing: (i) flushing during the onset of wet season, (ii) dilution over the course of the wet season, (iii) concentration during the dry season, and (iv) synoptic response to storms. Previous studies attempting to link the prevalence of faecal/waterborne diseases and temporal factors (e.g., dry vs wet season) have produced differing outcomes. Our study may help explain the relevant hydrological mechanisms leading to these varying observations. Presently, most communities in Thailand have access to 'improved' sanitation systems. However, due to the unsustainable implementation of these systems, the otherwise viable drinking-water resources in the form of the abundant local groundwater has become a genuine health hazard.

WR-A19

Application of Analytic Hierarchy Process (AHP) for the Assessment of Water Reclamation Alternative

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Abstract

The water scarcity problem is becoming serious problem as a result of the accelerated industrial and agricultural and an increased population. Reclaimed water offers prospects as an alternative water resources (Pedro-Monzonis et al., 2015; Hess et al., 2015). Coagulation-flocculation (CF) is popular for using as water reclamation process. It is well known to be inexpensive process and easy operation for water reclamation process (Yu et al, 2016). Ultrafiltration (UF) become an interesting alternative process for water reclamation because of relatively low-energy and high efficiency filtration process can effective removing microorganisms and successfully employed in water reuse applications (Ferrer et al, 2015). Recently, the integrate of coagulation-flocculation and ultrafiltration process (CF+UF) is interesting alternative for water reclamation technology in order to improve the NOM and microorganism removal efficiency (Kabsch-Korbutowicz, 2005) and to increase the flux of water and reduce the fouling effects (Yu et al, 2016). The selection of the optimal water reclamation alternative is usually uncertain and complex. Many factors may be important for the decision-making process including capital investment, removal efficiency and optional usages. Analytic Hierarchy Process (AHP) is useful for handling multiple criteria and objectives in the decision-making process. Thus, this study is focus on the application of AHP to assess the alternative of water reclamation by using case study in the previous research of Yimratanabovorn (2018). In the case study, three alternatives of water reclamation were assessed and compared against multiple efficiencies (color, turbidity and COD), optional usages (water supply, toilet flushing, urban landscaping and vehicle washing) and total cost (capital, operational and maintenance cost). Identify the criteria and sub-criteria then pairwise comparisons into decision matrix. The optional usages are highest criteria weight because of they are affect to human health. The removal performance of CF, UF and CF+UF processes were compared as shown in Figure 1. The result illustrated that the CF+UF had significant higher removal efficiencies of color, turbidity and COD than single CF and UF in rang of 68.80-92.50%, 60.69-92.19% and 30.0-80.0% respectively. The results showed the removal efficiency priority weight of CF+UF (0.53) higher than single CF (0.3) and UF (0.17) as shown in table 1. Whereas, the water quality of CF+UF that meet the standard of water supply, and CF and UF meet the standard of toilet flushing, urban landscaping and vehicle washing and the optional usages priority weight of CF+UF (0.4) is higher than single CF (0.3) and UF (0.3). The total cost of CF is lower than UF and CF+UF thus the total cost priority weight of CF (0.57) higher than UF (0.29) and CF+UF (0.14). The weight priority of all criteria was summarized as shown in Table 1. In conclusion, the total priority weights of CF+UF (0.37) is higher than single CF (0.35) and UF (0.27). Thus, CF+UF is the appropriate process for water reclamation in this study and the AHP showed that it is the good technique to select the water reclamation alternative within multiple-criterias.

Table 1 The summary of weight priority of all criteria for water reclamation alternatives assessment

System	Criteria						Priority Weights			Total Priority Weights
	Efficiency				Reuse Option	Total cost	Efficiency (0.2)	Optional usages (0.6)	Total cost (0.2)	
	Color	Turbidity	COD	Avg.						
CF	0.29	0.29	0.32	0.30	0.30	0.57	0.06	0.18	0.11	0.35
UF	0.14	0.14	0.23	0.17	0.30	0.29	0.03	0.18	0.06	0.27
CF+UF	0.57	0.57	0.45	0.53	0.40	0.14	0.11	0.24	0.03	0.37
Total	1	1	1	1	1	1	0.2	0.6	0.2	1

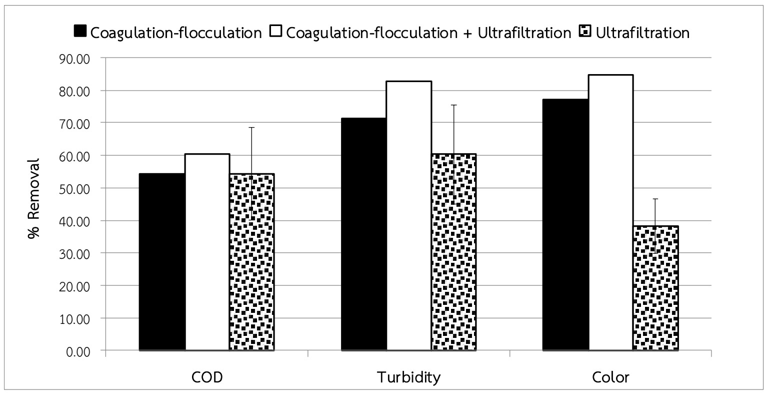

Figure 1 Comparison removal performance of three alternatives water reclamation processes

Keywords: Water reclamation; Analytic hierarchy process; Alternative water reclamation

WR-A20

Water Reclamation and Reuse from Centralized and Decentralized Wastewater Treatment Plants in Thailand

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Abstract

In this study, 10 effluent samples from both centralized and decentralized wastewater treatment plans in central area and suburban of Bangkok were randomly collected twice for a whole year in order to analyze chemical characteristics and quantities of fecal coliform and E-coli. Both phosphorus (P) and nitrogen (N) concentrations from these effluents are quite high. However, these concentrations are still lower than the standard (NO_3^- lower than 10 mg N/L and PO_4^{3-} lower than 2 mg P/L). The quantities of fecal coliform and E-coli are significantly higher than Thai's and US EPA's standards. All these effluents could not use as water resource of indirect potable water reuse for water supply. Conventional disinfection systems by using chlorine or UV are strongly recommended to install before these effluents could be used for any usable waters such as agriculture irrigation, landscape irrigation, non-potable urban uses, etc. Based on these results, using these effluents as watering a tree, washing floor, etc. are not possible and not recomended.

Keywords: water reclamation, water reuse, Thailand

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WR-A21

Water-reuse concepts for industrial parks in water-stressed regions in South-East-Asia

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Abstract

Including their megacities and urban areas, South East Asia belongs to the world's fastest-growing regions. Such tendencies of urbanization have a huge influence on new or on the expansion of industrial park locations as well. Referring to the water shortage in several of these regions (e.g. in China and Vietnam) sustainable water concepts are becoming more and more important. Especially the shortage of resources and the increasing environmental awareness require an ensured sustainable water supply. Therefore, the development of new water-reuse concepts for industrial parks to reduce their high water consumption from natural resources is an important approach to support urbanization.
The research approach develops an **I**ndustrial **W**aste**W**ater **M**anagement **C**oncept with a focus on **R**euse (IW^{2}MC→R) and includes a sustainable treatment of wastewater as well as the reuse of water for different purposes. The IW^{2}MC→R is aimed at an industrial reuse-factor (IRF, reuse water flow/whole water consumption) of more than 50 %, and therefore, it could have a high application potential in water-stressed regions. Considering the baseline for this research, which are two different initial situations of the wastewater treatment in industrial parks (see figure 1) – generated from investigations in China and Vietnam – it is obvious that the application of reuse water is not usual. Currently, the wastewater from different production plants is treated in a central wastewater treatment plant (CWWTP) in the park, which discharges the treated wastewater e.g. back into the water body. The central water treatment plant (CWTP) takes ground, tap or surface water for the water supply and provides e.g. three different water qualities: drinking water, industrial water and deionized water.

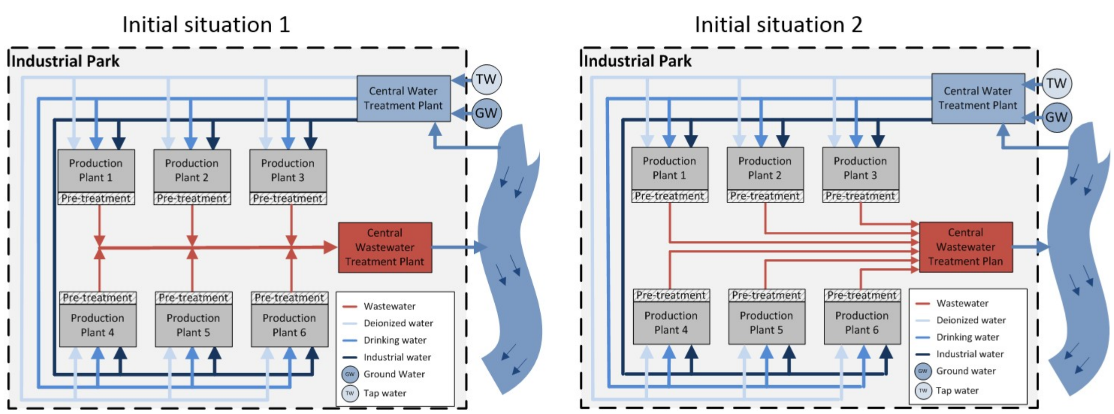

Figure 1 Initial situations of water management in industrial parks (Source: own figure)

The innovative IW^{2}MC→R, which is consisting of two different approaches (see figure 2), ties in with the initial situations of CWWTPs, but enables the supply of reuse water through a water-reuse plant (WRP). Reuse-approach 1 is based on one wastewater sewer from different production plants (linked to the initial situation 1) which is treated in in different steps (e.g. Head Works → Equalisation Tank → Flocculation-/Sedimentation → Deni-/Nitrification) in the CWWTP. In case of highly polluted wastewater, the connected production plants have typically their on-site pre-treatment plant. From the CWWTP, the treated wastewater is pumped into the WRP, where it is treaded additionally in different lines according to its subsequent use, e.g. for irrigation, street cleaning, toilet flushing etc. In reuse-approach 2, wastewater from several production plants is discharged in parallel sewers to the CWWTP (linked to the initial situation 2), where it is treated depending on the quality level in different treatment processes (C-Elimination, Nitrification, Deni-/Nitrification, Denitrification or Drying/Incineration). The different treatment processes for different wastewater flows enable a water quality production according to the principle "fit for purpose". After the CWWTP the water is derived to the WRP, where it is treated additionally in different lines, depending on its subsequent use. The application as reuse water for production processes or cooling purpose is also possible in both approaches.

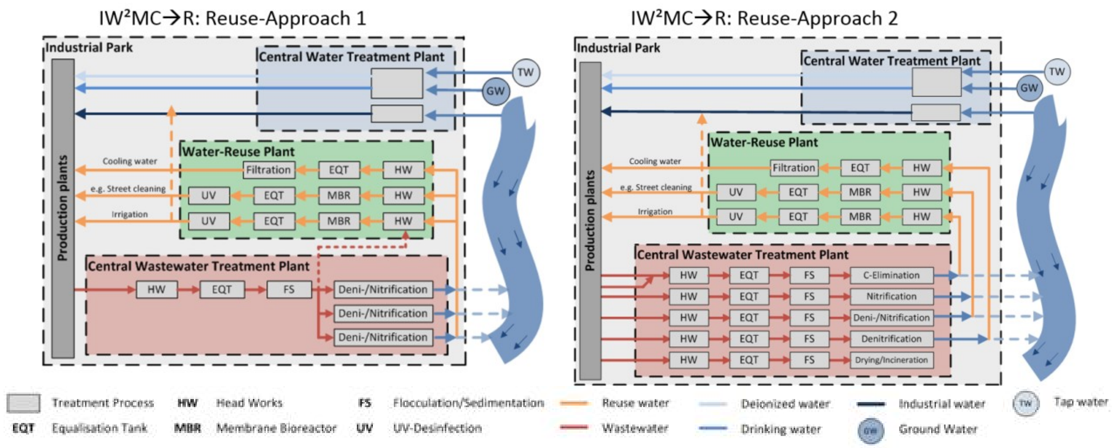

Figure 2 Different Reuse-approaches of an innovative IW²MC→R (Source: own figure)

By using a model industrial park (MIP), this approach enables the calculation of water input and output quantities. Therefore, in addition to the calculation of the required process water quantities within the production plants, a holistic calculation can be carried out for the entire MIP, since the model enables the calculation of the "external" water demand for different purposes, e.g. water for irrigation of green spaces within the park. The MIP also offers the possibility of modifying production types and allows using supplementary expansion areas to generate an efficient water-reuse solution to gain a reuse-factor of > 50 %. Hence, with the aid of the MIP the IW²MC→R provides a solution strategy, which is adapted to water output quantities and to appropriate water requirements, referring to the respective situation in the park. The MIP is thus preparing an implementation of the IW²MC→R to prepare the realization of new urban developments in water-stressed regions in South East Asia.

Keywords: water-reuse concepts in industrial parks; implementation water-reuse plant; reuse water "fit for purpose"

WR-A22

Introducing sequential managed aquifer recharge technology (SMART) for enhanced removal of trace organic compounds and pathogens during water reclamation

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Abstract

There is increasing interest worldwide to utilize unconventional water resources such as reclaimed water or impaired surface water to augment drinking water supplies. Given the presence of traditional and emerging microbial and chemical contaminants (e.g., pathogens, trace organic chemicals, nutrients) in these waters, efficient and reliable treatment processes are needed to assure a product water quality that is protective of environmental and public health. Natural treatment processes such as managed aquifer recharge (MAR) combine the benefits of efficient biological treatment for these contaminants with a low carbon footprint and a residual-free operation. The drawbacks of MAR are the rather large space requirements and a lack of process understanding that can guide more efficient design and operation of these facilities. This study reports on field-scale experiences using a new concept of subsurface treatment, - sequential managed aquifer recharge technology (SMART). SMART establishes oxic and carbon-depleted conditions which are much more favorable to degradation of trace organic chemicals and the attenuation of pathogens than conventional MAR systems since they result in a favourable shift of the microbiome regarding structure and function.

Keywords: Managed aquifer recharge; multi-objective treatment processes; trace organic chemicals

WR-A23

Wastewater Reuse in Turkey: From Present Status to Future Potential

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Abstract

Turkey is not a water rich country in terms of existing water potential. The amount of available water is about 112 billion m^3. Approximately 1400 m^3 fresh water per capita is available annually for water consumption. The State Institute of Statistics (SIS) has estimated that the population will reach 100 million and water availability in Turkey will fall 1100 m^3 per capita by 2030. Actual water consumption in Turkey is 74% of usage dedicated to irrigation, 13% of usage for domestic purposes and 13% of usage for industrial sectors (DSİ, 2017). The AQUAREC Project (2006), supported by the European Union (EU), has developed a model to estimate the reuse of treated wastewater in the EU. The current reuse of treated wastewaters in 2000 and potential reuse amounts in 2025 was determined with the model (TYPSA, 2013). According to the model results, it is seen that Turkey can take place in the ranking for potential re-use in number 4 after Spain, Italy and Bulgaria in 2025 with 287 million m^3 water reuse per year in the EU. When evaluating this potential, the execution of important projects and researches for the reuse of treated wastewater can be foreseen in the coming years in Turkey. Turkey has already launched two important projects after seeing this potential in the reuse of wastewater.

Turkey's Ministry of Environment and Urban Planning has carried out a major project in 2016 to determine the status of the wastewater treatment in the country including the efficiency and operational problems of domestic wastewater treatment plants in the whole country. Within the scope of "Determination of the Current Status of Domestic / Urban Wastewater Treatment Plants and Determining the Need for Revision (TURAAT)" project, it has been determined that Turkey has 1015 domestic wastewater treatment plants either in operation or under construction and 10.5 million m^3/day wastewater is treated daily (TURAAT, 2016).

In 2017, the Ministry of Environment and Urban Planning initiated the second important project, "Reuse of Treated Wastewater". With this project, all wastewater treatment plants were investigated for determining the wastewater recovery and reuse purposes for the first time. According to the results from this project, although there are 26 wastewater treatment plants with the different capacities of reuse facility, only 15 of them realized reuse in 2017. The amount of water recovered and reused from domestic/urban wastewater treatment plants was determined as 28.3 million m^3. Accordingly, the reuse rate of domestic wastewater in Turkey is defined as 0.78%. When looking at in which area this reuse was realised, one can see that industrial reuse ranks first with 59.4%, in-plant reuse (irrigation of green areas in the treatment plants, processes, etc.) with 17.5% comes second and irrigation follows with 4.65%.

In Turkey, wastewater reuse applications in agriculture are done rather indirectly by withdrawing river downstream or lake water from discharged effluent of wastewater treatment plants. Reuse of treated wastewater from the domestic wastewater treatment plants for planned agricultural irrigation purposes is not currently available. Reuse applications in water deficit industrial regions is the highest in Turkey due to water shortages and high water rates compared to other areas.

This paper aims to give an overview of wastewater reuse activities from present status to future potential in Turkey and the opportunities and challenges in expanding water reuse. A very limited number of European countries have guidelines or regulations on wastewater reclamation and reuse. Turkey began to apply wastewater reuse with the "Notification for Wastewater Treatment Plant Technical Procedures", published in 2010, for agricultural irrigation and uses Guidelines for Water Reuse (US EPA, 2004) for watering green areas. In addition, the current legislation in Turkey, and recent developments in the planned legislative changes are presented in this study. The realization of the planned goals and challenges are discussed after regulatory changes for reclaimed wastewater and reuse targets in Turkey for 2023. The status of wastewater treatment plants, the distribution of various treatment processes, treatment processes and their compliance with the wastewater treatment plants where reuse are carried out in Turkey, are evaluated in this study.

Keywords: Turkey; Treatment Plants; Water Reuse; Wastewater

WR-A24

Fertilizer effect of rice cultivation by reusing water treated with sewage of small region rural village in Japan

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Abstract

When using treated wastewater from domestic wastewater of rural settlement for paddy rice production, it causes excessive growth of rice caused by high nitrogen content in treated water. In general rice is ammonia vegetable plant and it is nitrate in treated water misunderstood that it can't use nitrogen. Since the paddy field is in an anaerobic condition, the oxygen in the nitric acid has been reduced to ammonia by microorganisms. It is thought that there is no fertilizer component because we want to enlighten that the treated domestic wastewater is highly clean. However, nitrogen required for paddy field rice cultivation is at a concentration of several mg / l or less, it is overlooked that we must adjust the fertilizer given before planting seedlings and nitrogen in treated water. Due to fertilizer design considering the characteristics of fertilizer requirements of paddy rice cultivation, it was examined in the actual rice paddy that the discharged water from the sewage treatment plant with high water purification ability such as the water source area can be used for paddy rice cultivation.

In urban areas, sewerage improvement, housing sewage, community plant, etc. were constructed, and in the rural villages wastewater treatment and septic tank were introduced and the toilet was washed. Processing of domestic wastewater in general as well as public health improvement has been carried out, and conservation of the water environment is being carried out. Furthermore, removal of nitrogen and phosphorus (N · P) in biological water treatment approached the physical advanced treatment (tertiary treatment: membrane filtration, etc.) and reached 2.5 th water quality. Therefore, in areas where water shortage occurs, attempts are being made to use for paddy fields and fruit trees. Generally, the excess of N · P makes it look good growth as the leaf color improves and grows greatly, so leaf color and growth are good at the beginning of treated water use. In the latter stage of growth, rice plants collapse, fruit trees do not become fruit, since nutrient growth does not change from nutrition growth to reproductive growth due to excess N. Common vegetable cultivation etc. and common knowledge on physiologically necessary plant nutrition in rice cultivation and fruit trees are quite different. Therefore, common sense of fertilizer requirement of general vegetables and common sense of rice and fruit trees are different but it is not distinguished, it is thought that processed water of domestic wastewater can't be used for agriculture.

In this study, fertilizer was designed considering the characteristics of plant nutrition physiology of paddy rice (as well as fruit trees and flower plants), and wastewater treated at the sewage treatment plant was supplied to paddy fields. As there are paddy fields around rural sewage treatment plants, it means that it is possible to use the treated discharge water for paddy rice cultivation. In addition, the amount of N · P in the discharged water reduced by changing the fertilizer design is not only reduction effect of fertilizer (= reduction of economic burden in agriculture), more than 60% N loaded on the environment It shows that it was reduced by absorbing it in rice.

"A" town is an agricultural place where rice can be harvested in early season in the Kanto(Tokyo) region. In order to use the discharged water of "A" town next to the paddy field, construction was carried out on the drainage line of the sewage treatment plant (with sludge reforming mechanism), and a water gauge and a control plug were installed (Photo 1). Cultivation was carried out according to the standard cultivation method and fertilizer management was adjusted based on the regional control calendar and adjusted to the fertilization design. The paddy field used is the place where farmland arrangement was carried out based on 20 m × 100 m (20 a). Koshihikari on the front side of photo 1 and Akitachomachi on the back side. Pest control was carried out in conjunction with the local control activities, and management from the sowing to the harvest coordination was done in the same process based on the regional work history.

The concept of fertilization design is shown in Fig. 1. It is in the special requirement of plant nutrition N of paddy rice (short grain rice) in Japan. The nutritional characteristics of this rice is the result of being culled and improved in the country where clear water is obtained, which is different from long grain type etc. As characteristics, seedlings at the time of rice planting are required to be in a state of high concentration for both N and P. It is known that the concentration of nitrate (NO_3^-) nitrogen in well water of drinking water source rises at the time of rice planting leading to intake restriction. Also, practical application of fertilization technology to rhizosphere only in rice planting has been underway.

Photo.1 Supply of treated water and water meter

The seedlings lived after rice planting are subjected to segregation (to increase the number of stems by dividing at the root) for rich fruit but after the seedlings are fully divided, they become larger, so that nutrients such as N · P Nutritional growth required. However, it is necessary to switch to reproductive growth by deficiency of N · P at the stage of attaching spikes with edible rice. When treated water is added to conventional fertilization design, rice continues vegetative growth, and does not switch to reproductive growth in over nutrition. Because rice continues to grow, rice falls and falls with strong winds and typhoons, so rice does not stick to it.
Table 1 shows the result of the harvest volume of the cultivation test, the result of the used water amount and the total N concentration. The amount of inflowing water in this treatment plant is about 7,500 cubic meters / month, the N of discharged water discharged after treatment is 3 mg / l, P is about 1 mg / l, and the regional conditions of the most severe discharged water It is a processing place to meet. If N / P in wastewater from this treatment plant is converted into per month, it translates N 22.5 kg and P 7.5 kg each month.

Table 1 Result of cultivation, usage of treated water and total nitrogen concentration

Year Stage	Harvest volume (kg/1,000m^2) Akitakomachi	usage of treated water (m^3)	Harvest volume (kg/1,000m^2) Koshihikari	usage of treated water (m^3)	Total Nitrogen mg/l (Averages of 2 to 4 measurements per month)			
					May	June	July	August
1st	520	2420	540	2023	0.3	<0.1	<0.1	0.3
2nd	505	2120	580	2230	0.6	0.2	<0.1	0.6
3rd	545	2585	530	2145	0.4	<0.1	<0.1	0.2

The wastewater from the field shown in Table 1 was shown to have been reduced to an N concentration of about 0.5 mg / l or less, which was reduced to about 1/6 or less. Since the cultivation period of rice is from the middle of March to the beginning of September, removal of N from discharged water by paddy rice cultivation was done during the cultivation period of about 6 months. For P, the result was less than the detection limit of 0.5 mg / l or less from the accuracy of analysis. About 1 mg / l for discharged water from the treatment site, it is considered that there was a removal rate of about 50% or more. It is estimated that 37.5 kg of N was used for rice or denitrification during the six months of cultivation period. For the entire treatment facility, five months of the one-year emissions are calculated by paddy rice cultivation.
If we use discharged water of about 2,500 m 3 for 20 a, we can accept all of the discharged water by using 360 a (18 paddy fields). One side of the paddy to the river in the back of Photo 1 is sufficient enough, and in the rice cultivation area it is sufficiently large enough to use a small amount of paddy fields (about a part of the area fields). In addition, it is possible to reduce N of 337.5 kg when all the discharged water at this treatment plant is accepted for rice cultivation, converted to 4218 kg in terms of home farming fertilizer (all 8), 420 bags in 10 kg bag It is a corresponding amount of reduction.

Keywords: Rice crop; Urban Sewage; Reuse treated water

WR-A25

Application of membrane technology in water reuse in China

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Abstract

The growing water stress both in terms of water scarcity and quality deterioration promotes the development of reclaimed water as a new water resource use. Because of high efficiency and automation, membrane technology is increasingly attracted in water reuse. This review mainly focused on commercial application status of membrane technologies (microfiltration, ultrafiltration, nanofiltration, reverse osmosis, forward osmosis, electrodialysis etc) in China. To evaluate the membrane market, the domestic and foreign membrane providers were compared. And the water-reuse equipment manufacturers also have been done the same comparison. In addition, the report surveyed the history of membrane technologies when they were applied to water reuse. It is supported that membrane technology is a better choice for wastewater treatment and reuse in the rural areas, especially expressway service area and railway station. After analysing government policies, standards, water prices and household consumption level in the past period, it proved that the membrane technology is potential and prospective in water reclamation in China. Strict rules will greatly promote the development of membrane technology in water reuse. However, the relational rules are not yet perfect. Based on above, this report finally summarized the opportunities and challenges of applying membrane technology in the water reuse process and showed the priority of future development.

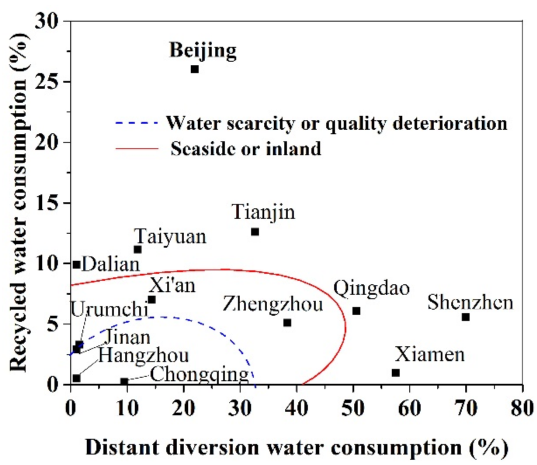

Figure 1 The relationship between recycled water and distant diversion water in metropolis of China. (The left side of the red line: inland city, the right side of the red line: seaside city; the left side of the blue line: water quality deterioration city, the right side of the blue line: water scarcity city)

Keywords: Membrane technology; Water reuse; China

WR-B01

Degradation of ibuprofen through the continuous adsorption and regeneration of activated carbon using electrochemical technologies

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Abstract

Pharmaceuticals have been increasingly identified in various environmental compartments, introduced through wastewater treatment effluent released into aquatic sources. They necessitate effective and efficient removal processes from wastewater before their release into the environment, especially when reuse applications are considered.
The use of adsorbents such as activated carbon within a fixed bed is a common treatment method given its ease of operation and high removal efficiency (Xu et al., 2017). Upon reaching saturation, adsorbents conventionally undergo thermal regeneration or are discarded in landfills. Choosing to discard the spent activated carbon is not environmentally sustainable. Similarly, thermal regeneration is an energy-intensive process and is often conducted at facilities off-site.
To overcome this drawback, electrochemical regeneration could be used as a cost-effective alternative (Bañuelos et al., 2015). In this study, granular activated carbon (GAC) derived from mango waste was saturated with ibuprofen, a common pharmaceutical pollutant in wastewaters.
Adsorption process of GAC was best represented by the Langmuir isotherm (Fig.1.a) showing an adsorption capacity of 166.6 mg/g. It was subsequently regenerated in-situ in an electrochemical reactor using the GAC as electrode to carry out the electro-Fenton process. The regeneration process was optimized based on parameters such as current density (Fig.1.b) and reduction of iron sludge through electrochemical deposition of iron on the GAC surface.

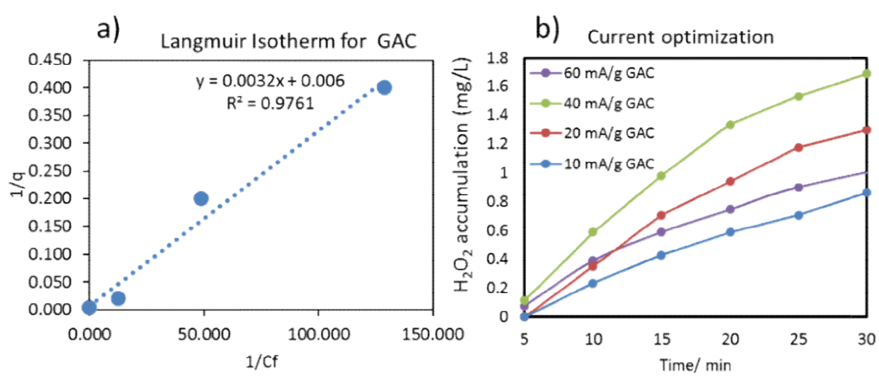

Figure 1. a) Adsorption isotherm and b) current density optimization for GAC.

Iron loaded GAC proved effective in providing iron catalyst in the electrolyte solution. High regeneration efficiencies and low energy consumption (Table 1), were obtained through five cycles of in-situ adsorption and regeneration. In conclusion, the continuous adsorption and in-situ regeneration of GAC by electro-Fenton is a promising technology that can potentially be applied in the treatment of pharmaceutical wastewaters at low cost.

Table 1. Regeneration efficiency and energy consumption after the electrolysis.

	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5
Regeneration (%)		75.3	75.9	97.2	98.0
Energy consumption (kWh/ g GAC)	0.00324	0.00319	0.00319	0.00331	0.00309

Keywords: wastewater treatment; activated carbon; electro-Fenton

WR-B02

Removal of Perfluorooctanoic acid (PFOA) from Wastewater by Electrocoagulation Process

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Abstract

In this study, the electrocoagulation process with iron anode was investigated to remove perfluorooctanoic acid (PFOA) in aqueous solution. The increase in current density from 2.4 to 40.0 mA/cm^2 led to an increase in the removal efficiency of PFOA from 10.0 to 100.0 %. The formation of shorter-chain perfluorocarboxylates (i.e., PFPeA, PFHxA, PFHpA), fluoride and formate ions were observed as byproducts from PFOA removal. The formation of formic acid indicated that the C-C bond between C_7F_{15} and COOH may be cleaved during PFOA decomposition. Our results imply that electrocoagulation process can be used to remove perfluorinated compound in wastewater.

Keywords: PFOA; electrocoagulation; mineralization

WR-B03

Electrochemical detection of low and ultra-low concentrations of heavy metals in natural waters

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Abstract

In recent years there has been a rising interest in the environmental sector of natural sciences, as an increase in pollution in the environment has been observed. The industrial activity to sustain an ever-growing human population leads to the uncontrolled release of pollutants, e.g lead.

As a result, rigorous limits have been set for the maximum allowed concentration for each pollutant in the environment. Since the content of pollutants occurring in natural ecosystems should be kept as low as possible, there is an ongoing search for analytical methods with ever-lower detection limits. For that, ion-selective electrodes (ISEs) are constantly investigated as they poses several desired properties for an environmental sensor. Namely, they are portable and relatively inexpensive and with maintenance limited to a minimum. The environmental analysis of ions requires the sensor to operate at low and ultra-low concentrations of analyte. Thus, extending the sensitivity range of the ISEs by lowering the detection limit is required.

In this presentation, the newest measurement protocols and application of ISEs for lowering the detection limit and measurements of ionic pollutants in natural waters will be discussed.

Keywords: Low detection limit; trace analysis of ions, potentiometric sensors

WR-B04

Use of leachate of saline-alkali land for oleaginous microalga growth and lipid accumulation

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Abstract

Soil salinization is a worldwide eco-environmental problem and the relatively mature and large-scale improvement measure is salt-leaching by hydraulic engineering. Although this measure has improved the saline-alkali land, the treatment of high salt-bearing effluent has become a problem. The leachate of saline-alkali land contains the nitrogen, phosphorus and trace elements needed for the growth of microalgae. Therefore, the cultivation of economical microalgae using leachate of saline-alkali land can reduce the cost of microalgae cultivation and is expected to achieve the purification of salt-bearing water. In this study, three common economic microalgae (*Chlorella* sp. HQ, *Scenedesmus* sp. LX1 and *Chlorella vulgaris*) were selected to screen out the most suitable one cultivated in leachate. The results showed that after 28 days of cultivation, among three microalgae, *Chlorella* sp. HQ grew best that its maximum density stood at peak of 1.17×10^{7} cells·mL^{-1} and total lipid production (0.047mg·L^{-1}) and lipid content (18.18%) were largest. The yield of triacylglycerides (TAGs) and total lipid content of *Scenedesmus* sp. LX1 were the highest, reaching 0.005 mg·10^{7}·cells^{-1} and 19.74%, respectively, which was slightly higher than 0.004 mg·10^{7}·cells^{-1} of *Chlorella* sp. HQ. Whereas, *Chlorella* sp. HQ was most suitable growing in saline-alkali land leachate by comprehensive comparison of biomass, lipids, and TAGs yields and contents. The growth status of *Chlorella* sp. HQ in leachate was further compared with that in SE medium, reclaimed water, and tap water. It was found that the sequence of the microalgae density of from large to small was in leachate of saline-alkali land, SE medium, reclaimed water, and tap water. Besides, the accumulation of high value by-products of *Chlorella* sp. HQ, including lipids, pigments, starch, protein and total sugar accumulation, were all superior than those in SE medium. The maximum content of photosynthetic pigment and total sugar content were reached when salinity were 0.32% and 0.45%, respectively, and the content of starch and protein decreased with salinity decreasing. It was also found that the contents of high value by-products such as lipids and TAGs of *Chlorella* sp. HQ were relatively high in tap water. It indicated that while nutrient stress is not conducive to the growth of microalgae, it can promote the accumulation of high value by-products.

Keywords: Saline-alkali land leachate; saline-alkali land leachate; biomass; high value by-products; lipid

WR-B05

Electro-Fenton treatment of pharmaceutical pollutants at near-neutral pH using tripolyphosphate

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Abstract

Large amounts of pharmaceuticals and personal care products (PPCPs) are constantly produced and discharged into the environment worldwide. Many of these compounds and their transformation products are biorecalcitrant and present toxic effects towards the aquatic organisms as pointed out by several investigations (Yang et al., 2017). The presence of such kinds of pollutants of "emerging concern" in the aquatic environment is a well-recognised issue that demands immediate action, especially for water reuse schemes where water safety is paramount.
Conventional wastewater treatment methods are unable to remove these toxic and non-biodegradable compounds. Their removal requires the use of strong chemical methods, known as advanced oxidation processes (AOPs). Electrochemically-driven AOPs, referred as EAOPs, have stood out as efficient and environmentally friendly technologies to degrade a great variety of organic pollutants, including PPCPs (Moreira et al., 2017). Electro-Fenton (EF) is the most widespread EAOP. It is based on the *in-situ* cathodic production of H_2O_2 and Fe^{2+} for the continuous generation of $^{\bullet}OH$ through the Fenton's reaction: H_2O_2 is formed via the 2-e^- reduction of dissolved O_2, while Fe^{2+} is regenerated from the reduction of Fe^{3+} (Brillas et al., 2009). Carbonaceous materials are generally used as electrodes (carbon felt, carbon fibers, carbon cloth, graphite and graphene among others). However, one of the main limitations of EF is its restricted acidic working pH (optimal value around 3).
In this context, the main goal of the present study was to investigate the feasibility of EF on the treatment of synthetic pharmaceutical wastewater at near-neutral pH with the use of the chelating agent tripolyphosphate (TPP) as supporting electrolyte. The synthetic pharmaceutical wastewater contained 6 drugs that were identified in a real effluent from a pharmaceutical industry (amitriptyline, carbamazepine, diclofenac, tetracycline, caffeine and bisphenol A). The main parameters effecting the process efficiency were systematically investigated: TPP concentration, Fe^{2+} concentration ([TPP]:[Fe^{2+}] ratio) and applied current. It was found that the efficiency was not significantly dependent on TPP concentration, while the optimal Fe^{2+}:TPP ratio and current value were 10:3 and 350 mA, respectively (the effect of [TPP]:[Fe^{2+}] ratio is shown in Fig. 1a). More than 90% of TOC removal was achieved following 6 h of treatment with 10 mM TPP and 3 mM of Fe^{2+} at 350 mA and pH 6 (80% of TOC removal in 3 h) (Fig 1b). Furthermore, when 5 mM of TPP were used along with 25 mM of K_2SO_4 (conventional electrolyte to ensure the conductivity of the solution), similar TOC decay was achieved, pointing out that only a small amount of TPP is needed to maintain Fe^{2+} ions in the solution available for the Fenton's reaction at near-neutral pH values. In all cases, the 6 pharmaceuticals were totally removed below HPLC-MS detectable limits within the first 5 min of treatment. These findings demonstrated that near-neutral EF with TPP electrolyte is a potential option for the treatment of organic pollutants, which enlarges EF applicability with a wider pH range of operability.

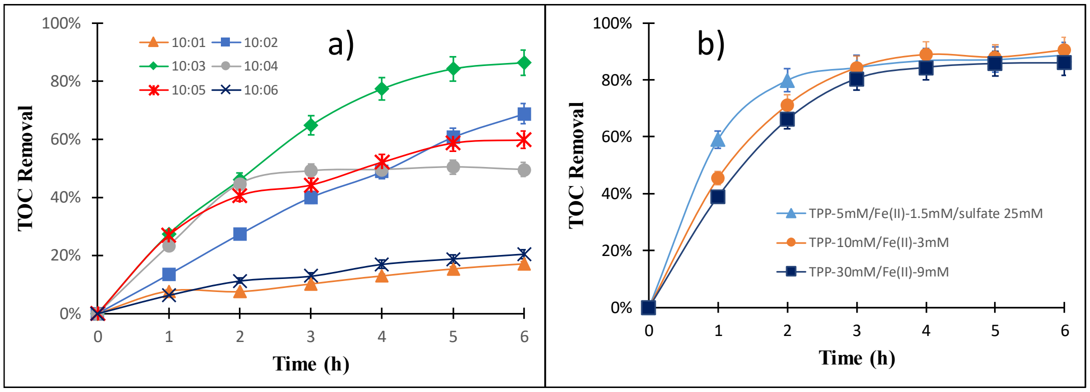

Figure 1 EF treatment of synthetic pharmaceutical wastewater a) effect of the [TPP]:[Fe2+] ratio with 10 mM of TPP and 150 mA of current, b) effect of TPP concentration at an optimal current value of 350 mA. Experimental conditions: batch undivided cell with a DSA (Ti/IrO_2-RuO_2) anode and carbon brush (carbon fibers) cathode, V = 400 mL, pH = 6, TOC_0 = 40 mg L^{-1}, room temperature, continuous aeration and stirring.

Keywords: electro-Fenton, pharmaceuticals, tripolyphosphate electrolyte

WR-B06

Demanding a change from wastewater treatment to resources recovery & zero liquid discharge in China – how have the government and industrial sectors reacted?

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Abstract

Price of fresh water is no longer a commodity consideration but rather a strategic resource. When cities need to transform from the industrial dependent activities to more modern and sustainable status, what will be the challenges behind and necessary infrastructure required?

Convinced with the direct correlation between the cleaner environment and the sustainable economic development, the State Council of China has, in 2015, laid out "Water Ten Plan" coordinating among the twelve ministries including Ministry of Environmental Protection which also released another set of even more stringent environmental legislations (with death penalty for the most severe case).

This presentation describes how the industries, in the last 20 years, have been evolving from the rationale of traditional wastewater treatment & discharge, to resources recovery, water reuse and even zero liquid discharge in order to align with the long term mission.

Case studies on advanced vibrating membrane technologies sustaining coal related industries, utility sectors, heavy industries, light (but polluting) manufacturing activities, will be presented to illustrate the path taken in China which could be a good reference for ASEAN countries.

WR-B07

Evaluation of Micro Pollutant Removal in Aquaculture Wastewater Treatment Process Using Dynamic Light Scattering Technique

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Abstract

This study focuses on the treatment of aquaculture effluent discharged from a commercial local Arowana fish ponding farm. The major pollutants analysed and compared at both the inlet and outlet points were BOD, COD, TSS, e-coli and phosphorus. The water samples collected were also measured in terms of zeta potential and dynamic light scattering of as a function of pH (pH 2 to 12) to determine the optimum pH range suitable for the chemical treatment applied. It was found that the initial pH for aquaculture effluent was detected at pH 6 with a negative surface charge at a value of -25 mV and corresponding z-average particle size of 400 d.nm. The surface charge of particles in the aquaculture effluent maintained a consistent negative value throughout the pH adjustment from 2 to 12. The coagulant selected was ferrous sulphate ($FeSO_4.7H_2O$), a chemical by-product disposed from a titanium manufacturing plant based in another state. The initial pH of $FeSO_4.7H_2O$ was detected at pH 5.5 with a slightly negative surface charge with a value of -10 mV and z-average particles size of 27 530 d.nm. In this case, ferrous sulphate also did not indicate any point of zero charge (PZC) similar to aquaculture effluent. The interaction between the aquaculture effluent and the coagulant were conducted systematically in two separate conditions i.e. pH 5 and pH 9 using the initial pH as the point of reference. In the first condition at pH 5, in the absence of $FeSO_4.7H_2O$, the zeta potential and particle size were -25 mV and 524 d.nm respectively. As the concentration further increased, both the surface charge and particle size changed accordingly. As the zeta potential reduced approaching 0 mV, the particle size increased from 5492 to 10111 d.nm when the concentration was between 360 and 560 mg/L. At 600 mg/L, charge neutralization occurred with a particle size of 10810 d.nm was measured. As the concentration was added, this lead to a transformation of surface charge from negative to positive. Concurrently, the increased concentration of $FeSO_4.7H_2O$ in the aquaculture effluent suspension led to partial disaggregation where the particle size started to fraction from 10204 d.nm to 9261 d.nm when the concentration was within 800 and 1100 mg/L. In the final phase of the experimental work where jar test was conducted, the optimum coagulant dosage selected was between 350 to 600 mg/L. Post treatment positively showed that there is a high opportunity of reclaiming water for aquaculture wastewater, where the following water quality parameters analysed indicated significant reduction for TSS, COD, BOD, P and e-coli percentage wise with results of 98.1%, 85.4%, 50%, 86.1% and 42% respectively.

Keywords: Aquaculture effluent; pollutant removal; coagulation; dynamic light scattering

WR-B08

Water Reuse Eco-toilets for Tourism Challenges & Sustainable Development: From Conceptual Evolvement to Reality Advancement

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Abstract

Seasonal factors, fluctuating peak load from ad hoc tourist visiting patterns, environmental concerns from sewage handling & discharge, minimal disturbance to harmony and landscape of historical heritages pose different challenges to the proper provision of sanitary facilities within tourism areas.

This presentation illustrates the evolvement of the concept of membrane bio-reactors (MBR) integrating microorganism and membrane technologies being transformed from large scale infrastructures into modularized setup bio-toilets (BT). Experience on installation, monitoring and management of over 130 BTs within the rural areas and along the scenic hiking trails of Hong Kong would be reported. Technical challenges are overcome to recycle the sewage into toilet flushing water within a short cycle time, and even to meet stringent standards for stream course eventually leading to reservoirs. Expensive and sometimes, infeasible piping infrastructure connecting the toilets to proper government treatment facilities have been eliminated.

The China National Tourism Administration had announced a 3 year "Toilet Revolution" to call for a sustainable operation and management philosophy focusing on "30% hardware and 70% management"; the lesson learned on the first tourism toilet being commissioned in Qingdao, China on the World Toilet Day would be highlighted.

Future solutions for the solar powered tourism toilets, design to harmonize with the surrounding landscape and other challenges such as Golden Weeks peak load, cold weather conditions would be discussed. A new proprietary aeration process to eliminate all the air blowers and compressors which reduce the energy and maintenance costs by 50% and the noise impact by 80%, and lead to the mobile, solar enabled version of BT would be shared.

WR-B09

Synergistic opportunities to utilize impaired waters in coastal regions

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Abstract

Urban communities that desalinate ocean water using reverse osmosis (RO) and treat wastewater in coastal facilities produce two main waste streams – an RO concentrate stream and a treated wastewater stream. Both streams are discharged to the ocean as shown in Figure 1.

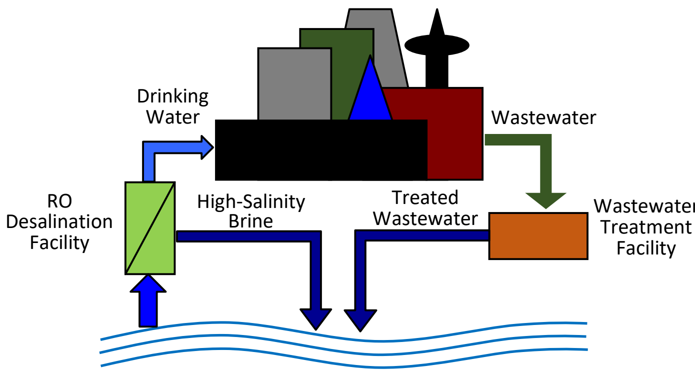

Figure 1 Schematic of a coastal urban water cycle in which two waste streams – reverse osmosis (RO) concentrate and treated wastewater – are discharged to the ocean.

Currently, the only synergistic use of these waste streams is the one called out in the draft amendment to the Water Quality Control Plan for Ocean Waters of California (i.e., California's Ocean Plan). The Ocean Plan states that "the preferred technology for minimizing intake and mortality of marine life resulting from brine disposal is to comingle brine with wastewater that would otherwise be discharged to the ocean"

Although the use of treated wastewater to dilute RO concentrate is central to solving the RO concentrate disposal dilemma, it assumes there is a plentiful and disposable supply of treated wastewater. However, because of increased conservation, wastewater flows have declined; and more importantly, as more wastewater is being reclaimed for reuse purposes, less treated wastewater is being discharged to the ocean. For this reason, other options to synergistically use both waste streams and make greater beneficial use of the treated wastewater should be considered.

Along these same lines, the drought and climate change concerns that are driving more interest in ocean water desalination are also supporting a "One Water" movement. The basis of this movement is that the lines between wastewater and drinking water have been fading and that wastewater, drinking water, stormwater, and groundwater are all One Water. With this in mind, it is becoming desirable to extract as much water as possible from treated wastewater prior to discharge. And in this case, other scenarios for synergistic use of the two waste streams become viable. The question becomes "How can RO concentrate and treated wastewater be combined to optimize water supply in arid regions - can we do better than simply mixing them?"

In this presentation, four options (Figure 2) to synergistically utilize RO concentrate and treated wastewater streams to achieve the highest beneficial use of both streams while minimizing energy consumption and environmental concerns will be presented and discussed and compared.

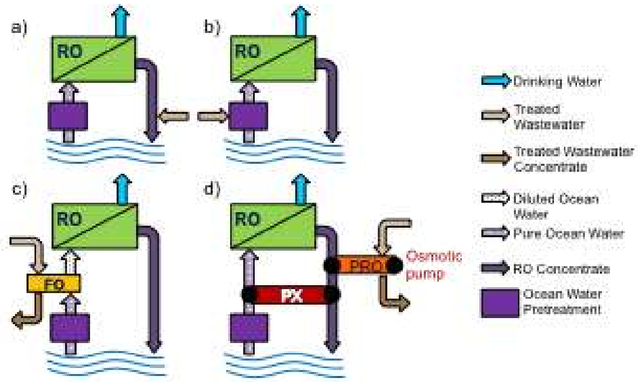

Figure 2 Four options to synergistically utilize seawater desalination and wastewater reclamation: a) Scenario 1: Blending treated wastewater with RO concentrate, b) Scenario 2: Blending treated wastewater into ocean water uptake, c) Scenario 3: Osmotic dilution (FO-RO), and d) Scenario 4: Salinity-gradient energy (RO-PRO).

WR-B10

Reduction of CO_2 emissions in sewage treatment systems by removing oil and fat from wastewater and using it for power generation

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Abstract

Wastewater containing of oil and fat (WCOF) may worsen water environment by declining performance of sewage treatment systems (STP) especially in urban areas, like Tokyo, which depend on combined sewerage. Since oil balls with combined sewer overflow (CSO) in rainy season have got a problem in Tokyo, Japanese government suggests three goals to improve combined sewerage. Grease-trap (GT), for the third goal, must be installed to remove oil/fat in WCOF from kitchens discharging much WCOF in Japan. Although GT efficiently eliminates oil/fat in WCOF as grease, collection of intercepted grease (IG) is onerous because IG is removed by hand with papers. A new technology, named Kankichikun-Jr (K-Jr), to automatically collect IG from GT has been developed to effectively utilize IG as a biofuel for power generation (FPGS), which is expected to reduce burden to sewage treatment systems as well as generation low carbon electricity, in Japan. Thereat, this study aims to quantitatively evaluate environmental effects with reduction of burden to STP for Tokyo by FPGS using a bottom-up model. As a result, 111 thousand t-CO_2, corresponding to 15% reduction in STP of Tokyo Metropolis, is annually reduced at sewage treatment systems by installing K-Jr at GT in Tokyo.

Keywords: Energy recovery; oil/fat-contained wastewater; grease-trap

WR-B11

Comparative Environmental Impacts and Economic Benefits of Different Wastewater Management for Cassava-Based Ethanol Production in Thailand

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Abstract

This research investigated the environmental impacts and economic benefits of cassava-based ethanol production when wastewater treatment system was modified from open lagoon to Upflow Anaerobic Sludge Blanket (UASB) for the purpose of water reuse and biogas production. In the assessment, this study experimented with a total of three different wastewater management schemes in cassava ethanol production, i.e. open lagoon, UASB with biogas recycle for steam production (biogas-steam), and UASB with biogas recycle for electricity generation (biogas-electricity). The ethanol production data was collected and analysed for input and output inventories. Moreover, the environmental impacts especially the potential water reuse, the greenhouse gas (GHG) reduction and economic benefits i.e. the payback cost and the reduction capital of ethanol production were investigated. The findings revealed that both UASB schemes reduced water consumption by 79% (415449 m^3/year). Moreover, the biogas-steam scenario decreased GHG by 83.25% of the total GHG in base case that was slightly higher than the GHG decreased by biogas-electricity scenario (82.76%). According to the economic benefits, the payback cost of biogas-steam and biogas-electricity was 0.14 and 4.48 years, respectively. In addition, the reduction capital of ethanol production was 1.39 and 1.07 THB per L ethanol of the biogas-steam and the biogas-electricity scenario, respectively. Based on objectives of this study, the cassava ethanol production using biogas for steam production scheme was the most preferable choice due to their lower the environmental impact and the economic costs.

Keywords: Cassava; UASB; Greenhouse gas; Payback cost; open lagoon; annual cost

WR-B12

Estimating coastal water quality in Danang Bay, Vietnam: models and parameter assessment

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Abstract

The development of coastal areas recently has paved the way for the new opportunities in Vietnam, when more investments and projects have been approved, promising a bright future of prosperous development. However, apart from those benefits, rapid development causes negative impacts on surrounding environment. Urbanization has unintentionally put a great pressure on infrastructure and ecosystems, coupled with pollution rooted from upstream streams, resulting in the expansion of polluted areas which causes great damage on living standards of those households living in coastal areas. With the purpose of evaluating imbalanced impacts of wastewater treatment plants on causing pollution in Danang Bay, this study applies the MIKE 21 model for evaluating different scenarios. Outcomes from the models will help assess the level of pollution associated with the pollutant volume of waste sources. Calibration, verification for hydrodynamics (HD) and advection – diffusion (AD), Ecolab models have been implemented to ensure the reliability of this study.

Keywords: Coastal water quality, Waste water, MIKE21, Validation, ArcGIS

WR-B13

Replacement/precipitation reaction for zinc removal using electrogenerated iron

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Abstract

Text content 10. Metal-bearing wastewater are hazardous to the environment and harmful to the public health due to the unsafe substance including heavy metals and organic substances. The conventional treatment processes were ineffective for the removal of ligand-complexed metal ions due to their high solubility and chemical stability. Electrocoagulation (EC) process has been regarded as a potential candidate in wastewater treatment due to a readily available of electrode material, inexpensive, and easy operation (Akbal and Camcı 2010). It is well known that ferrous ions (Fe(II)), not ferric ions (Fe(III)), were generated from iron electrodes and then were subsequently oxidized by dissolved oxygen to ferric ions under neutral and alkaline pH condition (Lakshmanan, Clifford et al. 2009). Since the constant stability of Fe(III)/EDTA being 8 to 9 orders of magnitude higher than that of Zn/EDTA, Fe(III) has potential to liberate zinc ions from Zn/EDTA. With iron anode, the generated iron might participate in the so-called replacement/precipitation process (Jiang, Qu et al. 2010, Xu, Gao et al. 2015) which is never investigated in the past. Therefore, the objectives of this study are systematic investigation of replacement/precipitation reaction for zinc-ligand removal using electrogenerated iron with the effects of iron dosage, initial pH, organic ligand species, and mixing mechanism being explored.
A schematic diagram of the experimental setup used in this study is shown in Figure 1. The effects of iron dosage on the removal efficiency of Zn was investigated with various initial pH values. As shown in Figure 2, Zn removal was independent of the initial pH. The efficiency of Zn removal increased linearly with iron dose until reaching completely removal at the same time for all the initial pH tested. The amount of Zn removal as a function of theoretical Fe generated with assumption of 100% current efficiency. The trends were linear and the slopes were around 0.17 to 0.19, corresponding to 5.5 to 6 mole Fe(II) generated per mole of Zn replaced. Figure 3 shows the plot of Zn removal vs. Fe residual. These data points lie along the 45-degree line indicating that Zn/EDTA was replaced by Fe ions except pH 3. Once Zn was removed, the complexation of Fe/EDTA formed immediately. Fe residual concentration was high with the initial pH 3 due to the free of Fe ions, which could not precipitate at low pH range. The pH of treated wastewater then was increased to remove the free of Fe ions and data point was along the 45-degrea line. As shown in Figure 4, TOC removal efficiencies are all less than 20%, indicating that Zn removal is mainly through the replacement/precipitation mechanism.

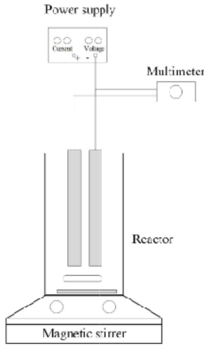

Figure 1 Schematic diagram of experimental setup

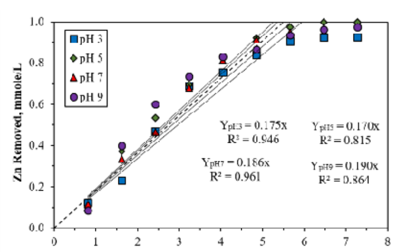

Figure 2 Zn removal as a function of theoretical Fe generated

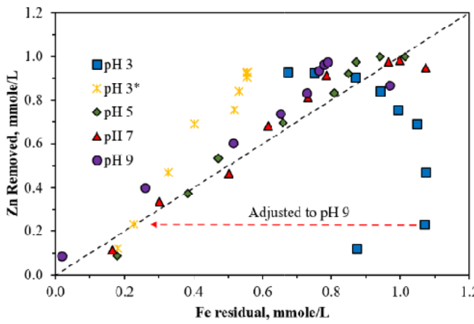

Figure 3 Zn removal as a function of Fe residual. *Treated wastewater was adjusted to pH 9.

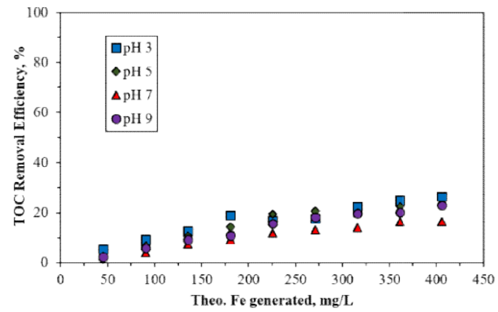

Figure 4 TOC removal efficiency as a function of theoretical Fe dose

Keywords: Decomplexation; Heavy metals; Replacement

WR-B14

Impact of flow rate on adsorption column capacities of different pore size distribution on activated carbons

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Abstract

This study focus on influence of pore size distribution and flow rates on two type of activated carbon adsorption columns (4 cm in diameter and 37.9 cm. bed high). Adsorption capacities at flow rates 60 and 120 ml/min on surface water parameters color in Pt-Co unit (15.14 – 30.8 Pt-Co), UV absorbance at wavelength 254 nm (UV_{254}) (0.157 – 0.214 cm^{-1}) and dissolved organic carbon (DOC) (4.955 – 7.053 mg/l) were studied. Commercial grade (8x30) coconut-shell base (CAC) and bituminous-coal base activated (BAC) activated carbon with similar specific surface area at 849.35 and 901.55 m^2/g respectively that indicate to similar adsorption capacity but different in pore size distribution were used. Coconut-shell base activated carbon consist 36% (by total volume) mesopores volume and 64% micropores volume. Meanwhile, Bituminous-coal base activated carbon show higher mesopores volume at 56% and lower micropores volume at 44% with similar total pore volume. To ensure similarity of adsorption capacities of CAC and BAC batch adsorption isotherm at 30.7 ºC and adsorption kinetic at contact time 0 – 10 minutes were conducted before adsorption column investigation.
The batch adsorption studies reveal well fitted to Langmiur of all adsorbents on CAC and BAC with similar q_{max} (maximum adsorption capacity). The result from kinetic adsorption study demonstrate that BAC and CAC adsorption rate are in common with negligible higher of BAC at contact time within 10 minutes. For DOC adsorption second-order adsorption reaction with similar reaction rate constant at 0.24 and 0.3 l/mg-hr of CAC and BAC respectively were found. Furthermore the plot of specific ultraviolet absorbance (SUVA) against contact time within 10 minutes reflect similar trend of SUVA influence reduction which indicate to the same organic molecular weight proportion removal. Results that obtained from all of these studies ensure us about similarity of adsorption capacities of CAC and BAC in batch and kinetic studies. Meanwhile, Breakthrough curve of DOC and UV_{254} on CAC in fig.1(a) and BAC in fig.1(b) at flow rate 60 and 120 ml/min show difference of DOC adsorption capacities of CAC and BAC at the same flow rate (at 60 ml/min CAC capacity is 1.09 and BAC capacity is 0.67 mg/ g carbon, at 120ml/min CAC capacity is 0.74 and BAC capacity is 0.97 mg/ g carbon) while UV_{254} adsorption capacity are tend to similar in all adsorption conditions which disagree with result that obtain from bath and kinetic adsorption studies. To prove this conflicting result scanning electron microscope was conducted to analysed pore conformation of activated carbon. At magnification 100 times of CAC and BAC (fig.2(a), fig.2(b), respectively) and 2000 times of CAC and BAC (fig.2(c), fig.2(d), respectively) the images exhibit clearly broader macropores of BAC at external surface. By explanation that broader pore and proportion of mesopores tend to make adsorbent be easier to desorb, the lower BAC capacity results at flow rate 60 ml/min is supported (Cecen and Aktas, 2012; Hsieh and Teng, 2002). At 120 ml/min higher DOC adsorption capacity on BAC was found due to increment of Thomas model adsorption rate constant (K_t) from 0.020 to 0.034 l/mg-hr which illustrate adsorption behaviour base on Langmuir adsorption isotherm with assumption that the rate driving force obey second-order reversible reaction that contribute to higher adsorption rate. Under increment of flow rate liquid film resistance is decreased contribute to higher adsorption rate (Chatzopoulos and Varma, 1995). In the other hand decrease of CAC adsorption capacity was found at flow rate 120 ml/min. Although K_t of CAC is increase from 0.099 to 0.0278 l/mg-hr but longer sorption zone than sorption zone at 60 ml/min clearly indicate that the adsorption rate is not high enough to retain DOC. This behaviour of CAC may describe by lower proportion of boarder external pores and mesopores; the pores that reduce length of diffusion path to narrow and high adsorption energy pore inside activated carbon (Cecen and Aktas, 2012; Hsieh and Teng, 2002).
The result of this study demonstrate that DOC Adsorption capacity of activated carbons in adsorption column in difference of pore size distribution tend to be impacted differently when flow rate are changed.

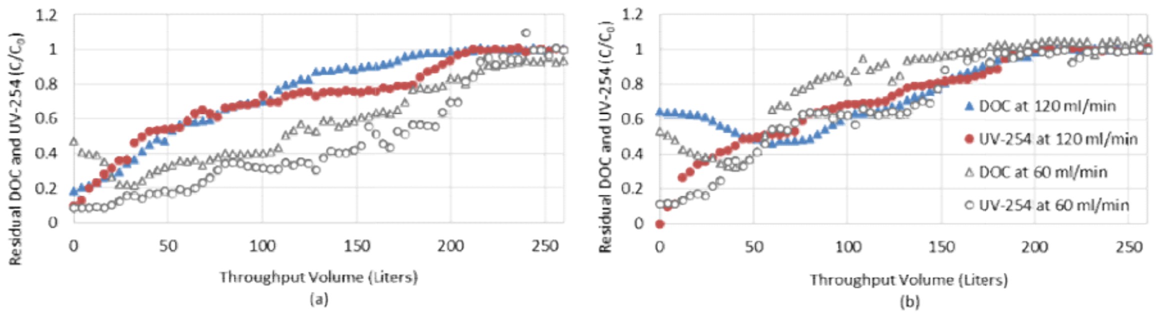
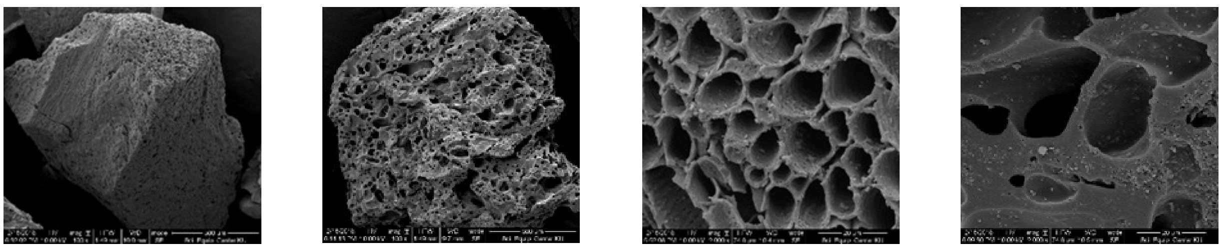


Figure 1 Breakthrough curve of CAC (a) and BAC (b) on DOC and UV_{254} adsorption.



(a) (b) (c) (d)

Figure 2 SEM image at magnification x100 of CAC (a) and BAC (b), x2000 of CAC (c) and BAC (d)

Keywords: Activated carbon adsorption column; Pore size distribution; Flow rate variation

WR-B15

High capacity adsorbents for trace Cr(VI) removal from drinking water

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Abstract

Hexavalent chromium is carcinogenic in nature and one of the contaminants of emerging concern in drinking water. Cr(VI) contamination in groundwater used for drinking is rampant in various places of the world. Currently, only California has tap water standard for Cr(VI) at 10 ppb. Although there are number of studies for removal of Cr(VI) in wastewater, removal of trace concentration of Cr(VI) from the drinking water sources has been rarely studied. Commercial anion exchangers are unable to selectively remove dissolved Cr(VI) at neutral to alkaline pH in the presence of other competing anions, namely, sulfate, chloride, bicarbonate, and nitrate. In a recently concluded study, it was found out that weak-base anion exchange resins with phenol formaldehyde matrix showed an extraordinarily high Cr(VI) removal capability, at least one order of magnitude higher than other common strong base anion exchangers. A further investigation indicated occurrence of a novel removal mechanism which consisted of anion exchange followed by redox reactions within the matrix of the ion exchanger. However, possibility of leaching of toxic organic substance due to such reactions could be an issue against practical use. Motivated by the novel removal mechanism, we prepared a redox-active adsorbent which showed a similar capacity of Cr(VI) removal. The presentation shall discuss the findings of the studies carried out to investigate the mechanism of removal of chromate removal by the synthetic resins. It shall also elucidate the synthesis of the new adsorbent and its selective removal capabilities of trace concentration of Cr(VI) from a background of other competing anions.

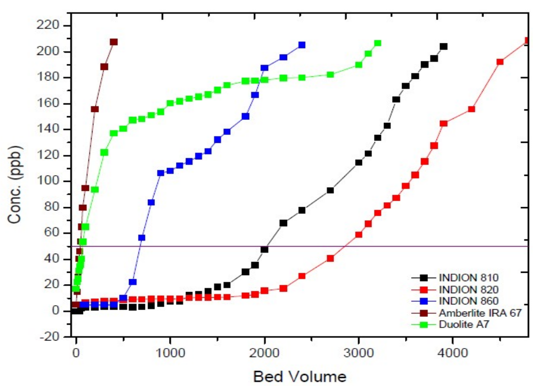

Figure 1 Breakthrough history of all the resins studied at neutral pH

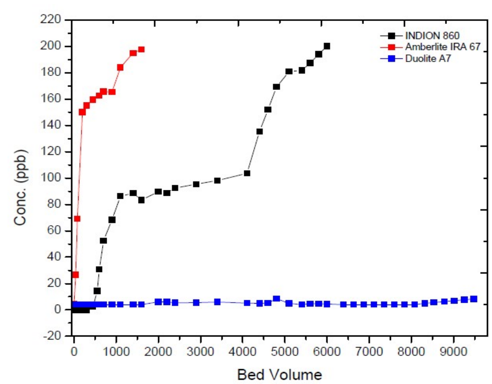

Figure 2 Breakthrough history of weak base anion exchange resins studied at pH 5.0

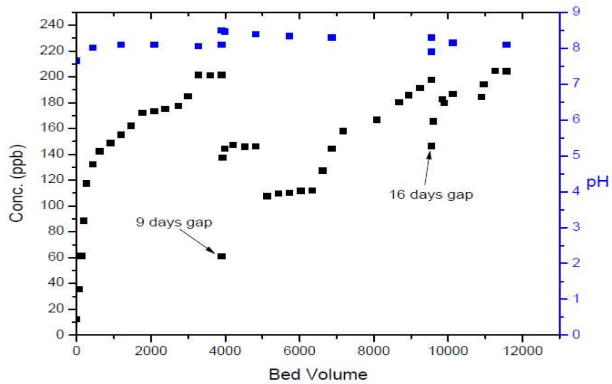

Figure 3 Column run of Duolite A7 at pH 7.0

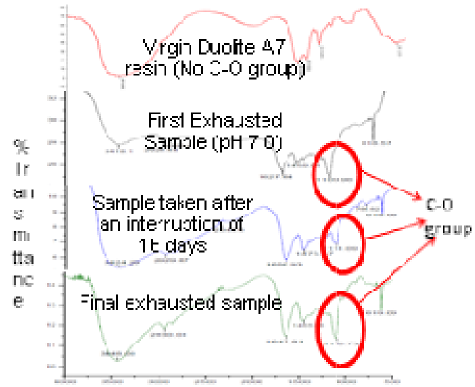

Figure 4 FTIR Analysis showing the formation of new C-O group in the exhausted resin

Keywords: Drinking Water Treatment; Hexavalent Chromium; Ion exchange; Redox reaction

WR-B16

Electro-stimulated reutilization of volatile fatty acids for bio-alcohols production by mixed cultures under different organic loads

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Abstract

Bio-alcohols can be produced by mixed cultures through the reduction of acetic and butyric acids under anaerobic digestion. When the process is electro-stimulated by a small external power input, conversion efficiencies and products recovery are expected to be higher, thus; the process might be scaled up and efficiently applied to reutilize waste streams containing volatile fatty acids.

Loading the system with high concentrations of organic acids has been considered as one approach to improve alcohol production; however, high substrate concentration are known as detrimental for microbial growth and metabolism as well. The aim of this work is to estimate a close approach to the best initial input of these organic acids for the operational improvement.

Four double-compartment (anode and cathode) reactors were individually operated for three consecutive cycles of five days. Compartments were separated by a proton exchange membrane and cathodes were set up under different initial substrate concentrations of 2.0, 4.0, 6.0 and 8.0 g COD/l of a mixture of acetic and butyric acids at a ratio of 1:1 (based on COD concentration). Reactors were connected to an external power supply of 1.5 V. to ensure reductive conditions at cathode chambers. Low pH was set up (5) at the beginning of the operation as required condition to drive reduction process and to avoid methanogenic activity. However, pH was not controlled during the process.

Bio-alcohols production was achieved from the first day of operation. Highest production levels of bio-alcohols were detected within three days of operation at maximum values of 0.320±0.026, 0.437±0.041, 0.36±0.04 and 0.43±0.039 g COD/l for 2.0, 4.0, 6.0 and 8.0 g COD/l, respectively. Methanol was the more abundant produced alcohol and interestingly, no butanol production was detected. From this time, alcohols seemed to be re-assimilated since its concentration decreased.

By five days of operation, initial substrate concentrations were recovered in form of alcohols by 11.14%, 8.68%, 5.1% and 3.5% under 2.0, 4.0, 6.0 and 8.0 g COD/l concentrations respectively.

The higher the substrate concentration, the lower the recovery in form of alcohols. pH rise was noticed from the first day of operation and methane gas was the main product under all the four conditions by the end of the cycles. Furthermore, significant non-converted volatile fatty acids amounts remained in the solutions, specially under 6.0 and 8.0 g COD/l. This study suggests that initial organic load of volatile fatty acids can affect the overall performance of the operation for alcohol production and pH variation is a critical factor, which can determines the final conversion efficiency.

Keywords: bio alcohols, electro stimulation, volatile fatty acids

WR-B17

Evaluation of Nitrification and Denitrification Performance of Down-flow Hanging Sponge System for High-Strength Domestic Wastewater Treatment

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Abstract

The main objective of this study is to confirm the nitrification and denitrification process of the pilot-scale Down-flow Hanging Sponge (DHS) system for high strength sewage treatment. The DHS reactor has been fed with high strength domestic wastewater from apartment for more than one year. The process performance of the DHS reactor under various HRT of 4 hours and 5 hours has been observed. DHS reactor effectively eliminated COD at about 85% even under flow fluctuation condition. Ammonia removal efficiency was achieved 86% and total nitrogen removal efficiency was 37%. The oxygen uptake rate of nitrifying bacteria was at 0.143 gO_2/gVSS/day. In addition, the sponge can accumulate sludge highest at 19.5 gVSS/L-sponge and denitrification activity was 3.82 mgN/gVSS/day.

Keywords: DHS;Nitrification;Denitrification;On-site wastewater treatment

A novel high-pressure electrocoagulation system for dyeing wastewater treatment

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Abstract

Ferrous ions are the major ion species generated from iron sacrificial anode (Lakshmanan et al. 2009). Since ferric hydroxide precipitates are the active ingredients for the removal of organic matters in the acidic pH region, a novel pressurized electrocoagulation (EC) was developed to facilitate the conversion of ferrous to ferric under acidic pH region and was denoted as a high-pressure electrocoagulation system (HPES). Operation of EC under a high-pressure environment could potentially speed up the conversion of ferrous to ferric due to the increase of dissolved oxygen and lower the solution pH due to the dissolved carbon dioxide (CO_2) (Li et al. 2007), creating a favourable condition for adsorption of organic contaminants (Kobya et al. 2007). When the solution was released from HPES into the sedimentation column, fine bubbles were generated due to the sudden pressure drop, causing sludge floatation to the top.
In this study, the effects of operation pressure and initial pH values on the removal of color and COD (TOC) from dye-containing wastewaters were investigated. Figure 1 shows the schematic diagram of the experimental setup. The HPES outperformed the traditional EC process, achieving 100% of color removal after 1.5 min reaction under a 2-bar pressure while traditional EC processes with mechanical mixing and aeration needed 6 min and 3 min, respectively, to remove color completely (Figure 2A). The removal efficiency of TOC increased dramatically and reached approximate 86% with the increase of pressurized level. On the contrary, TOC removal increased with time, reaching 68% and 80%, respectively, using the traditional EC processes under mechanic mixing and aeration. In order to investigate the effect of the solution pH on dye removal, a series of experiments were performed by adjusting the initial pH of the solution ranging from 3 to 10 while conducting the HPES at the fixed reaction time (2 min) and pressure level (2 bar). The results showed that the removal efficiency of color and TOC removal reached 100% and 78%, respectively, at the initial pH of ≤8. A significant drop in dye removal efficiency was observed at the alkaline pH of >8. The high removal efficiency observed under neutral and acidic pH conditions were attributed to an amphoteric behaviour of the coagulant of Fe(III) which produced under pressurized condition. In the contrary, the complexation of Fe(III)/EBT is formed under alkaline pH (Masoud et al. 2002), resulting in the low removal efficiency.

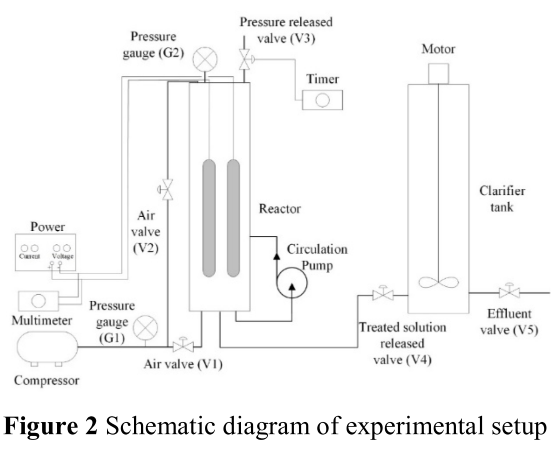

Figure 2 Schematic diagram of experimental setup

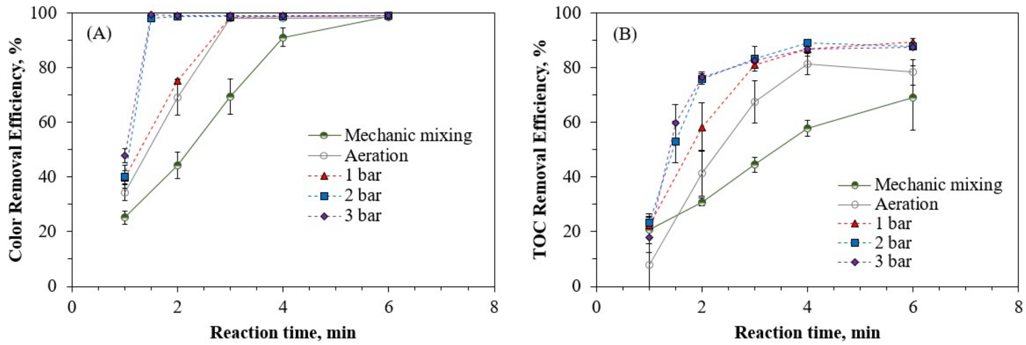

Figure 3 (A) Colour and (B) TOC removal efficiencies vs. time. Experiment condition: Current = 1 A; Conductivity = 5 mS/cm; Initial pH around 4.89.

Keywords: Dyeing wastewater; High-pressure; Electrocoagulation

WR-B19

Evaluate of the Biodegradability on High Carbohydrate Wastewater Treated by Fungal

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Abstract

Conventional biological wastewater treatment generates large amounts of low-value bacterial biomass. The treatment and disposal of this excess bacterial biomass accounts for about 40–60% of wastewater treatment plant operational costs. Fungi could offer this benefit over bacteria in selected wastewater treatment processes. The biomass produced during fungal wastewater treatment has, potentially, a much higher value than that from the bacterial activated sludge process. Different fungal strains have shown their ability to degrade a wide range of environmental pollutants, which have the ability degrade lipids, proteins, complex carbohydrates, heteropolymers, aromatic hydrocarbons and other recalcitrant anthropogenic chemicals, either as sole carbon sources or in co-metabolism, by means of a wide array of extra- and intracellular oxidative, hydrolytic and conjugative enzymes (Maza-Marquez et al., 2016). In this paper, evaluate of the performance and biodegradability on high carbohydrate wastewater treatment by Fungal at various HRT condition. Synthetic wastewater was prepared from the tapioca starch factory. Characteristics of the synthetic wastewater COD and TKN was about 1693 and 10.31 mg/l. Enrichment of seed fungi sludge followed by Patcharin Racho (2009)**.** The experimental set-up consisted of SBR operated varying 6-48 hrs hydraulic retention time (HRT), mixed by a diffused aeration system, and the pH was adjusted to an optimum level of approximately 3.0±0.2 (Takahiro et al., 2001). The fungal SBR system provided the effluent with COD, SCOD and BOD in range of 164-265 mg/L, 36-55 mg/l and 21-45 mg/L, respectively, corresponding to the removal efficiency of 83.79-90.31% for COD, show in figure 1. At HRT of 24 hours, it showed optimal condition for removal organic matter on high carbohydrate wastewater removed 90.31%, 38.01% and 85.16% for COD, SCOD and BOD, respectively, when compared to other conditions. The COD fractionation was evaluated for representing the biodegradability potential. The influent contained a particular inert (X_I) fraction and readily biodegradable (S_s) of about 77.93% and 0.71% of TCOD, respectively. The high carbohydrate wastewater has a high molecular weight that is hardly biodegradable by heterotroph bacteria. After the treatment by fungal, readily biodegradable (Ss) increased to about 13.10% of TCOD at HRT of 24 hours, show in figure 2. Furthermore, the effluent provided the BOD/COD ratio of 0.275, which is 1.53 times higher than that of the influent, indicating that the biodegradable fraction can be increased through the utilization by fungal.

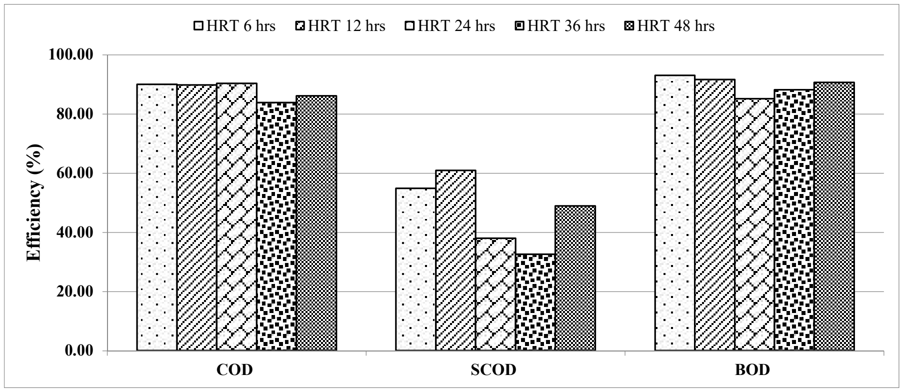

Figure 1 Efficiency organic removal of fungal treatment at various HRT

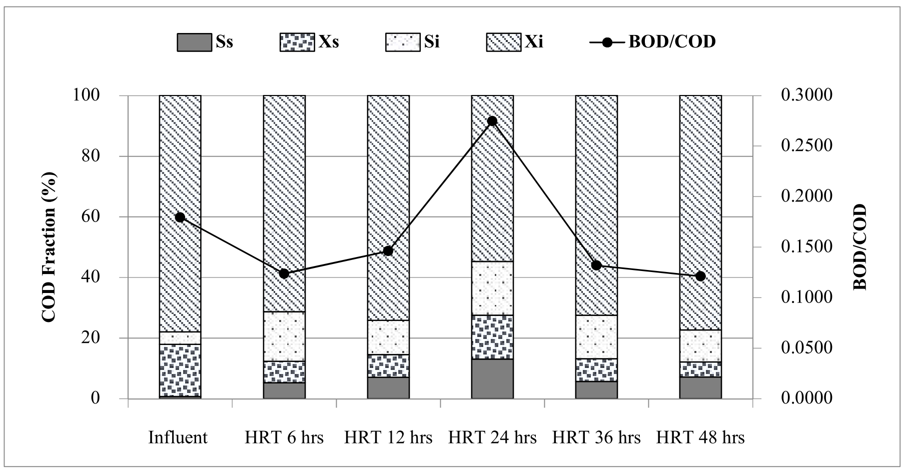

Figure 2 The COD fractionation and biodegradability of fungal treatment at various HRT

Keywords: Starch wastewater; Fungal treatment; COD fractionation

WR-B20

Characterization of dissolved effluent organic matter (EfOM) from industrial park wastewater treatment plant as a function of color

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Abstract

Color comes to a matter of concern for industrial wastewaters (textile, coking etc) but it is getting highlighted for industrial park wastewater reclamation as well. Ozonation and activated carbon have been reported as the effective technologies for the removal of color from secondary effluent. However, little information is known about the contribution of different fractionated organic compounds to the color. At the same time, researchers performed different advanced techniques on industrial park wastewater as a function of effectiveness, removal efficiency etc but it had never been emphasized the effect on different fractionated organic samples as a function of color. So there is a significant gap in information from the previous research works. The purpose of this research is to characterize the color or color bearing compounds, emphasizing the effect of different treatments (secondary effluent – biological treatment, SE followed by ozone treatment, SE followed by activated carbon treatment) on each fractionated samples of dissolved effluent organic matter (EfOM).

The experiment was carried out on three types of treated industrial park wastewater samples (secondary effluent – biological treatment, SE followed by ozone treatment, SE followed by activated carbon treatment), collected from Yixing industrial park wastewater treatment plant (Yixing, China). Each samples were fractionated by Amberlite XRD-8 resin (non-ionic). The fractionated samples are hydrophobic acid (HPOA), hydrophobic basic (HPOB), hydrophilic (HPI) and hydrophobic neutral (HPON). Later on the fractionated samples (HPOA, HPOB. HPI & HPON) were examined through UV-Vis spectrophotometer to get the absorption spectroscopy at different wave length to determine the color according to the standards methods (ISO 7887:2011, λ= 436nm, 525nm, 620nm and EPA Method 110.2, Colorimetric-Platinum-Cobalt; λ=455nm). The COD level and DOC level of each fractionated samples were determined. Furthermore other analytical tests like Chromatograms of molecular weight distribution (MWD), excitation emission matrix (EEM) and X-ray photoelectron spectroscopy (XPS) were performed to characterize the chemical property of each fractionated samples.

From the secondary effluent, it has been found that a significant portion of color is occupied by HPOA and HPI (HPOA>HPI) compared with other fractionated samples but for ozone and activated carbon treated samples HPI contains the higher color intensity than HPOA (HPI>HPOA). Which comes to a point that, Ozone and activated carbon treatment functions more likely to those compounds which are HPOA in nature, in other words HPI is not sensitive to ozone or activated carbon treatment as HPOA. Furthermore there is a significant relation between color and MWD, which also justify the fact that HPOA and HPI contains a major portion of color. Furthermore it has been found that, with the decrease of MWD the color intensity decreased and similar behaviour was found for COD and DOM to color. In total, it can be said that color not only act as an aesthetic property but also brings assumption about other technical parameters like COD, DOM, MWD and most importantly carries significant information about different fractionated samples for industrial park wastewater.

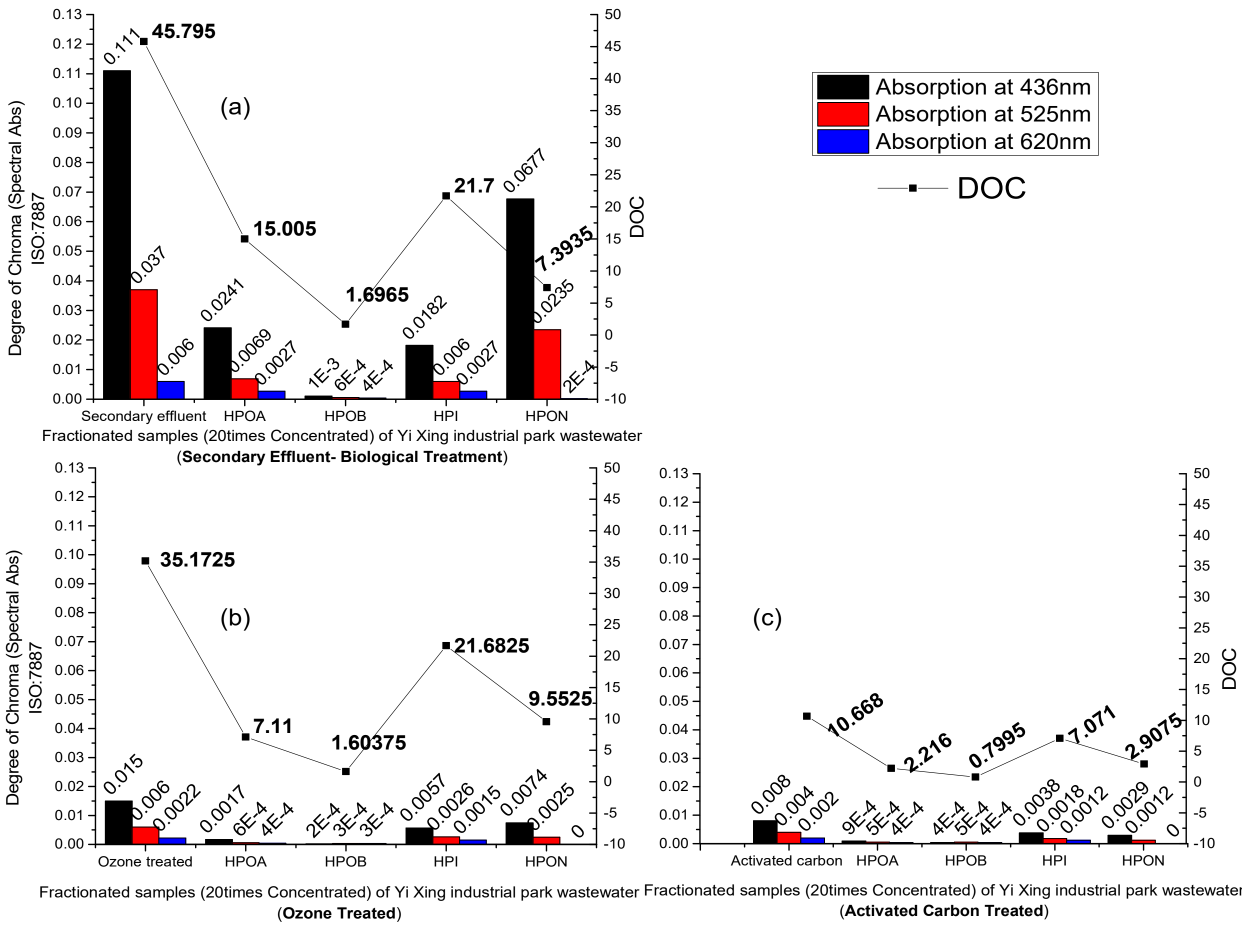

Figure 4: Comparison among different fractionated samples of (a) Secondary effluent (b) Ozone treated (c) Activated carbon treated to DOC and determined color by ISO: 7887

Keywords: Color; Dissolved organic matter; Industrial park wastewater; O3; Activated carbon

WR-B21

Investigation on Recovery of Anammox-Enriched Culture on Attached Growth after Two Starvation Conditions (Warm and Cold Temperatures)

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Abstract

The recovery of anammox-enriched culture on attached growth after starvation conditions (5 months) by keeping at 25°C (representative of warm temperature) and 4°C (representative of cold temperature) was investigated in anaerobic sequencing batch reactors (SBRs). The anammox-enriched culture on biofilm after starvation condition by keeping at room temperature could significantly accelerate recovery than the starvation condition by keeping at 4°C. Real-time polymerase chain reaction results showed that the quantities of anammox-enriched bacteria before and after starvation by keeping at room temperature were higher in the anammox-enriched bacteria by keeping at 4°C. The results from this work could be applied in the recovery of anammox-enriched culture on attached growth system of pilot and full scale wastewater treatment systems

Keywords: Anammox-enriched culture; recovery; warm temperature; cold temperature

WR-B22

Optimization of metal oxide composite electrocatalysts for anodic degradation of hazardous water micropollutants: Catalytic activity and durability

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Abstract

Toxic organic chemicals present in industrial wastewater effluents, such as, 1,4-dioxane and dyes, can be hardly removed only by biological treatment processes (Oller et al., 2011). Chemical oxidation (e.g., ozone, H_2O_2, or UV) or carbon adsorption is thus often required for further removal of such organic contaminants before discharge. Recently, electrocatalytic processes have much attraction as an attractive strategy for advanced wastewater management because they are compact and modular in their design without extra chemical addition (Park et al., 2013). A large number of electrode materials have been developed and tested for effective degradation of various organic substances and currently, boron-doped diamond (BDD) is considered to be the most robust and effective electrocatalytic material for organics degradation (Zhang et al., 2017). It is because it can generate hydroxyl radicals, which are non-selective and most powerful oxidants. However, it is very costly and still impractical for large scale applications. Therefore, this study aimed to develop new metal oxide composites, which are as effective and stable as BDD, for anodic degradation of water contaminants (e.g., 1,4-dioxane and dyes). Particularly, optimal composition of metal oxide composite electrocatalysts were determined based on the statistical design and of experiments and further experimental verification.

Synthetic and real industrial wastewaters containing 1,4-dioxane and dyes were used for evaluating the performance of electrocatalysts. A laboratory glass reactor that can hold an anode-cathode couple was used for the experimental tests of various laboratory made electrodes. 1,4-Dioxane was analysed using a gas chromatograph equipped with a solid-phase micro-extraction autosampler and a mass detector. The color measurement was made based on the standard true color measurement method using a spectrophotometer. Instead of Ti plates, Ti meshes were used as the base anode material that has a 3-D structure regarding electrochemical reactions (Fig. 1a). Through the tests of various metal oxide composites in terms of 1,4-dioxane degradation, xRuO$_2$-yTiO$_2$ composites (x = 0.6-0.9 and y = 0.4-0.1 at x + y = 1) were found to be most effective for the degradation of 1,4-dioxane (Fig.1b). The composite anode had a high O_2-overpotential property (Fig. 1c) and so it appeared to produce hydrogen peroxide via anodic water oxidation in addition to the anodic generation of reactive chlorine species (Fig. 1d). These mediated oxidants are found to be responsible for the degradation of 1,4-dioxane and dyes present in textile industrial wastewater effluents. The lifetime of the composite anode was evaluated under harsh conditions, e.g., 3.4% NaCl at 1 A/cm^2. The accelerated life tests revealed that the Ti mesh used as the base material were broken every shortly, but metal oxide coating extended the service life significantly. The life of the composite electrode with the Ru:Ti molar ratio of 0.6:0.4 was extended approximately 50 times than that of the base material. The composite even had a longer life than the RuO_2/Ti electrode.

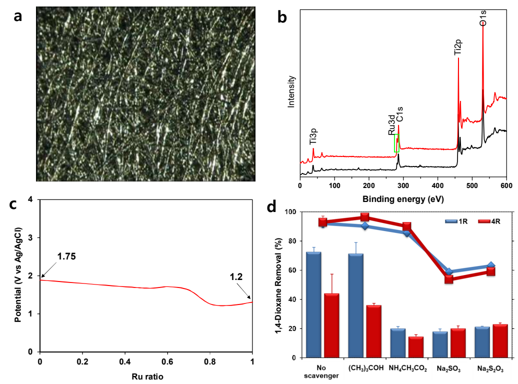

Figure 1 (a) Ti mesh used as the base electrode material, (b) XPS peaks of the composite electrode, (c) potential (V vs. Ag/AgCl) for O_2 evolution reactions, and (d) 1,4-dioxane and color removal efficiencies with and without oxidant scavengers.

Keywords: 1,4-Dioxane; Electrochemical oxidation; Metal oxide composite; Electrocatalyst

WR-B23

The Intergration of Hydroponics into a Brewery Effluent Treatment System

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Abstract

Brewery effluent (BE) is an organic effluent that contains valuable resources such as water and nutrients. Constructed wetlands (CW) treat BE to a standard suitable for aquaculture and crop irrigation at our experimental effluent treatment facility. There is a need to identify economically valuable crops, that can be used in place *Typha capensis*, to recover nutrients in BE before it is reused in down stream activities. The aim of this study was to determine the nutrient removal efficiency of commercial crops, the influence of pH on this efficiency, and the effect of alkalinity on crop growth and health when an aquaponic production system was incorporated into a brewery effluent treatment plant. Cabbage, saltbush and millet plants were grown in a recirculating hydroponic system fed treated BE that was either pH adjusted or pH left unadjusted

The pH adjustment of post-primary facultative pond (PFP) BE had a major influence on the growth, health and chemical composition of plants grown in hydroponic systems. The chlorophyll concentration index of cabbage, saltbush and millet plants were all significantly higher when grown in the pH adjusted hydroponic systems (Repeated measures ANOVA, $F_{(15,36)}=12.40$, $p<0.0001$, Figure 1). The macro and micronutrient concentrations of cabbage leaves increased when the pH of post-PFP BE was adjusted to 6.5 at the start of each irrigation cycle. Post-PFP BE that was not pH adjusted was not a suitable water and nutrient source for the hydroponic production of cabbage and millet plants as plants in these systems hardy grew. However, pH adjustment of BE renders it much more suitable for hydroponic/aquaponic crop production. The high alkalinity of BE is a major issue, firstly for deceasing the availability of nutrients in recycled effluent, and, secondly for making it hard to maintain a pH range of between 6.5 and 7.0 to optimise the availability of nutrients to the plants. Continual pH adjustment would increase the conductivity of the effluent, putting more osmotic stress onto the irrigated plants. The generation of alkalinity needs to be fully understood and technologies or practices need to be investigated that can reduce the alkalinity of the effluent. The pH plays a major role in the availability of nutrients to plants as well as influx/efflux of cations and anions through the plasma membrane. This needs to be further investigated because there is evidence that pH can influence the sodium efflux rate and sodium tolerance of plants.

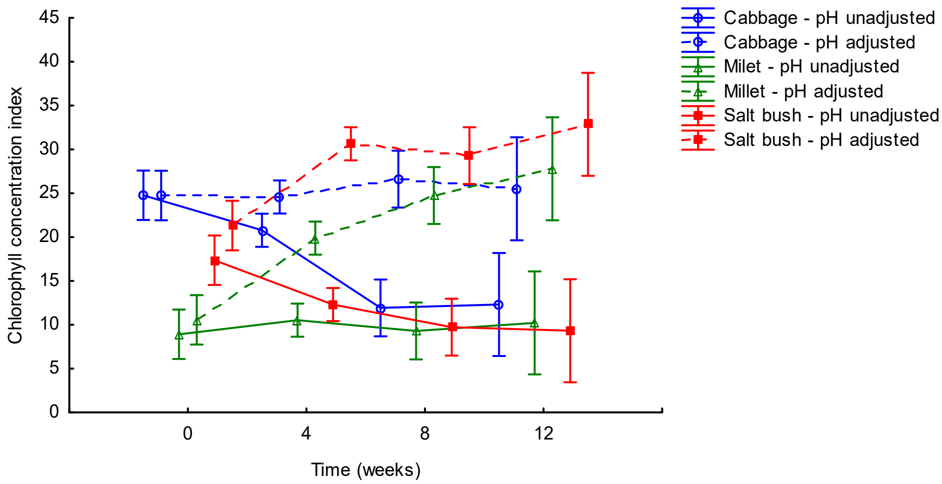

Figure 1 The mean (± 95% confidence interval) chlorophyll concentration index of cabbage, millet and saltbush plants irrigated with post primary facultative pond effluent, over the 12 week experiment (Repeated measures ANOVA, $F_{(15,36)}=12.40$, $p<0.0001$).

Keywords: Beneficiation; nutrient removal; hydroponics

WR-P01

Computer Surge Modeling and Proof of Design of your reuse water system

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Abstract

Is the municipality impairing, altering or contaminating the reuse water system every time they turn off a pump? The water purveyor shall take or cause to be taken, the necessary measures to ensure that the reuse water distribution system is protected from any actual or potential backflow hazards within the distribution piping system. When the municipality turned off their pump, did the pressure in the distribution system fall to the point where backsiphonage or a net movement of water from outside the pipe to the inside through cracks, breaks, or joint in the distribution system that are common in all water systems. Such a system failure carries with it a high potential that fecal contamination or other disease-causing organisms could enter the distribution system. These conditions may pose an imminent and substantial health endangerment to persons served by the system.

"Water Hammer" is a serious concern for the municipalities today in order to insure water quality and to keep fluid distribution pipelines efficiently operating consistently without expensive downtime. Whether the application is pump station control, pressure/flow balancing or age of water; a systematic approach is needed to prevent potentially catastrophic events from occurring. By utilizing computer surge modeling software and transient monitoring equipment, the causes and effects of water hammer can be identified, analyzed, and resolved through a system design solution that may involve pump control valves, surge vessels, air/vacuum valves, surge anticipatory valves, control valves and check valves.

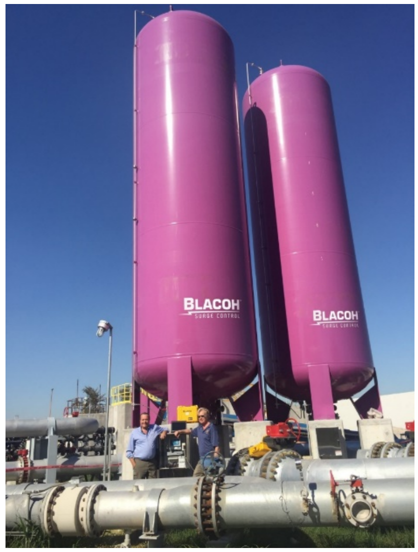
Site operators and managers have not traditionally had the tools necessary to assess what specifically happens when the pump(s) start/stop or when a valve is suddenly closed with the pump(s) running. The mathematical calculations for pressure surge effects are quite extensive and only through computer surge modeling can this process be conducted quickly and accurately. In conjunction with transient pressure monitoring equipment that can record data at over 100 times per second, municipal personnel now will know exactly what is happening with their pumping system and how to resolve it safely and comprehensively.

By incorporating both computer surge modeling and transient pressure monitoring at the time of identifying that a problem exists and finally at the start-up/commissioning of mitigation equipment, the selected solution can be confirmed as performing to expectations via this "*proof of design*" methodology. The mitigation equipment chosen (vessels, valves, etc.) can be tested and quantifiably measured with reporting results available the same day via email in text or graphical format.

A detailed computer surge analyses study of your pump stations and distribution system followed by "*proof of design*" of equipment during startup and commissioning shall avoid hazardous and costly problems. Each step in this process will provide clarity on what can and likely will happen when surge events are not properly identified and inaccurate data leads to incorrect equipment being selected and installed. This study provides a cautionary example of the dangers, cost and bad publicity that can follow when pressure surge events are not treated seriously enough with the modeling and monitoring solutions that are available today.

The pump trip can cause a negative transient vacuum wave below atmospheric pressure affecting the entire system. The transient monitoring system shall alert the operator of any transient pressure wave which drops below the minimum operating pressure of the municipality. The SurgeWave employs a patented system of dynamic pressure transducers and digital technology to monitor pipelines for indefinite periods of time. When a transient such as a pressure surge, pressure spike or water hammer event is detected, the system records the high speed data at 100 times per second. When the pressure drops back to steady state, the system records the running average which is defined upon startup. The SurgeWave can record multiple devices to record transient pressure, flow, pressure, level, air/vacuum breaker movement and pump speed.

The paper will include several reuse water system designs to include computer surge modeling, transient pressure monitoring and pump cycle control.



WR-P02

Fabrication of Ultrafiltration PLA Hollow Fiber Membrane for Surface Water Treatment Applications

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Abstract

Novel ultrafiltration Poly(lactic acid) (PLA) hollow fiber membranes were successfully fabricated via nonsolvent induced phase separation (NIPS) by dry-wet spinning method. The preparation procedure of the hollow fibers is quite complicated especially when the new material was used. The solution used for spinning contains 20 % PLA, 2 % glycerine, 0.5 % Polyethylene glycol (PEG1500) and *N*-methyl-pyrrolidone (NMP). The spinning mixture was heated above 60 pressurized using nitrogen gas with various spinneret parameters. The spinning parameters such as feed pressure, air gap and take-up speed significantly affected the structure, morphology and filtration performance of the membranes. The asymmetric structure of the hollow fiber membrane was examined by field-emission scanning electron microscope (FE-SEM). The FE-SEM image showed that the PLA hollow fiber membranes have double finger-like structure (macrovoid), which was the normal structure formed in NIPS method. The PLA hollow fiber membrane exhibited excellent ultrafiltration performance of 99 % in bovine serum albumin (BSA) rejection. Moreover, the PLA hollow fiber membranes can completely remove *E. coli* and total coliform from surface water. These results indicated that the PLA hollow fiber membranes can be a promising candidate for fabricating hollow fiber membranes made of nonpetroleum based polymer in surface water treatment application.

Keywords: Polylactic acid (PLA); Hollow fiber; Membrane

WR-P03

Identification and quantification of Ammonium Oxidizing Bacteria (AOB) for ammonia oxidation in Full Scale of Activated Sludge Systems in Bangkok and Samut Prakan Province

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Abstract

In this work, influents and effluents were analyzed with respect to flow rate, biochemical oxygen demand (BOD) and ammonium concentration. Wastewaters in the study were from the following two full scale wastewater treatment plants (WWTP) in Bangkok and Samut Prakan province. Low efficiency of nitrogen removal at centralized WWTP in Bangkok was found in the summer period. Influent ratio of COD:N at centralized WWTP in Bangkok is less than 3. The overall of total of nitrogen in this plane is low but ammonium removal efficiency is high. Another WWTP is located at Samut Prakan province. At this WWTP, influent ratio of COD:N is higher than 5. For this reason, the overall of total nitrogen is high and ammonium removal is also high. Fluorescent in situ hybridization (FISH) was used to identify and quantification specific nitrifying bacteria: Nitrosomonas sp. and Nitrospira sp. were most prevalent in the aeration tank at the Samut Prakan WWTP rather than in the aeration tank at Bangkok WWTP.

Keywords: AOB; Bangkok and Samut Prakan Wastewater Treatment Plants

WR-P04

IOT based Real time monitoring of water levels in tanks using machine learning with Android application

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Abstract

In this paper, the project of water level monitoring as well as controlling with IoT and android application is introduced to an extent. Wastage of water in the current scenario, merely due to overflowing tanks is not affordable. Conventional water tanks in households can neither monitor nor control the water level in tank, leading to large amount of wastage. The need of removal of these short-comings and providing an efficient and economical solution has been the main focus of this project.

The project includes the following technical aspects: IoT usage for collection of water consumption data of a household. Calculate average requirement of water in a tank by a household (Daily/ weekly/ monthly/ yearly), per person, per household or in a society and an Android Application for giving control to the user to use water judiciously in a cost efficient way and to adapt to changing needs of the household.

The water level to be monitored for each tank is collected by the ultrasonic sensor and simultaneously the data collected is shifted to the server via ESP12-e. The values of maximum and minimum levels are obtained by ESP from the database. These values are set from the android app. The current level of water is obtained from the ultrasonic sensor. Depending upon these values, the motor is turned ON / OFF through relay switches The height of tank is to be set once in ESP. The height of the water tank varies with the household and is stored by the household's respective ESP. This height shall be used to determine the percentage of water. Calculations of the current water level will be done with this. Making decisions with percentage proves to be easier to implement the logic in programming.

As the data is collected over a substantial period of time, certain statistical analysis has to be performed over the data collected. The missing values and the noise data is removed and only the useful data is kept and sorted likewise. For each household in a particular society, Per year consumption, Per month average consumption, Peak time consumption(maximum consumption), Per day average consumption is computed statistically. For each society as a whole, Average monthly consumption, Average yearly consumption, Average daily consumption is also calculated. These values will be helpful in classification of the household in the society based on the usage.

The analysis and classification part is being done by python and an adaptive learning algorithm for the same has been developed. Studying the following options, SVM seems the best for the classification of this type of supervised problem. We choose SVM as it is high speed. In the current dataset taken from kaggle.com, there was data for 19 households in a society in Venice city. For each household, 8561 entries were there, each entry having two fields, time and corresponding water level, this counts for 16264 records. NN cannot be used in this kind of problem as there are only two parameters. Two algorithms, SVM (Support Vector Machine) and K Nearest Neighbour, have been applied on the currently available dataset. SVM gave 100% accuracy whereas K Nearest neighbour gave an accuracy of 97.49%.

Thus, Support Vector machine classifies the water consumption levels of a house per day into two clusters (one cluster having houses with water consumption less than particular threshold that depends on the houses under study and the other having houses with value more than that threshold) with maximum accuracy of 100%.

According to this classification, the information of the daily water consumption of a house is determined which further determines the lower and maximum limits of water tank height for a particular house. After the limits are determined, the minimum water availability level for a house can be set so that a house will never face shortage of water. The availability of the maximum water level of a house will help make sure that the water doesn't overflow and is not wasted.

Keywords: Machine Learning; Real Time monitoring; IoT

WR-P05

Impact of Weather Variables on Urban Water Consumption at Multiple Temporal Scales: The Case of Bangkok, Thailand

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Abstract

Population growth and urban development have contributed to increase in base urban water consumption in a long-term temporal scale such as interannual variability (Palmer, 2010). However, if we consider a short-term temporal scale, weather variability is an important factor for forecasting daily, monthly or seasonal water consumption (Goodchild, 2003). This study examines the relationship between urban water consumption in the Metropolitan Waterworks Authority (MWA) service area (including Bangkok, Nonthaburi and Samut Prakan provinces) and two weather variables (average temperature and rainfall) at two temporal scales (daily and monthly time scales). The study period starts from 1st October 2008 to 30th September 2016 (totally eight years).

In this study, we did not consider the water consumption data during October 2011 to January 2012 due to the 2011 Thailand mega flood. The growth of water consumption in a long-term temporal scale was normalized based on the consumption in October 2008. Monthly consumptions were recorded by MWA, but daily consumptions were estimated by recorded daily inflows minus estimated volumes of water loss. The daily water loss volumes were calculated by the annual water loss volumes. Then, data from five weather stations were used to calculate the areal average temperature and rainfall for the analysis. Figure 1 shows the daily changes of the normalized water consumption, temperature and rainfall. We can find that the daily temperature ranges from 18.2°c to 34.2°c with the average value of 29.2°c, and the daily rainfall ranges from 0 mm to 116 mm with the average value of 5.18 mm.

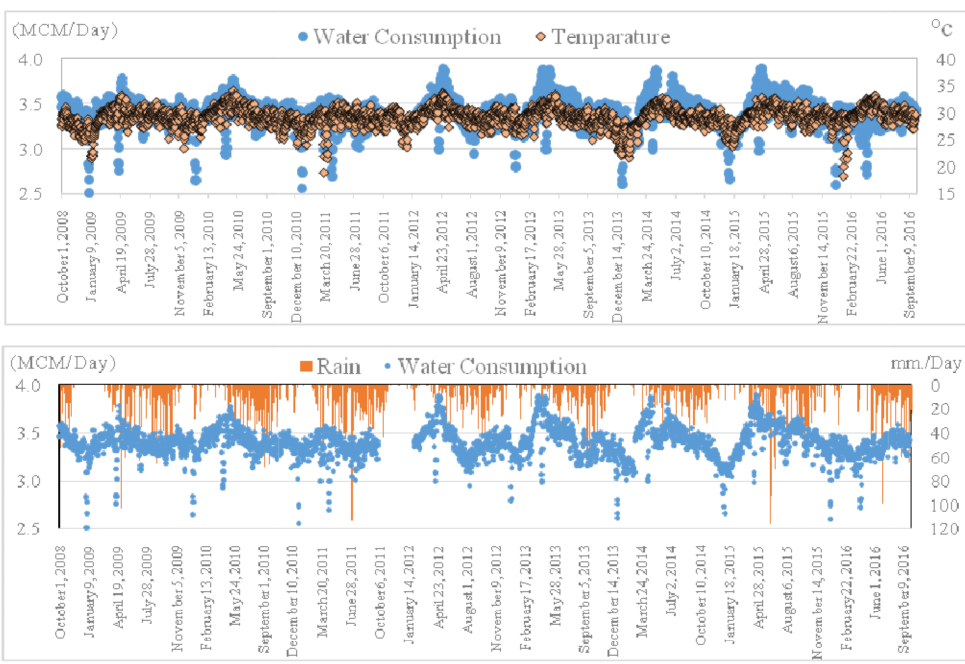

Figure 1 Temporal changes of daily water consumption with temperature (Upper) and rainfall (Lower) during October 1st, 2008 – September 30th, 2016 in the MWA service area.

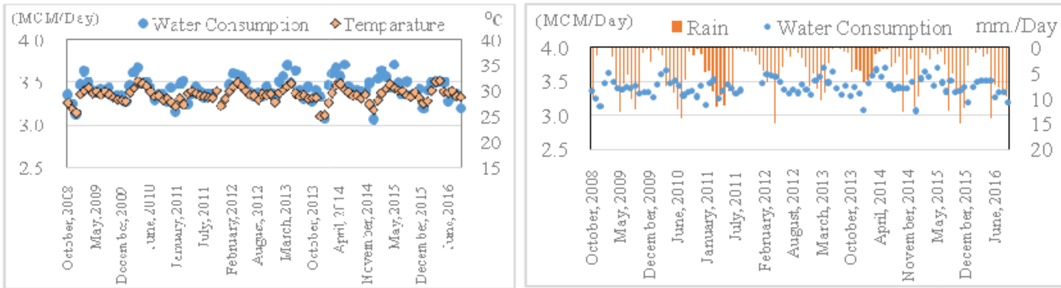

Figure 2 Temporal changes of monthly water consumption with temperature (Left) and rainfall (Right) during October 2008 – September 2016 in the MWA service area.

Table 1 Results of multivariable linear regression of the normalized MWA water consumption (Y) to the average temperature (X_1) and the rainfall (X_2) in the daily and monthly temporal scales.

Time scales	Coefficient of X_1, a (10^6 m^3/day/°c)	Coefficient of X_2, b (10^6 m^3/mm)	Intercept, c (10^6 m^3/day)
Daily	0.052877	-0.000062	1.872
Monthly	0.064588	-0.004915	1.557

Figure 2 show the monthly change of the normalized consumption, temperature and rainfall. The similar trend as the daily change can be found. Then, we analysed the relationship between the normalized water consumption (Y: million m^3/day) and the average temperature (X_1: °c) and the rainfall (X_2: mm/day) using multivariable linear regression as follows:

$$Y = aX_1 + bX_2 + c.$$

Table 1 shows the results of our study. From Table 1, a positive correlation between the consumption and the temperature and a negative correlation between the consumption and the rainfall were found. The results from the daily data show that if the average temperature increases 1°c, the normalized water consumption volume will be increase by approximately 52,877 m^3/day (+1.64%) while if the rainfall increases 10 mm/day, the normalized water consumption will reduce around 620 m^3/day (-0.11%). The results from the monthly data also give a similar pattern. Thus, the impact of temperature is larger than that of rainfall, and MWA should consider the temperature variability for a better management of water production and distribution.

Keywords: Water Consumption, Multiple Temporal Scales, Weather Impact

WR-P06

Using Nitrite Oxidizing Bacteria (NOB) to identify Aerobic Condition in Full Scale of Activated Sludge in Bangkok and Phuket Province

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Abstract

Molecular technique on Fluorescent in situ hybridization (FISH) was used to identify and quantify specific nitrite oxidizing bacteria: Nitrobacter sp. and Nitrospira sp. on two wastewater treatment plans (WWTPs). Frist WWTP is located in Bangkok (centralized WWTP, flow rate is higher than 200,000 m^3/day). Second WWTP is located in Phuket Province (also centralized WWTP but the flow rate is lower than the first one (30,000 m^3/day). The result is shown that in both WWTPs, Nitrospira sp. are dominated. Also low efficiency of total nitrogen removal at centralized WWTP in Bangkok was found. At Phuket WWTP, COD:N is higher than 5. Based on this ratio of COD:N could be postulated that there was enough carbon source for denitrifying bacteria.

Keywords: NOB; Bangkok and Phuket Wastewater Treatment Plants

WR-P07

Variation of fluorotelomer alcohols and perfluoroalkyl carboxylic acids in municipal wastewater treatment plants over a period between 2013 and 2016

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Abstract

Fluorotelomer alcohols (FTOHs) are a class of important industrial intermediates and have been applied in a wide range of products. In addition, biotransformation of FTOHs to perfluoroalkyl carboxylic acids (PFCAs) has been observed in mixed microbial systems and WWTP sludge (Lee et al. 2010). Our previous study calculated the mass balance of FTOHs and PFCAs along the treatment process and provided the field evidence for potential biotransformation of FTOHs to PFCAs in the aerobic unit in one WWTP (Chen et al. 2017). However, more information on the long-term variation and correlation of FTOHs and PFCAs in municipal wastewater treatment plants was needed.

In this study, wastewater and sludge samples were collected from 5 municipal WWTPs in three cities of China from November 2013 to April 2016, and six kinds of FTOHs and eight kinds of PFCAs (C4~C11) were detected using the ultra performance liquid chromatography-electrospray ionization-tandem mass spectrometry (UPLC-ESI-MS/MS) method. The concentration and detection frequencies of FTOHs in influent samples (n=118), effluent samples (n=102), and sludge sample (n=100) of five municipal WWTPs are present in Table 1. Generally decreasing concentrations of FTOHs in wastewater samples were observed between the influent and effluent. The mass changes (influent, effluent and sludge) of FTOHs and PFCAs, and correlation analysis between the decreasing of FTOHs and increasing of PFCAs was calculated. Significant correlations were found between the mass changes of FTOHs and PFCAs. As shown in Figure 1, in plant A and Plant B, significant correlation between mass changes of PFOAs and 10:2 FTOH (p=0.016), 8:2 FTOH(p=0.028) was found. In other WWTPs, significant correlations could also be found between mass changes of FTOHs and PFCAs. In plant C, good correlation between mass changes of 6:2 FTOHs and PFBA (C=4, p=0.001), PFPeA (C=5, p=0.012), and $\sum C_{4\text{-}6}$PFCA (p=0.001). These results further indicated that the decreasing mass load of FTOHs was correlated with the increasing mass of PFCAs in a long-time period. Overall, this work provided the long-term evidence on the transformation from FTOHs to PFCAs.

Table 1 Concentrations and detection frequencies of FTOHs in wastewater and sludge samples of five municipal WWTPs (2013-2016)

FTOHs	Influent （n=118）				Effluent （n=102）				Sludge （n=100）			
	Concentration （ng/L）			Freq.[a] （%）	Concentration （ng/L）			Freq.[a] （%）	Concentration （ng/g dw）			Freq.[a] （%）
	Min	Max	Mean		Min	Max	Mean		Min	Max	Mean	
4:2FTOH	<0.12[a]	2.92	0.66	92	<0.10	1.89	0.34	56	<0.01	1.2	0.25	93
6:2 FTOH	0.36	3.11	1.35	100	<0.09	2.15	0.89	90	0.22	4.63	1.21	100
8:2 FTOH	1.86	30.6	7.27	100	1.21	23.3	4.99	100	0.67	28.5	5.27	100
10:2 FTOH	<0.08	7.64	1.77	97	<0.03	4.28	1.12	75	0.29	19.2	3.56	100
12:2 FTOH	<0.06	3.37	0.47	43	<0.05	2.17	0.25	27	0.29	2.75	0.8	100
14:2 FTOH	<0.09	0.93	<0.09	5	<0.08	<0.08	<0.08	0	<0.05	1.93	0.53	97

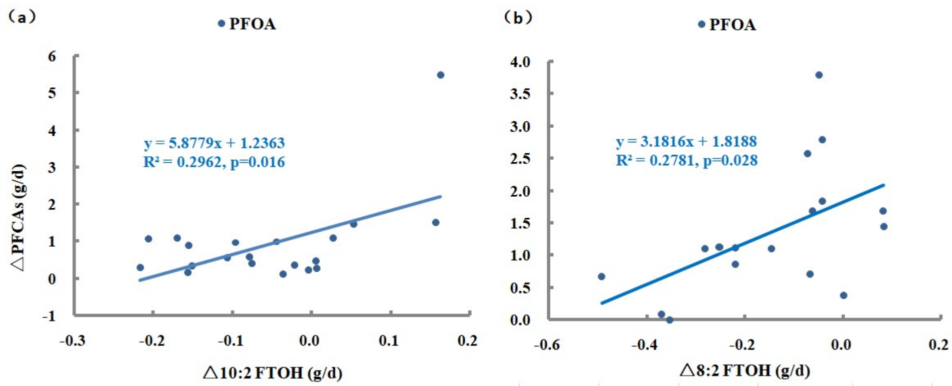

Figure 1 Correlation between mass changes of 6:2FTOH and PFCAs in plant A (a) and plant B (b) over a period of 2013~2016

Keywords: fluorotelomer alcohols; long-term occurrence; correlation analysis

WR-P08

Comparison of Natural Dyes Removal by Coagulation Process with Different Coagulants

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Abstract

Textile wastewater is a considerable source of environmental contamination due to its strong color, high pH and chemical oxygen demand (COD). The discharge of textile wastewater not only has diverse aesthetic effects, but such discharge can be carcinogenic, mutagenic and generally detrimental to our environment (Chandra, 2016). The natural dyes is interesting alternative dye because it can be derived from almost anything plants, minerals, and even some insects. The advantage of natural dyes is eco-friendly, do not create any environmental problems at the stage of production and do not affect the health. Thus, the household textile industry in Thailand, especially Thai silk enterprise, has used natural dyes. However the wastewater should be removed completely before they are discharged into received water. Coagulation is widely used processes due to their relatively simple operation and low cost (Chen et al., 2010) thus they are interesting alternative wastewater system for household industry. The aim of this study was using the Poly aluminium chloride (PAC) and Ferric chloride ($FeCl_3$) as coagulants to removal natural dyes from textile wastewater of Bandu enterprise. The studies were carried out to collect wastewater from Bandu enterprise, Nakhon Ratchasima, Thailand. The wastewater samples which used Lac (*Laccifer Lacca Kerr.*) Khe (*Maclura cochinchinensis Corner*) and Golden shower pods (*Cassia fistula*) as natural dyes were analyzed for various parameters as shown in Table 1. They were found that the wastewater characteristics were in wide range of COD from 3,712-24,576 mg/l, pH from 4.7-7.28 and color from 3,487.78-9,056.67 Pt-Co. The ratio of TDS/TS of all wastewater samples were in range of 0.72-0.97. These results indicated that textile wastewater contained dissolved solid more than 70%. The coagulation experiments were used a jar test apparatus with two coagulant agents; PAC and $FeCl_3$ for comparison the removal efficiencies. The coagulation studies of each natural dyes were determined the optimum pH rang, optimum coagulant dosage and polymer dosage for removal efficiency. The result of optimum conditions for coagulation of each natural dyes were concluded in Table 2. The optimum conditions for each coagulation studies were set to measure the COD and color removal efficiencies. As shown in Figure 1 the color removal efficiency for PAC and $FeCl_3$ were 94.65 and 62.76 % for Lac, 76.19 and 79.88 % for Khe , 30.41 and 4.20 % for Golden shower pods respectively. And the COD removal efficiency for PAC and $FeCl_3$ were 33.33 and 23.64% for Lac, 47.83 and 65.22% for Khe, 22.47 and 0.00% for Golden shower pods respectively. They showed the were concluded coagulation had effective in removal natural dyes both Lac and Khe but less effective for Golden shower pods. The outcome of this study could be applied to treat wastewater from textile household industry.

Table 1 The characteristics of textile wastewater of Bandu enterprise.

Parameter	Unit	Natural dyes		
		Lac	Khe	Golden Shower Pods
pH	-	4.7	7.28	5.42
COD	mg/l	4,664.00	3,712.00	24,576.00
Color	Pt-Co	3,487.78	8,801.11	9,056.67
TS	mg/l	2,413.33	1,560.00	24,710.00
TSS	mg/l	672.00	46.67	5,630.00
TDS	mg/l	1,741.33	1,513.33	19,080.00

Table 2 The conclusion of optimum conditions for coagulation process with PAC and $FeCl_3$ as coagulants.

Set	Natural dyes								
	Lac			Khe			Golden Shower Pods		
	Coagulant (mg/l)	Polymer (mg/l)	pH	Coagulant (mg/l)	Polymer (mg/l)	pH	Coagulant (mg/l)	Polymer (mg/l)	pH
PAC	250	0.7	6	200	0.6	8	300	0.7	2
$FeCl_3$	560	0.6	5	400	1	8	480	0.8	8

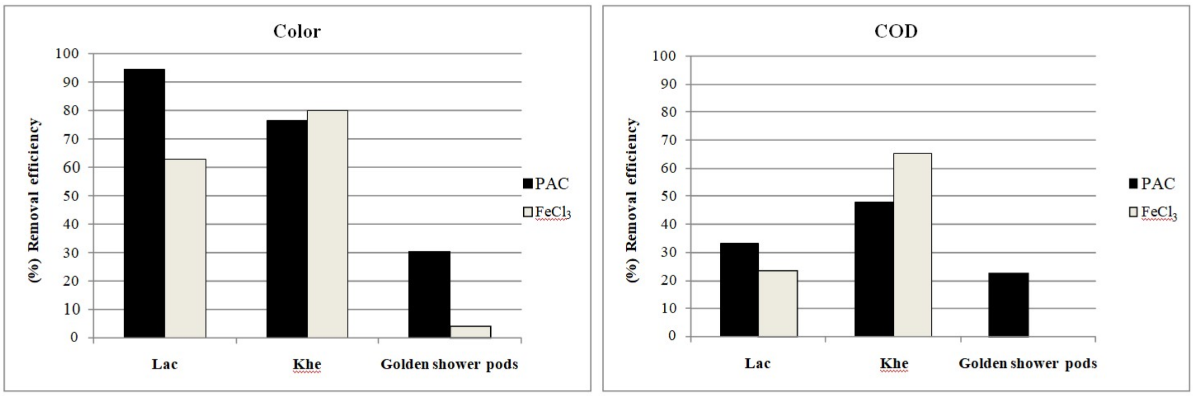

Figure 1 The results of COD and color removal efficiencies for coagulation process of PAC and $FeCl_3$ as coagulants.

Keywords: Natural dye; Coagulation process; Textile household industry

WR-P09

Addressing governance issues in sanitation through IoT based platform

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Abstract

2.3 billion people still lacked even a basic sanitation service over the world including 892 million people who practised open defecation (WHO-UNICEF, 2017). Out of these, 524 million people are only from India who practised open defecation. In parallel to United Nations' Sustainable Development Goal (SDG) 6, many nations have initiated various programs to encounter the present scenario. Under these initiatives, authorities are constructing toilet infrastructure everywhere in order to bring down the gap, but they are not realizing the fact that capacity building at massive scale may create bigger problem in form of service delivery, operation, maintenance and other governance related issues. Several field-visits and surveys are conducted to observe the need from ground reality. Service delivery is the base for any public or private services from users' perspective as well as service-provider's point of view, where users are more interested in finding a public toilet, reporting an issue about an unusable toilet, while the service-providers look for the provisioning and the state of toilets with other maintenance parameters so that requirement-goals of service-quality are predictably satisfied. Apart from service-delivery turf-issues, corrupt mentality, lack of awareness, non-transparency, policy loopholes, lack of public and civic participation, unaccountability, ineffective complaint registry, etc. leads to shoddy governance.
In the middle of Digital-Age, we explore the IoT interventions to encounter these present as well as upcoming issues. We have developed an IoT based application (**Figure 1**) where-

- Users are able to locate and navigate to a specific toilet infrastructure within a pre-defined proximity.
- Users can inform about any improper information such as inexistence of any specific toilet infrastructure.
- Users are able to visualise and rate the condition of any specific toilet-
    - Cleanliness & Hygiene
    - Infrastructure & Maintenance
    - Security
- Users can report an issue or lodge a complaint or provide a feedback with ratings, images and comments.
- Both the users and administration are able to visualize the general statistics of sanitation condition i.e. number and location of toilets as per their rating.
- Users can get the broadcasted information related to awareness campaign, budget, report, etc.
- Users can also take part in floated referendum.

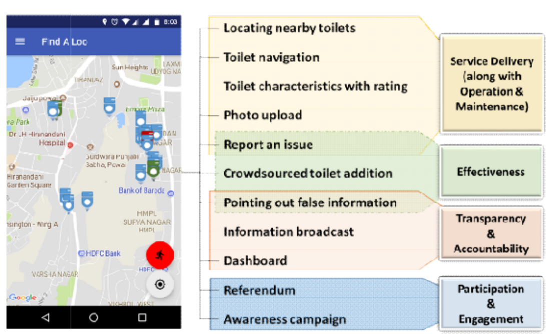

Figure 1 IoT based platform addressing sanitation issues

The unique feature of crowdsourced based toilet addition, made this platform scalable up to global level. This study

is the need of the hour for those who are linked with sanitation, such as people, governing authority, researchers, policy makers, surveyors, NGOs and CBOs. The IoT based platform is able create a databank. Further, researchers and policymakers can conduct various type of analytical-research based on the collected information intended towards further policy amendments.

Keywords: IoT; Sanitation; Governance

WR-P10

Contamination and risk assessment of PFOA, PFOS and other Per- and Polyfluoroalkyl substances in tap water and drinking water in Bangkok, Thailand

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Abstract

Contamination levels of PFOA, PFOS, and other per- and polyfluoroalkyl substances (PFASs) in tap water and drinking water were monitored and consumption risk was assessed. Water samples were extracted by solid phase extraction (SPE) and analyzed by HPLC-MS/MS. Concentrations of PFOA, PFOS, and other PFASs in tap water were 0.77 ng L^{-1}, 0.48 ng L^{-1} and 1.74 ng L^{-1}, respectively. Drinking water is filtered to make it safe for human consumption and concentrations of PFOA, PFOS, and other PFASs were then significantly lower at 0.49 ng L^{-1}, 0.24 ng L^{-1} and 0.81 ng L^{-1}, respectively. Risk levels of PFOA and PFOS for all water samples did not exceed 1. Contamination from PFOA and PFOS in tap and drinking water in Bangkok does not pose a health risk for the local population.

Keywords: Per- and polyfluoroalkyl substances (PFASs); tap water; drinking water

WR-P11

Anaerobic Reactor in order to use for water reclamation (case study on development of high quality biogas technology)

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Abstract

Anaerobic wastewater treatment combines water purification and energy production by converting the chemically bound energy in organic waste into energy. Process wastewater re-use of water containing high concentration is limits by energy consumption. Anaerobic wastewater treatment is the best alternative in the term of low energy consumption and low excess sludge. Renewable energy anaerobic treatment is the important factor for water re-use project succession.

One of the key issues in using renewable energy from industrial waste and waste from human activities in the form of biogas is a problem of low-energy gas contamination (CO_2) and gases that cause corrosion problems (H_2S). Base on the current technology to remove CO_2 and H_2S, there are problems with high operating costs and the way to remove the chemicals by-product from the gas purify processes. If the unit can be integrated biogas and removal of CO_2, can be carried out in the same reactor. It is one alternative to solve the problem effectively. Therefore, the development of high pressure reactor technology for the treatment of waste to produce biogas and a consistent approach to the problem of low quality biogas yield. The development of this technology is based on the Henry's Law. Since CO_2 has a higher solubility than CH_4, it will proportion more to the liquid phase at higher pressures. Therefore, high pressure biogas is characterized by a measured CH_4 content reaching equilibrium values between 70-85% at a pressure of 0.30 - 2.0 bar. The result show that a high percentage up to 85% by operating in high pressure condition compare to digestion at normal condition (56%). Ideally, high-quality biogas can be directly used for electricity and heat generation or injected in a local natural gas distribution line. In the present study, using acetate salt as substrate and anaerobic granular sludge as inoculum, batch-fed reactors showed a pressure increase up to 4.0 bar; the maximum allowable value for CSTR reactors. However, the specific methanogenic activity (SMA) of the sludge decreased on average by 24.6% compared to digestion at ambient pressure (0.2 bar). High pressure biogas show that it is a highly promising technology for anaerobic digestion and biogas upgrading in a single step reactor system. This study also shows that low volume flows of biogas can be upgraded for further use by in-situ methane enrichment in high pressure reactor systems without having to invest in external biogas upgrading equipment.

Table 1 SMA test results in various pressure conditions

Pressure	SMA(g COD – CH_4/ gVSS-d)
ambient pressure	0.57
2 bar	0.43
2.2 bar	0.42

Keywords: gas purify processes; the Henry's Law; High-pressure; anaerobic digestion; CO2 solubility

WR-P12

Direct production of reusable water using sequencing batch reactors – floating micro-filter membrane process

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Abstract

The rapid urbanization and industrialization made over the past decades in developing countries have caused significant water pollution and scarcity of clean water available for daily use of the residents. To resolve the clean water shortage issue, a variety of seawater desalination and wastewater reuse technologies have been developed and applied (Whenhai et al., 2017). In addition, As the importance of water-energy nexus is being emphasized in the recent years, wastewater treatment and reuse technologies demanding low cost and energy supply have been sought for (Shaoqing et al., 2016).

In this study, we have developed an innovative process called sequencing batch reactors – floating micro-filter membrane (SBR-FMFM) to treat wastewater and produce reusable water (Fig. 1). Organics, nitrogen, and phosphorus in wastewater are first biologically removed in the SBR process, which was operated with the following cyclic modes: 50 min feeding, 70-120 min mixing, 90-130 min aeration, 30-40 min idle, and 30 min settling. Effluent from the SBR process was further treated in the chamber containing the FMFM module. Since the FMFM module was floating on the surface of water in the chamber, less fouling could form, resulting in less aeration demand and maintenance.

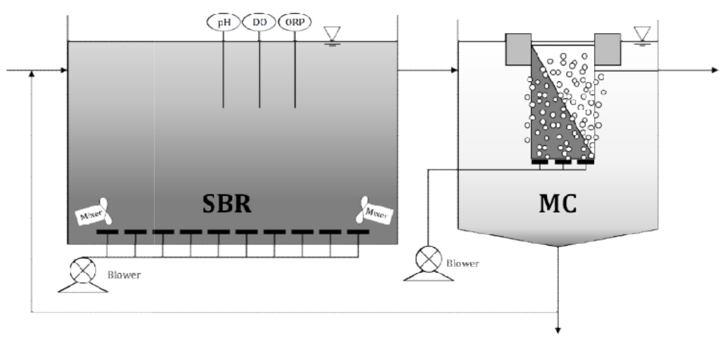

Figure 5 Schematic of SBR-MC process

The SBR-FMFM system had been operated for 12 months and its performance was evaluated. In short, the average removal efficiencies of COD_{cr}, (average influent COD_{cr}: 223 mg/L), TN (average influent TN: 35.6 mg/L), and TP (average influent TP: 3.8 mg/L) were 94%, 77%, and 94%, respectively. Considering its reduced operating cost and less maintenance demand, the SBR-FMFM system is a promising technology which can be applied in developing countries and contribute to resolve their water shortage issues.

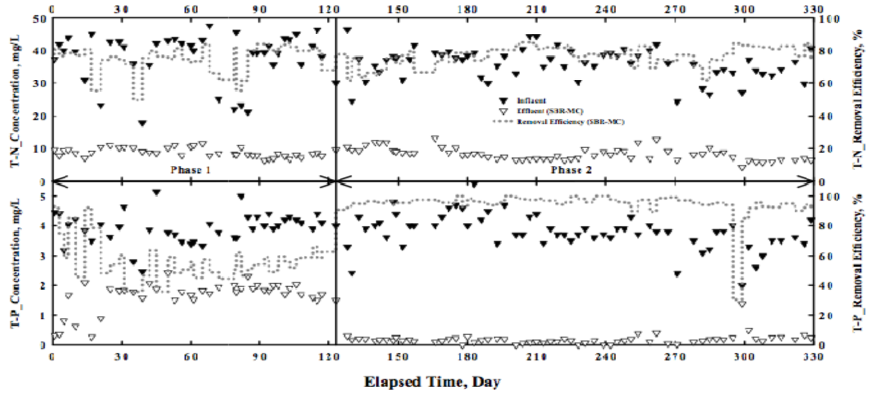

Figure 2 Results of SBR-MC process.

Keywords: Sequencing Batch Reactor, Membrane, Wastewater treatment plants

WR-P13

Polysulfone Membrane to Treat Wastewater on Effect Study of Plasma Treatment Time for Improvement of Surface Hydrophilicity

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Abstract

Membrane technology is widely used in industrial processes and in industrial wastewater treatment. That is a clean technology, environmentally friendly and a process that can be recycled of water. Polymer membrane was widely used in the industry due to low cost and an acceptable selectivity rate. Polysulfone (PSF) is one of the top polymers for flat sheet membrane produce. However, it has hydrophobic property that can cause of fouling and low permeability. Many researchers would like to modify PSF membrane for improving hydrophilicity of the membrane but it is difficult because PSF has strong chemical bond of molecular structure. In this research, plasma technology has been used to modify the membrane surface. The low-pressure DC plasma generator has many advantages for modifying membrane surface. During irradiating plasma beam on membrane surface, multiple interactions between plasmas and membrane have been occurred such as corrosion, deposition and reprocessing process. By reprocessing process, the nanoparticles will accumulate on the membrane surface that will enhance the hydrophilicity on the membrane surface. The difference of plasma treatment time will affect the different of water contact angle (WCA) on the membrane surface. The WCA is slightly decreased when increasing of plasma treatment time and leading to increase of hydrophilicity of membrane surface. The four min of argon plasma treatment time correspond with the slightest WCA, as shown in figure 1(b).

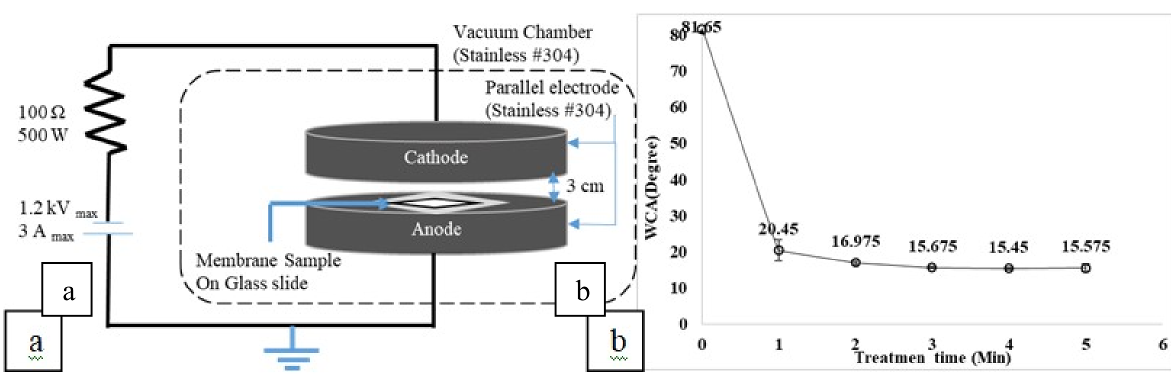

Figure 1 Schematic diagram of the low - pressure DC plasma generator (a), WCA of PSF membrane after Ar-plasma treatment (b).

The low-pressure DC plasma generator has been used to modify the PSF membrane with the distance between of 3 cm, power of 60 W, base pressure of $1.0x10^{-1}$ mbar, initial gas pressure of $2.0x10^{-1}$ mbar and argon and oxygen have been used as working gas.

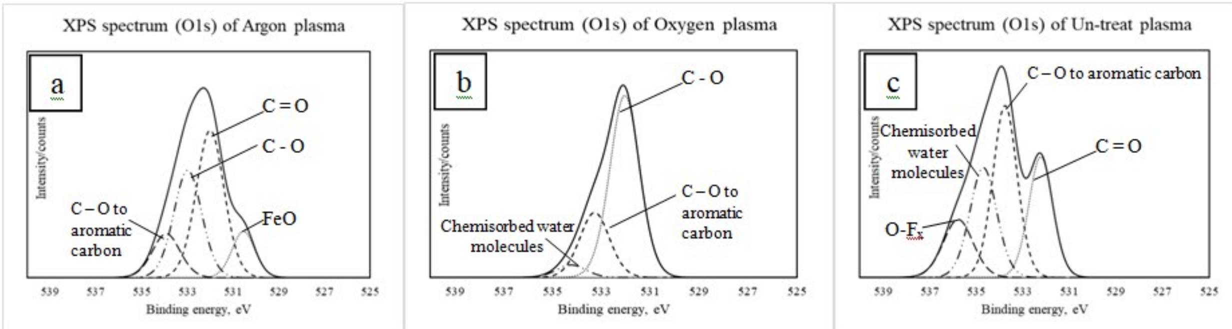

Figure 2 X-ray photoelectron spectroscopy (XPS) spectrum of O1s, (a) argon plasma, (b) oxygen plasma and (c) Untreated plasma.

X-ray photoelectron spectroscopy shown O1s state substantiate of hydrophilicity on PSF membrane surface after treatment by argon and oxygen plasma at treatment time of 4 min. The treated membrane shown the intensity of C=O and C-O peak higher than the untreated membrane as shown in table 1. This means that the treated membrane will enhance the effectiveness of wastewater treatment.

Table 1 The intensity peak of XPS spectrum (O1s)

Plasma treatment	FeO	C=O	C-O	C-O to aromatic carbon	Chemisorbed water molecules	$O-F_x$
Argon plasma	11.3	43.7	32.0	13.0	-	-
Oxygen plasma	-	-	70.2	24.9	4.8	-
Untreated	-	24.6	35.5	-	25.1	14.8

Keywords: surface modification, hydrophilicity membrane, low-pressure DC-plasma, polysulfone, wastewater treatment

WR-P14

Experimental study for Greywater treatment Using Greenwall Concept

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Abstract

Water is considered as an important natural resource as only 3% of world's total water is freshwater that is available for human use. Wastewater that is generated in household or office buildings without any fecal contamination is known as greywater e.g wastewater from showers, sinks, baths, washing machine or dishwashers etc. In domestic households the total contribution of greywater is about 75% of the total waste water generated (Tsoumachidou et al., 2016). This 75% of the greywater which is otherwise being wasted could be utilized for other non drinking purposes such as landscape, garden irrigation, flushing etc, thereby reducing the demand of potable water for non-potable purpose. Many researchers have investigated grey water treatment techniques throughout the world (Boyjoo et al., 2013). As greywater reuse systems require lot of horizontal space, it becomes difficult to find free space in current metropolitan cities especially like Mumbai, hence any treatment which require less horizontal space are preferred. In the current study, the green wall concept is utilised for the treatment of grey water. A wall which is partially or completely covered with greenery is known as green wall (Fowdar et al., 2017). Currently the green wall across the globe has a huge demand of water with potable quality for its existence, hence they are considered as major water consumers (Prodanovic et al., 2017). It is necessary to develop such systems which reduce the usage of potable water. Hence in this study an attempt is made to apply the grey water for the green wall, that helped to reduce the use of potable water for the green wall and also helped to treat the grey water using the growing media. The methodology adopted here consists of three different stages. Initial stage involves testing the efficiency of the growing media in treating greywater. Second stage focused on selecting a suitable greywater friendly plant. The third stage involves the testing of grey water with growing media along with selected plants. In this paper only the results of the first two stages are discussed. The first stage of investigation of testing the efficiency of the growing media using coirlite in treating greywater yielded the following results (Table 1). The testing parameters included in the study were pH, COD (Chemical Oxygen Demand) and BOD (Biochemical Oxygen Demand). It is observed that around 50% reduction was observed in BOD and COD when grey water is applied through the growing media (coirlite).

Table 1 Test Results of Growing Media

Parameters Tested	Inlet (mg/l)	Outlet (mg/l)
pH	12.3	7.5
COD	290	136
BOD	125	61

The plants which were shortlisted for testing the suitability of the plants for the grey water treatment were Rhoeo, Chlorophytum, Sprengeri, Ferns, Evergold Sedge and Red Ivy. The results of the direct grey water application on the plants showed that, only Fern and Evergold sedge were sustained. Figure 1 indicates the methodology for the selection of the green wall plant species.

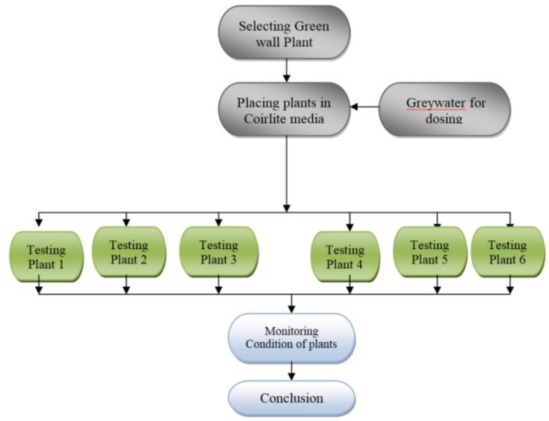

Figure 1 Methodology for the selection of green wall plant species

The test results conclude that, the growing media of coirlite was found to be efficient in reducing the tested parameters. The media as such doesn't constitute a green wall, hence to reach to a conclusion of testing efficiency of entire green wall the media along with the plants and entire green wall setup needs to be tested and analyzed.

Keywords: Blackwater, Greywater, Green wall, Growing media

WR-P15

MPPE
Separation of organics from water

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Abstract
Macro Porous Polymer Extraction system removes dispersed and dissolved organics from water with efficiencies down to low ppb level.
A wide range of components, including aliphatics, (poly)-aromatics, halogenated hydrocarbons, ethers and ketones, are removed and recovered from industrial waste water, groundwater, storage water, produced water and in-process water.

Diversity and versatility of separation

Due its versatility the MPPE system is the separation solution in numerous applications and can be used in various markets. Is it also your solution?

In-Process Separation Solutions

• Steam stripper substitution
• Distillation column replacement
• Increase of organics concentration for re-use

End-of-Pipe Separation Solutions

• Enhancement of bio treatment
• (In-Situ) Groundwater
• Industrial waste water
• Produced water

Broad range of organics removal, also for multiple organics mixtures

The robust MPPE removal and recovery system separates a broad range of toxic and damaging organics from the water stream, resulting in a Zero Harmful Discharge. Whichever application you have, Veolia MPP Systems guarantees to meet the discharge limits over the complete lifetime of the MPPE unit.
The cleaned water can be re-used for various process applications or it can be discharge into the sewage system, used for further drinking water treatment or directly discharged into open water. The recovered organics are with an almost 100% purity ready for re-use, other process purposed or immediate return on your revenue.

Keywords: Separation; Organics; Recovery

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WR-A05

Energy consumption in baffled membrane bioreactor (B-MBR)

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Abstract

We investigated the operating conditions of a baffled membrane bioreactor (B-MBR) under which long-term stable operation can be achieved through a continuous operation of a pilot-scale B-MBR. In addition, the energy consumptions in the operating conditions recommended based on the results of pilot-scale experiment were also estimated. The results of continuous operation of the pilot-scale B-MBR revealed that the B-MBR can be stably operated with a net flux of 0.5 m^3/m^2/day and a specific air demand per membrane surface area (SADm) determined for membrane aeration of 0.30 m^3/m^2/hr. The value of SADm used in the pilot-scale B-MBR corresponds to an SADm of 0.08 m3/m2/hr in a full-scale B-MBR taking the difference in effective length of hollow fiber membrane into consideration. The results of estimation of energy consumption suggest that energy consumption in full-scale B-MBRs operated under the operating conditions mentioned above were in the range of 0.20~0.22 kWh/m^3. The results obtained in this study strongly suggest that energy consumption in MBR operation can be significantly reduced by applying the concept of B-MBR.

Keywords: Baffled membrane bioreactor; nitrogen removal; energy-saving

1. Introduction

Membrane bioreactors (MBRs) have various advantages compared with conventional biological wastewater treatment processes (e.g., conventional activated sludge process), including small-footprint, superior treated water quality, and ease of operation (automation) (Judd, 2006). These features of MBRs are particularly attractive when up-grading an existing wastewater treatment facility with limited available space. MBRs are also a suitable choice when water reclamation and reuse are required because the treated water of MBR basically does not contain any suspended solid, and therefore, MBR can serve as excellent pretreatment for reverse osmosis (RO) membrane process, which is often utilized for producing reclaimed water to be reused in various purposes. Despite such important features of MBRs, wide-spread application of this technology is hampered particularly by its high operation and maintenance costs. Especially the cost associated with energy consumption is generally a dominant economic burden in the operation of MBRs (Kraume and Drews, 2010). Reduction of energy consumption during MBR operation is apparently important, though the specific energy consumption in operating MBRs has been significantly decreased by recent intensive research and development activities (Krzeminski et al., 2017).

MBRs are divided into two categories based on the location of membrane. One type of MBRs is side-stream MBR, in which membrane modules are placed outside of a biological reaction tank, and the mixed liquor suspension is recirculated between the reaction tank and membrane module by recirculation pump. The other one is submerged MBR. In submerged MBR, membranes are directly submerged into the reaction tank and membrane filtration is performed by suction pump. Although locating membrane outside of the reaction tank is particularly advantageous for cleaning and replacement of membranes (Hoque et al., 2012), the energy consumption of the operation of side-stream MBR is generally much higher than that of submerged MBRs (Buer and Cumin, 2010). Therefore, at least in municipal wastewater treatment, submerged MBRs are generally preferred.

Among the apparatuses used in submerged MBRs, an air-blower used for introducing coarse bubbles aimed at cleaning membrane (membrane aeration) generally account for the largest fraction of energy consumption (Gil et al., 2010; Verrecht et al., 2010; Krzeminski et al., 2012). On this basis, significant research and development activities have already been made for reducing energy consumption associated with membrane aeration (Verrect et al., 2011; Kurita et al., 2015; Yan et al., 2016). Owing to such intensive efforts, the specific energy consumptions in MBR operations have been significantly reduced. Recently, Tao et al., (2010) achieved an specific energy consumption of 0.37 kWh/m^3 in a fully optimized MBRs treating real municipal wastewater (primary effluent). We also developed an energy-saving MBR, which equipped with a modified hollow-fiber membrane element (both effective fiber length and packing density were increased compared with conventional membrane element). The results of our estimation strongly suggest that the energy-saving MBR developed can be operated with a specific energy demand of less than 0.37 kWh/m^3 (Miyoshi et al., 2018a). However, these values are still higher than conventional activated sludge method (0.2-0.3 kWh/m^3) (Fenu et al., 2010), and therefore, further reduction in specific energy consumption in MBR operation is required for wide-spread application of this technology. For further reduction in energy consumption, approach for reducing energy consumption associated with apparatuses other than membrane aeration should also be investigated.

In MBRs applied to municipal wastewater treatment, complete nitrification is usually achieved. Taking the decrease in pH as a result of complete nitrification into account, performing denitrification is typically indispensable for satisfying the limitation in pH standard of the treated water. In typical submerged MBRs, denitrification is achieved by installing anoxic tank and recirculating mixed liquor suspension from aerobic to anoxic tank. For achieving nitrogen removal in such arrangements, recirculation pump and mixer installed at anoxic tank are indispensable. The energy consumptions of these apparatuses also account for great fractions in the overall energy consumption of MBRs (Miyoshi et al., 2018a). Based on the background mentioned above, we focused on the application of baffled MBR (B-MBR). In B-MBR, baffles are inserted into the biological reaction tank of a submerged MBR and water level is appropriately controlled by intermittent introduction of raw wastewater to the reactor (Kimura et al., 2008). By applying such operational scheme, B-MBR can be operated without installation of recirculation pump and mixer in an anoxic tank, and therefore, the energy consumption of these apparatuses can be reduced. By combining the concept of B-MBR and our energy-saving MBR (Miyoshi et al., 2018a), further reduction in specific energy consumption of MBR operation could be possible. However, the specific energy consumption depends heavily on the membrane flux and air-flow rate at which stable operation of MBR can be achieved. At present, this point is not clear for the combination of B-MBR and our energy-saving MBR. Therefore, we investigated the membrane flux and air-flow rate of membrane aeration under which long-term stable operation of the B-MBR combined with our energy-saving MBR concept can be achieved. Afterword, the specific energy consumption under the above-mentioned operating condition was also estimated.

2. Experimental

2.1 Concept of B-MBR

The details of the concept of B-MBR can be found elsewhere (Kimura et al., 2008; Miyoshi et al., 2018b). Briefly, baffles inserted in the biological reaction tank of a submerged MBR divide the inside of the tank into two compartments, and a membrane unit is installed at one side of the compartments created by baffles. Both membrane aeration and biology aeration (the aeration aimed at supplying dissolved oxygen (DO) to the biomass) are performed only at the compartment at which the membrane unit is installed. In addition, the water level is fluctuated during the operation of B-MBR by intermittent introduction of raw water into the reaction tank. As a result, there are two phases in an operation cycle of B-MBR, namely recirculation phase, in which mass exchange between interior and exterior zones of baffles takes place, and separation phase, in which nitrification and denitrification are promoted in compartments at which are presence and absence of the membrane element, respectively (Fig. 1). By repeating such cycle, B-MBR is capable for removing nitrogen by nitrification and denitrification reactions without installing anoxic tank and recirculation pump for transporting mixed liquor suspension from aerobic to anoxic tanks. When the entire reaction tank is sufficiently mixed during the recirculation phase, a mixer, which is indispensable for anoxic tank can also be omitted. Therefore, the energy consumptions associated with these apparatuses can be reduced in the operation of B-MBR.

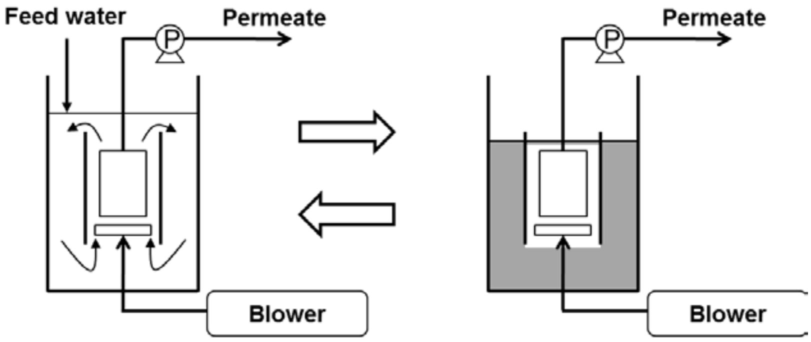

Fig. 1. Schematic description of B-MBR. This figure is reproduced from Miyoshi et al., (2018b), with permission from the copyright holders, IWA Publishing.

2.2 Continuous operation of pilot-scale B-MBR

A pilot-scale B-MBR installed at an existing municipal wastewater treatment plant connected to a combined sewer system (Soseigawa Wastewater Treatment Center, Sapporo, Japan) was continuously operated using the influent of primary sedimentation basin as raw water. The membrane used in this study was the same to the one used in our energy-saving MBR (Miyoshi et al., 2018a), though the effective length of membrane fiber used in this study (0.8 m) was much shorter than that used in our previous investigation (3 m). The membrane element was comprised of a vertically aligned hollow-fiber membrane fabricated by polytetrafluoroethylene (PTFE) with a nominal pore size of 0.2 µm. Because specific air-demand per membrane surface area (SADm) required for stable operation of MBR is thought to be reduced by increasing the effective length of membrane fiber in an MBR equipped with vertically aligned hollow fiber membrane, the SADm value adopted in the continuous operation in this study was higher than that used in our previous investigation (Miyoshi et al., 2018a). As explained in detail later, this difference is corrected in the evaluation of specific energy consumption of the B-MBR.

In the pilot-scale MBR apparatus used in this study, two membrane units (Units A and B) were installed side-by-side, and operated in parallel. Intermittent membrane filtration (9-min filtration and 1-min relaxation) was carried out in both membrane units. Unit A was used for evaluating the development of membrane fouling under the operating conditions, which are expected to be standard in B-MBR operation. The other membrane unit was used for the adjustment of flow rate and subsequently hydraulic retention time (HRT) during the continuous operation of B-MBR. The HRT was set at 5.9 h. Mixed liquor suspended solid (MLSS) concentration during the continuous operation was in the range of 6.5~14.5 g/L. In this paper, the development of membrane fouling is discussed only for the results obtained from Unit A. The Unit A has an effective membrane surface area of 15 m2 and membrane filtration was performed with a membrane flux (net flux) of 0.5 m^3/m^2/day (approximately 25 L/m^2/hr). The Unit A was also equipped with a dummy membrane element (a membrane element which was not used in membrane filtration) with identical structure. Membrane aeration in the Unit A was evenly distributed among the two membrane element with an air-flow rate of 9 m3/hr. Therefore, the SADm in the membrane filtration in the Unit A was 0.30 m3/m2/hr. The Unit B had an effective membrane surface area of 30 m^2, and membrane filtration and membrane aeration were performed with a membrane flux of 0.25 m3/m2/day (approximately 12.5 L/m^2/hr) and SADm of 0.30 m^3/m^2/hr, respectively. During the continuous operation, chemically enhanced backwash (CEB) with alkaline solution (NaClO 500 mg/L, NaOH 0.02%) and acid solution (H_2SO_4 0.2%) was performed every week and every alternative week, respectively. The continuous operation of the pilot-scale B-MBR was divided into six sub-periods, in which the pilot-scale B-MBR was operated with different air-flow rate of biology aeration and the volume ratio between interior (aerobic) and exterior (anoxic) zones (Table 1).

Table 1 Operating conditions of pilot-scale B-MBR in each sub-period. Volume ratios are expressed as interior: exterior zones. Air-flow rate indicates the average air-flow rates of biology aeration. DO concentration presented here is average DO concentration in interior zone of baffles.

	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
Date	Jan. 18th , 2018 ~Jan. 29th, 2018	Feb. 14th, 2018 ~Mar. 1st, 2018	Mar. 2nd, 2018 ~Apr.2nd, 2018	Apr. 3rd, 2018 ~Jun. 13th, 2018	Jun. 14th, 2018 ~Jul. 12th, 2018	Jul. 13th, 2018 ~Jul. 27th, 2018
Volume ratio	1: 2	1: 1	1: 1	1: 1	1: 1	1: 2
Air-flor rate (Nm^3/hr)	5.3 ± 0.7	10.7 ± 2.7	2.3 ± 2.5	5.4 ± 0.8	8.7 ± 3.4	3.6 ± 0.9
DO concentration (mg/L)	0.9 ± 0.4	1.2 ± 0.6	3.2 ± 1.0	0.6 ± 0.5	1.6 ± 0.7	1.7 ± 0.7
Temperature (°C)	13.6 ± 0.2	13.5 ± 0.7	10.9 ± 1.7	17.5 ± 2.3	20.3 ± 0.9	22.5 ± 0.7

2.3 Estimation of energy consumption

Based on the results obtained in the continuous operation of the pilot-scale B-MBR, we estimated energy consumption in hypothetical full-scale B-MBRs assuming typical wastewater treatment plant in both Thailand and Japan. Specifications assumed in the estimation are summarized in Table 2. Fig. 2 shows the apparatuses considered in the estimation. The membrane elements utilized in the pilot-scale B-MBR operated in this study (effective length of 0.8 m) was considerably shorter than the one used in full-scale B-MBRs (effective length of 3 m). The specific air-demand per membrane surface area (SADm) adopted in the continuous operation of the pilot-scale B-MBR was corrected to the one used in full-scale B-MBRs assuming that the difference in the vertical length does not affect the demand of membrane aeration: corresponding SADm in hypothetical full-scale B-MBRs used for the estimation of energy consumption was 0.08 m^3/m^2/hr. Although a primary sedimentation basin was included in the estimation of energy consumption for the hypothetical wastewater treatment plant in Japan, this facility was not considered in the estimation of energy consumption for the one in Thailand. This difference is associated with the difference in raw water quality. Due to the low value of biochemical oxygen demand (BOD) in the raw water assumed for the hypothetical wastewater treatment plant in Thailand (Table 2), installation of a primary sedimentation basin may result in insufficient denitrification associated with limited availability of electron donor required in denitrification reaction. As indicated in Fig. 2, the apparatuses considered in the estimation of energy consumption are limited to water treatment process, and other function of wastewater treatment facility such as lifting pump or sludge treatment were not involved in the estimation performed in this study.

2.4 Analytical methods

During the continuous operation, samples of feed and treated water were corrected and analysed. BOD and concentrations of suspended solid (SS), ammonium-nitrogen, total nitrogen (T-N), total phosphorus (T-P), MLSS, and mixed liquor volatile suspended solid (MLVSS) were determined in accordance with Japanese standard methods (Japan Sewage Works Association, 2012).

Table 2 Specifications used for the estimation of energy consumption. The water qualities of raw water in Japan were selected based on typical primary effluent qualities.

	Thailand	Japan
Dairy average flow rate (m^3/day)	10,000	10,000
Dairy maximum flow rate (m^3/day)	14,000	12,000
Net flux (m^3/m^2/day)	0.5	0.5
HRT (hr)	6	6
MLSS concentration (mg/L)	8,000	8,000
MLVSS concentration (mg/L)	6,400	6,400
Average DO concentration in aerobic zone (mg/L)	1.5	1.5
Minimum temperature (°C)	25	13
Oxygen transfer efficiency (membrane aeration) (%)	8	8
Oxygen transfer efficiency (biology aeration) (%)	25	25
α factor	0.65	0.65
BOD (raw water) (mg/L)	50	120
SS concentration (raw water) (mg/L)	40	100
T-N concentration (raw water) (mg/L)	15	30
BOD (treated water) (mg/L)	3	3
SS concentration (treated water) (mg/L)	N.D.	N.D.
T-N concentration (treated water) (mg/L)	5	5

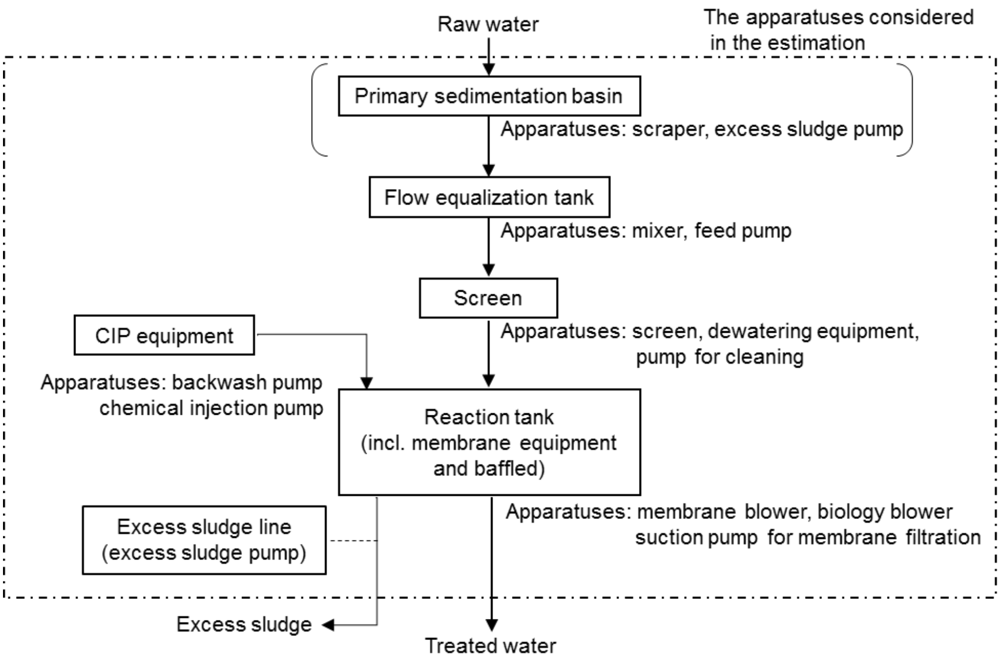

Fig. 2. Apparatuses considered in cost estimation. Primary sedimentation basis was not involved in the cost estimation on the wastewater treatment plant in Thailand.

3. Results and discussion

3.1. Water quality

Fig. 3 shows the changes in water quality indices in the raw water and treated water during the continuous operation of the pilot-scale B-MBR. As mentioned above, the operating conditions of the pilot-scale B-MBR were changed several times during the continuous operation. Nevertheless, BOD was effectively removed by the B-MBR irrespective of the operating conditions. This result indicates that the B-MBR operated in this study was capable of removing BOD under wide-range of operating conditions. On the other hand, the removal efficiency of total nitrogen was partially affected by the operating conditions. At the beginning of the continuous operation (Periods 1 and 2), the BOD and T-N concentration in the raw water were higher than those in the other periods. Although T-N was effectively removed during Period 1, the concentration of ammonium-nitrogen in the treated water slightly increased during this period. This tiny deterioration in the nitrification may be explained by low temperature (this operating period corresponded to a winter period) or insufficient oxygen supply during this period.

On February 14th, the ratio between interior and exterior zones of the pilot-scale B-MBR was changed from 1:2 to 1:1 (expressed as interior: exterior zones). This change resulted in significant increase in oxygen consumption in the interior zone of the baffles, and DO concentration in the interior zone did not reach to sufficient level for promoting nitrification in an entire cycle of B-MBR operation. It is strongly suggested that the oxygen demand during B-MBR operation increases by increasing the fraction of interior (aerobic) zone in the entire volume of reaction tank of B-MBR. On this basis, we changed the setting of biology aeration control protocol for increasing oxygen supply. This change resulted in increase in air-flow rate of biology aeration (Table 1). As a result, sufficient oxygen was supplied to the biomass and the total nitrogen removal during this period was sufficient. The experimental results mentioned above suggest that oxygen demand during B-MBR operation becomes lower when operated with smaller fraction of aerobic zone relative to that of anoxic zone. This tendency is further confirmed at the end of the continuous operation as described later. The operating conditions in Period 3 were identical to those in Period 2. In this period, however, due to the intrusion of snow runoff, the water temperature in the biological reaction tank of B-MBR suddenly decreased. The oxygen consumption in this period was likely to be lower and air-flow rate of biology aeration was also smaller than the other periods.

Taking the sufficient removal of total nitrogen during Periods 2 and 3 into consideration, we changed the setting of biology aeration control protocol into the original one (i.e., identical to the protocol adopted in Period 1) at the beginning of Period 4 (the beginning of April). Although total nitrogen was effectively removed at the very beginning of Period 4, it was greatly deteriorated after the end of April. Because the ammonium-nitrogen concentration in the treated water also significantly increased at the same time, this deterioration in the nitrogen removal was thought to be mainly attributed to the deterioration in nitrification. During this experimental period, DO concentration in the interior zone of the baffle was apparently lower than the other experimental periods (Table 1). The oxygen consumption in this period was likely to exceed the oxygen supply capacity of the operating conditions adopted in this period. This result also supports the previous discussion based on the results obtained in Periods 1 and 2, which suggest that more intensive biology aeration is required for achieving sufficient nitrogen removal by increasing the volume fraction of aerobic zone in the biological reaction tank of B-MBR. This insufficient nitrification can be avoided by either increasing the air-flow rate of biology aeration (Period 5) or decreasing the volume fraction of aerobic zone in the biological reaction tank of B-MBR (Period 6). Because sufficient treated water quality can be achieved with reduced air-flow rate of biology aeration in Period 6, it can be said that the operating conditions adopted in this operating period are the optimum among those examined in the present study.

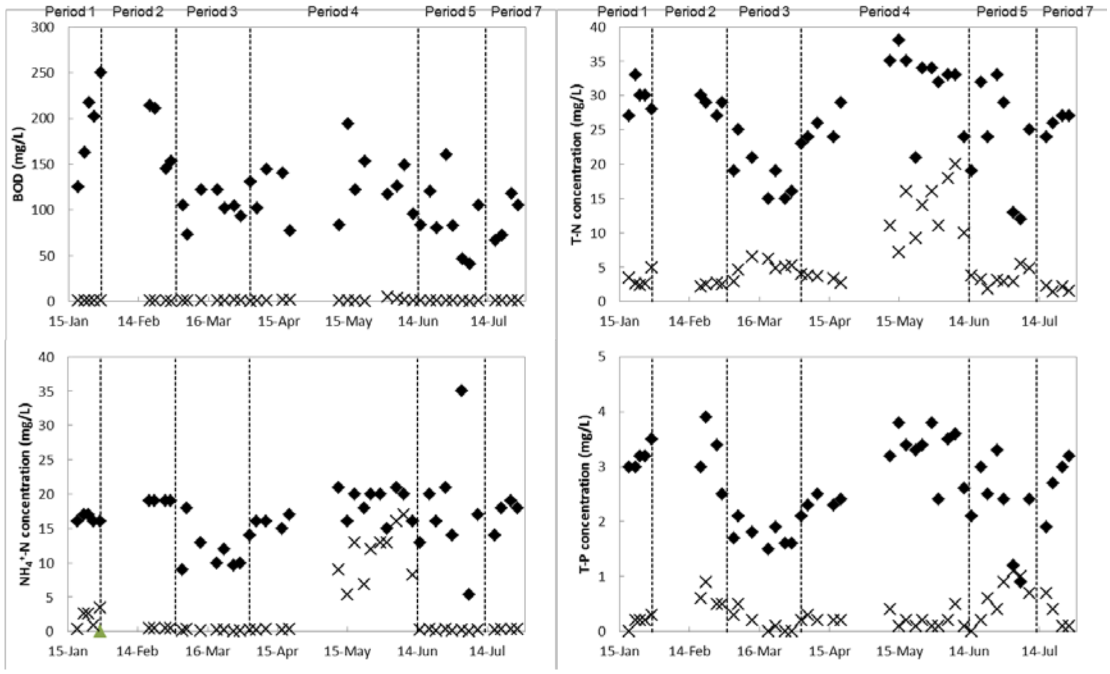

Fig. 3. Changes in water quality indices during continuous operation of pilot-scale B-MBR. Squares: raw water, crosses: treated water.

3.2 Membrane fouling

The change in transmembrane pressure (TMP) during the continuous operation of the pilot-scale B-MBR is shown in Fig. 4. Data presented in Fig. 4 were corrected to 20°C equivalent values taking the influence of water viscosity on TMP required for achieving the designated flux into consideration. During the continuous operation described in Fig. 4, no chemical recovery cleaning was performed. TMP was sharply increased from the middle of February to the end of March. This sharp increase in TMP was attributed to decrease in water temperature (Table 1) associated with intrusion of snow runoff. In the present study, we operated the pilot-scale B-MBR with regularly performed CEB. Because TMP rapidly decreased from the beginning of April, at which snow melting was likely to be completed, it can be said that the membrane fouling developed during this period was reversible to the CEB performed in this study.

Except the rapid increase in TMP associated with unusual decrease in temperature mentioned above, the continuous operation of the pilot-scale B-MBR was quite stable and the increase in the TMP was marginal (i.e., from the end of April to the end of the continuous operation). The continuous operation can be continues without any interruption as a result of performing chemical recovery cleaning. This result indicates that, despite of the irregular event associated with snow melting, the maintenance cleaning protocol adopted in the continuous operation (i.e., the combination of membrane aeration and CEB) was sufficient for stably operating the B-MBR. Therefore, estimating the energy consumption under the operating conditions adopted in this continuous operation is thought to be valid. The details of the estimation of energy consumption will be given in the following section. Taking the effective elimination of membrane fouling by the regularly performed CEB into consideration, the rapid increase in TMP during the experimental period with extremely low water temperature could be mitigated by increasing the frequency or chemical concentration in the CEB protocol.

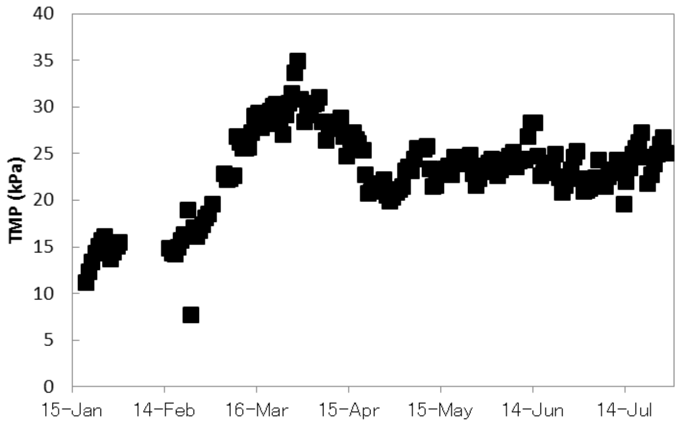

Fig. 4. Change in TMP during continuous operation of pilot-scale B-MBR.

3.3 Estimation of energy consumption in B-MBR operation

The results obtained in the continuous operation of the pilot-scale B-MBR strongly suggest that B-MBR can be stably operated under an SADm of 0.30 m^3/m^2/hr. As explained in the section of the methods for estimating energy consumption, an SADm of 0.30 m^3/m^2/hr in the pilot-scale B-MBR operated in this study corresponds to an SADm of 0.08 m^3/m^2/hr taking the difference in effective length of membrane fiber in membrane element into account. Therefore, we estimated the energy consumption in operating hypothetical B-MBRs operated with an SADm of 0.08 m^3/m^2/hr. The estimation was performed for two different situations, namely wastewater treatment plants in Thailand and Japan. BOD and T-N concentration in the raw wastewater in wastewater treatment plants in Thailand are generally lower than that in the one in Japan.

Fig. 5 shows the estimated energy consumptions in the two cases of hypothetical B-MBR. In both situations, the estimated energy consumptions are very small compared with the previously reported energy consumption in MBR operations (i.e., slightly less than 0.4 kWh/m^3) (Tao et al., 2010; Miyoshi et al., 2018a). As explained above, a sludge recirculation pump for recirculating mixed liquor suspension from aerobic to anoxic tanks and a mixer installed at anoxic tank are not required in the operation of B-MBR. Therefore, energy consumptions associated with these apparatuses can be reduced by utilizing B-MBR technology. In addition, the energy consumption associated with membrane aeration was also reduced as a stable operation of the pilot-scale B-MBR can be achieved with reduced air-flow rate of membrane aeration. Based on the results obtained in the continuous operation of the pilot-scale B-MBR, it is highly possible that a full-scale B-MBR can be operated with an SADm of 0.08 m^3/m^2/hr and net flux of 0.5 m^3/m^2/day. The operation under these operating conditions corresponds to a specific air demand per permeate (SADp) of 3.84 m^3-air/m^3-permeate. This value of SADp is substantially lower than typical MBRs (more than 10 m^3-air/m^3-permeate) (Judd, 2008). Both omitting recirculation pump and mixer and reducing air-flow rate of membrane aeration played important roles for reducing overall energy consumption in wastewater treatment plant utilizing B-MBR technology.

Although the energy consumption estimated for a wastewater treatment plant in Thailand was slightly lower than that estimated for one in Japan, the difference between the two situations was not significant. This result suggests that the advantage of B-MBR in reducing energy consumption can be utilized in a wide-range of wastewater treatment plants. The difference in the energy consumptions estimated for the two situations was likely to be mainly attributed to the difference in raw water quality: both BOD and T-N concentration of raw water in Thailand was substantially lower than that in Japan.

The high energy consumption during the operation of MBR has been one of the biggest obstacles for its wide-spread application in municipal wastewater. However, the specific energy consumptions estimated in the present study were comparable to that of wastewater treatment plants utilizing conventional activated sludge process (Fenu et al., 2010). This fact indicates that the issues associated with high energy consumption of operating MBR can be almost completely overcome by applying the achievement obtained in this study. Because B-MBR also has all of the advantages of MBRs (e.g., excellent treated water quality, small footprint, and ease of automation), applying B-MBR concept would allow us to take advantages of MBRs without any additional expenditure on energy consumption. Therefore, the achievement obtained in this study could be a breakthrough for wide-spread application of MBRs.

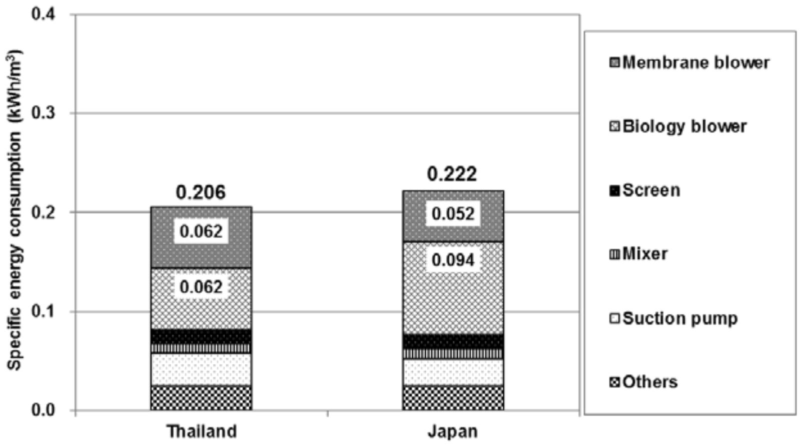

Fig. 5. The results of estimation of energy consumption**.**

4. Conclusions

In this study, we investigated operating conditions under which long-term stable operation of B-MBR can be achieved by performing long-term continuous operation of a pilot-scale B-MBR with real municipal wastewater. The specific energy consumptions in hypothetical full-scale B-MBRs operated under the operating conditions examined in the pilot-scale experiment were also estimated. The results obtained in the continuous operation revealed that B-MBR can be operated under SAD_m of 0.30 m^3/m^2/hr and net flux of 0.5 m^3/m^2/day (the value of SAD_m examined in the pilot-scale B-MBR corresponds to an SAD_m of 0.08 m^3/m^2/hr in a full-scale B-MBR taking the difference in the effective length of membrane fiber). The specific energy consumptions in the operation of full-scale B-MBRs under these operating conditions were estimated to be 0.206 and 0.222 kWh/m^3 in wastewater treatment plants in Thailand and Japan, respectively. These values of specific energy consumptions are almost comparable to those typically found in the operation of conventional activated sludge process. The results obtained in this study strongly suggest that application of B-MBR concept allows us to utilize MBR technology without substantial increase in energy consumption of treatment plant.

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WR-A19

Application of Analytic Hierarchy Process (AHP) for the Assessment of Water Reclamation Alternative

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Abstract

The water scarcity problem is becoming serious problem as a result of the accelerated industrial and agricultural and an increased population. Reclaimed water offers prospects as an alternative water resource. The selection of suitable water reclamation alternative involves multiple objectives or criteria. This study uses analytical hierarchy process (AHP) for select suitable water reclamation process. The objective hierarchy criterion is considered based on three factors; optional usages, removal efficiency and capital investment. The results obtained that the integration of CF+UF is the most suitable alternative for water reclamation. The study indicates that the AHP are powerful tools which can be used for implementation of appropriate water reclamation process considering the multiple objective-decisions. By doing laboratory scale studies, optional usages, removal efficiencies and capital investment criteria for full scale process can be worked out based on the engineering design and expert analysis and an appropriate water reclamation alternative can be recommended for implementation

Keywords: Water reclamation; Analytic hierarchy process; AHP; Ultrafiltration; Coagulation-flocculation; integration process

1. Introduction

Water is the source of life and one of the most important parts of the global ecological system. The water scarcity problem is becoming serious problem as a result of the accelerated industrial and agricultural and an increased population. Therefore, it is extremely urgent to alleviate the water scarcity by studies on water reclamation technology. Reclaimed water offers prospects as an alternative water resources (Pedro-Monzonis et al., 2015; Hess et al., 2015). It is one of the effective ways to reduce sources of pollution and solve the issue of water scarcity as an effective method of saving water resources. Water reclamation is very demanding in terms of water quality and health security. Coagulation-flocculation (CF) is popular for using as water reclamation process. It is well known to be inexpensive process and easy operation for water reclamation process (Yu et al, 2016). Ultrafiltration (UF) become an interesting alternative process for water reclamation because of relatively low-energy and high efficiency filtration process can effective removing microorganisms and successfully employed in water reuse applications (Ferrer et al, 2015). Recently, the integration of coagulation-flocculation and ultrafiltration process (CF+UF) is interesting alternative for water reclamation technology in order to improve the NOM and microorganism removal efficiency (Kabsch-Korbutowicz, 2005) and to increase the flux of water and reduce the fouling effects (Yu et al, 2016). The selection of the suitable water reclamation alternative is usually uncertain and complex. Many factors may be important for the decision-making process. Therefore, in decision making to select appropriate process is necessary to consider the efficiency of process, cost of construction and control system and the water quality for optional usages. Analytic Hierarchy Process (AHP) is useful for handling multiple criteria and objectives in the decision-making process. The advantage of the AHP technique is that it provides a systematic approach for consolidating information about alternatives using multiple-criteria. It can be applied for complicated multicriteria decision-making to obtain scientific and reasonable results. It has been accepted by the international scientific community as a robust and flexible multicriteria decision-making tool to deal with complex decision problem (Chang et al, 2009). The objective of this study is to apply the AHP using the previous results of Yimrattanabovorn et al. (2018) for optimum selection of water reclamation alternative. The AHP is used to construct the hierarchy of criteria are based on three factors viz. optional usages, removal efficiencies and capital investment. This study is intended to utilize AHP for facilitating the related environmental decision-making process and it will then be applied to actual water treatment alternative for verification and demonstration.

2. Materials and method

2.1 The Analytical Hierarchy Process (AHP)

The Analytical Hierarchy Process (AHP) is designed to structure a decision process in a scenario affected by multiple independent factors. In the analysis, a complex problem can be divided into several sub-problems that are organized according to hierarchical levels, where each level denotes a set of criteria or attributes related to each sub-problem. The top level of the hierarchy denotes the factors of the respective upper levels. The analysis is based on three fundamental principles: breaking down the problem; pairwise comparison of the various alternatives; synthesis of the preferences (Bottero et al, 2011). It is an objective weighing technique for setting the weighing scale for qualitative and quantitative data. A general description of the AHP process would be helpful and the steps described below.

Step 1 Development of the structure of the decision-making process: The decision-making structure must be defined through the main objective. Such an objective should later be divided into groups that are made up of various elements.

Step 2 Pairwise comparison: Pairwise comparisons are made to establish the relative importance of the different elements. The comparisons are made with the Saaty's Fundamental Scale. The numerical judgements established at each level of the network make up pair matrices. The weighted priority is calculated through pairwise comparisons between elements. (Saaty, 2003). The comparisons are generally made on the scale of 1-9. A matrix such as "A" can be formed based on these pairwise comparison. The result of pairwise comparison is a_{ij} if a_{ij}=1 and $a_{ji}=1/a_{ij}$. The following criteria in assigning the preferences to factors.

1	Equally important: two decision factors equally influence the parent decision factor
3	Moderately more important: one decision factor is moderately more influential than the other
5	Strongly more important: one decision factor has stronger influence than the other
7	Very strongly more important: one decision factor has significantly more influence over the other
9	Extremely more important: the difference between influences of the two decision factors is extremely significant
2, 4, 6, 8	intermediate judgment values: judgment values between equally, moderately, strongly, very strongly, and extremely

The consistency index (CI) is normally used to check the consistency of matrix 'A' as;

$$CI = \frac{1}{n-1}(\lambda_{max}-n)$$

Where λ_{max} is the maximum eigenvalue and n is the number of factors in the judgement matrix. Accordingly, Saaty (1980) defined the consistency ratio CR as

$$CR = CI/RI$$

Where RI is the consistency index of a randomly generated reciprocal matrix from 9 point scale, with forced reciprocals. The consistency ratio CR is a measure of how a given matrix compares to a purely random matrix in terms of the consistency index. A value of the consistency ratio $CR \leq 0.1$ is considered acceptable. The RI has been purposed for various *n*, which is al shown below for the sake of continuity.

n	1	2	3	4	5	6	7	8	9
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45

Step 3 Final priorities: The priority weight is synthesized to obtain the overall ranking of the alternatives and find appropriate process. The real example of AHP process in this case study make it more understanding.

2.2 Application to the study case

In the case study, alternatives of water reclamation include alternative 1 Integrate of coagulation-flocculation and ultrafiltration (CF+UF), alternative 2 Coagulation-flocculation (CF), and alternative 3 Ultrafiltration (UF). The selection of water reclamation alternative is associated with distinct multi-criteria. Fig. 1 illustrates the hierarchical levels criteria. The main objective is select suitable water reclamation alternative. The criteria are optional usages, removal efficiency and capital investment. The sub-criteria of optional usages consider water quality that meet water quality standard in purpose of water supply, toilet flushing, urban landscaping and vehicle washing. The sub-criteria of removal efficiency are including removal efficiency in terms of chemical oxygen demand (COD) turbidity and color. The sub-criteria of capital investment considering in terms of capital cost, operation and maintenance cost. The weighted priority is calculated through pairwise comparisons between elements in level to finding the total priority weight are obtain the overall ranking of all criteria and select the suitable alternative.

To determine the relative importance of the criteria. A total number of three pairwise comparisons were made to calculate the priority weights and these are shown in Table 1. The weight of optional usages criterion is 0.63 as compared to 0.26 for removal efficiency and 0.11 for the capital investment criteria, indicating that the importance of the optional usage is more than removal efficiency and capital investment. The optional usages are highest criteria weight because of they are affect to human health.

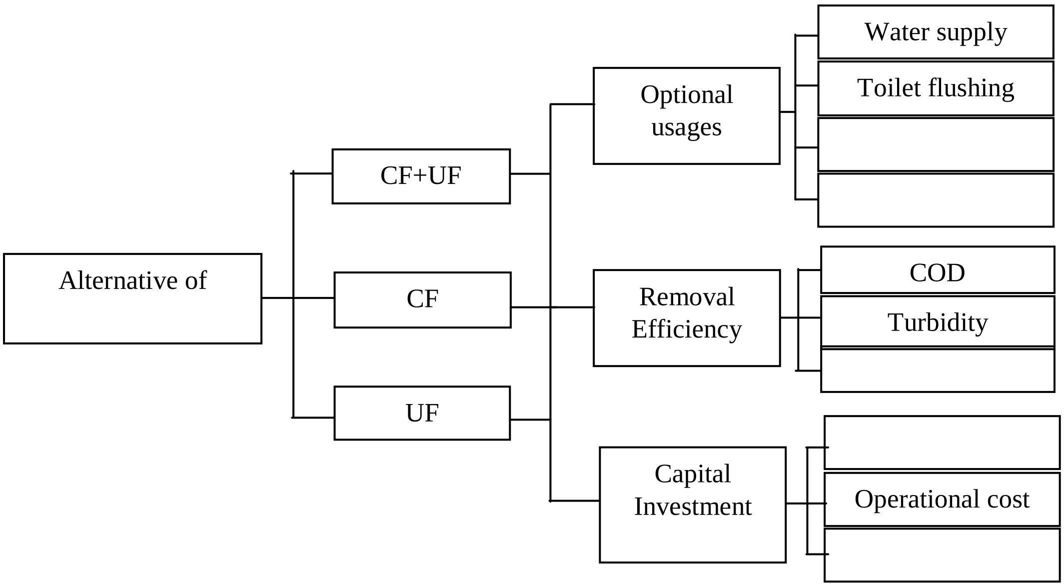

Fig. 1. The hierarchical levels criteria of water reclamation alternative

Table 1 The pairwise comparison of objective criteria

Criteria	Optional usages	Removal efficiency	Capital investment	Priority Weights
Optional usages	1	3	5	0.63
Removal efficiency	1/3	1	3	0.26
Capital investment	1/5	1/3	1	0.11
Total	1.53	4.33	9.00	1

3. Results and discussion

Determine the relative importance of the sub-criteria. The optional usages consider water quality that meet water quality standard in purpose of water supply, toilet flushing, urban landscaping and vehicle washing. The water quality were compared with water quality standard of water supply (WHO, 2011), toilet flushing, urban landscaping and vehicle washing (Rodrigues, 2002). The priority weights results as shown in Table 2, that the optional usages for CF+UF (0.4) higher than CF (0.3) and UF (0.3), indicating that the importance of CF+UF is more than single CF and UF. This implies that the CF+UF has positive features in term of optional usages.

Table 2 The water quality that meet water quality standard of three alternatives

System	Water supply	Vehicle washing	Urban landscaping	Toilet flushing	Total	Priority Weights
CF+UF	✓	✓	✓	✓	4	0.4
CF	✗	✓	✓	✓	3	0.3
UF	✗	✓	✓	✓	3	0.3
Total	1	3	3	3	10	1

Determine the relative importance of the sub-criteria. The removal efficiency in terms of COD, turbidity and color by using data from the previous research of Yimratanabovorn et al (2018). The result of removal efficiency of CF+UF, CF and UF processes are shown in Table 3 illustrates the mean removal efficiency of CF+UF CF, and UF. As shown Fig. 2, the removal efficiency of three alternatives were compared. It shown that the CF+UF process had higher removal efficiency of COD, Turbidity and color than the single CF and UF process. A total number of three pairwise comparisons were made to calculate the priority weights and these are shown in Table 4. The weight of COD, turbidity and color removal efficiency for UF+CF (0.63) higher than CF (0.26), and UF (0.11) indicating that the importance of UF+CF is more than single CF and UF for removal efficiency. This implies that the CF+UF has positive features in term of removal efficiency.

Table 3 The COD, Turbidity and color removal efficiency of three alternative (Yimrattanabovorn et al, 2018).

Criteria	Mean ± SD		
	COD	Turbidity	Color
CF+UF	60.30 ± 13.90	82.66 ± 7.21	84.80 ± 5.10
CF	54.40 ± 15.77	71.28 ± 9.65	77.06 ± 11.91
UF	38.25 ± 14.19	38.92 ± 15.15	21.21 ± 8.87

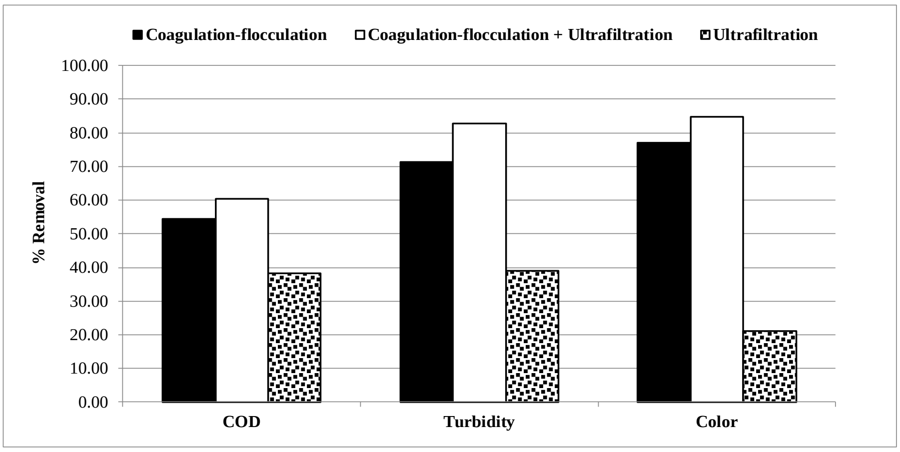

Fig. 2. Comparison removal efficiency of three alternatives water reclamation processes

Table 4 The pairwise comparison of COD turbidity and color of three alternatives

System	Pairwise Comparisons									Priority Weights		
	COD			Turbidity			Color					
	CF+UF	CF	UF	CF+UF	CF	UF	CF+UF	CF	UF	COD	Turbidity	Color
CF+UF	1	3	5	1	3	5	1	3	5	0.63	0.63	0.63
CF	1/3	1	3	1/3	1	3	1/3	1	3	0.26	0.26	0.26
UF	1/5	1/3	1	1/5	1/3	1	1/5	1/3	1	0.11	0.11	0.11
Total	1.53	4.33	9.00	1.53	4.33	9.00	1.53	4.33	9.00	1	1	1

Determine the relative importance of the sub-criteria. The capital investment in terms of capital cost, operation and maintenance cost. The capital investment of CF+UF is \$0.39/m3, CF is \$0.10/m3 (Ni et al, 2003) and UF is \$0.29/m3 (Drouiche et al, 2001). A total number of three pairwise comparisons were made to calculate the priority weights and these are shown in Table 5 capital investment for CF (0.63) higher than UF (0.26) and CF+UF (0.11), indicated that the importance of CF is more than UF and CF+UF. This implies that the CF+UF has positive features in term of capital investment.

Table 5 The pairwise comparison of capital investment of three alternatives

System	Pairwise Comparisons			Priority Weights
	CF	UF	CF+UF	
CF	1	3	5	0.63
UF	1/3	1	3	0.26
CF+UF	1/5	1/3	1	0.11
Total	1.53	4.33	9.00	1

The total priority weight of all criteria was summarized as shown in Table 6 the total priority weights of CF+UF (0.49) is higher than single CF (0.29) and UF (0.23). Thus, CF+UF is the suitable process for water reclamation in this study. The study indicates that AHP is powerful tools which can be used for implementation of appropriate water reclamation process considering the multiple objective-decisions.

Table 6 The summary of weight priority of all criteria for water reclamation alternatives assessment

System	Priority Weights of sub-criteria			Priority Weights of criteria			Total Priority Weights
	Optional Usages	Removal Efficiency	Capital Investment	Optional Usages (0.2)	Removal Efficiency (0.6)	Capital Investment (0.2)	
CF+UF	0.40	0.63	0.63	0.25	0.16	0.07	0.49
CF	0.30	0.26	0.26	0.19	0.07	0.03	0.29
UF	0.30	0.11	0.11	0.19	0.03	0.01	0.23
Total	1	1	1	0.63	0.26	0.11	1.00

4. Conclusion

The paper illustrates a comparison of three water reclamation alternative (the integration of CF+UF, single CF and single UF) have been considered with multicriteria analysis; optional usages, removal efficiencies and capital investment. The results obtained that the integration of CF+UF is the most suitable alternative for water reclamation. The study indicates that the AHP are powerful tools which can be used for implementation of appropriate water reclamation process considering the multiple objective-decisions. By doing laboratory scale studies, optional usages, removal efficiencies and capital investment criteria for full scale process can be worked out based on the engineering design and expert analysis and an appropriate water reclamation alternative can be recommended for implementation.

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WR-A21

Water-reuse concepts for industrial parks in water-stressed regions in South East Asia

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Abstract

With regard to the water shortage in several regions of South East Asia, the paper focuses on the development of a sustainable Industrial Wastewater Management Concept with the focus on Reuse (brand name: IW²MC→R) to reduce water consumption from natural resources. The IW²MC→R includes the sustainable treatment of wastewater in industrial parks to provide reuse water for different purposes. The main objective is to reach the highest possible Industrial Park Reuse Factor (IPRF). The IPRF describes the relation between wastewater inflow (IF) to the Central Wastewater Treatment Plant (CWWTP) and the outflow of reuse water for different applications. The Infrastructure Reuse Factor (IRF), one component of the IPRF, relates to infrastructural reuse applications (e.g. irrigation, street cleaning, toilet flushing). To determine the IRF, a Model Industrial Park (MIP) is applied. A first calculation resulting in an IRF of ~ 25 % includes reuse applications for irrigating green spaces, street cleaning, and toilet flushing. In case, other applications for reuse water are considered (e.g. cooling or fire fighting water), the IRF can be higher than 25 %. Thus, the IW²MC→R provides a sustainable solution strategy, especially for water-stressed regions, to drive new industrial park developments by reducing water extraction from natural resources.

Keywords: Industrial Park Reuse Factor (IPRF); "fit for purpose"; reuse water; sustainable indus-trial wastewater treatment; water-reuse concept for industrial parks; water-stressed regions in South East Asia

1. Introduction

With their megacities and urban areas, South East Asia belongs to the world's fastest-growing regions with high urbanization rates. Urbanizations have a large influence on the expansion of existing resp. the development of new industrial parks, and, vice versa, industrial park developments – especially in China – are a significant factor for urban developments (Zhao et al. 2017). Several investigations have shown the extent of spillover effects to the local environment (Zheng et al. 2017). Worldwide, industrial production plants are increasingly placed in planned industrial parks to ensure regional compatibility and the plants' special supply and disposal demands. Due to water shortage, e.g. in China and Vietnam, and increasing environmental awareness, sustainable water supply is becoming more and more important. Industrial parks, es-pecially, have high water requirements depending on their individual production plants and processes, and also need water for infrastructural purposes, such as street cleaning or irrigation of green spaces. Especially in water-stressed regions, industrial water demand increasingly competes with municipal and agricultural water demand, often resulting in the limitation of industrial expansions. Therefore, the development of new sustainable water-reuse concepts for industrial parks to reduce their high water consumption from natural resources is an important approach to enable more flexible and sustainable industrial park developments, especially in regions with high water-stress indices (e.g. western parts of China and northern parts of Vietnam).

This paper presents the development of an innovative, sustainable Industrial WasteWater Management Concept with the focus on Reuse (IW²MC□R). The con-cept includes the sustainable treatment of wastewater in industrial parks to provide reuse water for different infrastructure purposes such as water for irrigation, street cleaning, and toilet flushing.

To accomplish the goals of a sustainable IW²MC→R, the following parameters and requirements have to be considered resp. achieved:

- The Industrial Park Reuse Factor (IPRF), describing the relation between wastewater inflows (IF) to the CWWTP and the reuse water outflows for various reuse applications, should be higher than > 25 %.
- The energy consumption of the CWWTP plus Water Reuse Plant (WRP) is less or equal to that of the Central Water Treatment Plant (CWTP). The energy required for the conveyance and treatment of raw water and the subsequent distribution typically is in the range 0.35 – 2.8 kWh/m³, depending on the water source and specific regional parameters. In case, desalination is applied, the energy demand increases to more than 5 kWh/m³ (Lazarova et al 2012).
- Via area-saving construction, thus reducing the consumption of land, the WRP is assumed to take up no more than an additional 10 % of the area of the CWWTP.
- The treatment processes are to be optimized in order to reduce the consumption of resources (e.g. via biological phosphorus removal instead of precipitation).
- High automation level of the treatment processes is to be achieved in order to secure a high quality level of the produced reuse water.

The Infrastructure Reuse Factor (IRF), one component of the IPRF, relates to the infrastructural reuse applications (e.g. irrigation, street cleaning, toilet flushing). A first calculation results in an IRF of ~ 25 %, indicating that the IPRF can be even higher than 25 % in case, further reuse applications are considered. The reuse water undergoes an optimized wastewater treatment process according to the principle “fit for purpose” depending on the intended application. Thus, the energy consumption of CWWTP and WRP are reduced. Low consumption values are achieved by applying optimized aeration technologies, which account for up to 70 % of the total energy requirement of an activated sludge process (ASP; Jenkins and Wanner 2014). Furthermore, nitrification/denitrification is not required when treating water for irrigation, thus reducing the energy consumption up to 40 % (Wagner 1992). In addition, the oxygen transfer can be reduced by installing particularly deep reactors/tanks, using the reactor design to reduce area requirement at the same time. The latter is particularly important due to the restricted availability of space for treatment plants (Ranade and Bhandari 2014). Available space is preferably used for the construction of production plants, indicating the necessity of optimizing the different treatment processes in order to reduce land consumption by CWWTP and WRP and thus ensure the sustainability of the IW²MC→R. Applying membrane processes, is another measure to reduce land consumption. Due to the low inflow loads from the CWWTP to the WRP, the dimension of the latter is assumed to take up no more than an additional 10 % of the area of the CWWTP. Another positive side effect of optimizing treatment processes and thus increasing the sustainability of the concept, refers to the reduction of resource consumption (e.g. via biological phosphorus removal instead of precipitation). A high automation level of the treatment processes (e.g. online measurement and smart glasses for maintenance) in connection with disinfection of the treated wastewater secures a high quality level of the produced reuse water.

2. Methods for developing an innovative, sustainable water-reuse concept - Identification of typical industrial park systems via investigations in China

In order to identify water-reuse applications and thus enable the development of the sustainable IW²MC→R concept, several investigations in South East Asia were carried out to get an overview on the existing industrial park systems. Inter alia, the water supply situation, current wastewater treatment systems, and potential water-reuse applications were analysed. The analysis of different case studies, on the one hand, included interviews with technical and managing experts from water supply and wastewater treatment plants and, on the other hand, on-site visits of industrial parks in China and Vietnam. Furthermore, interviews with German industrial park experts were conducted.

The focus of the investigations was on China as it was chosen as case study for subsequent analyses and calculations (see chapter 3). A first result of the investigations is that in China, parks with diverse industries are much more common than thematic parks. In addition, China is particularly dynamic in developing greenfield areas as new industrial park locations. Furthermore, due to the uneven distribution of natural water resources and the partly high levels of pollution of waterbodies, water shortage is a challenge in South East Asian countries (see e.g. water-stress index for China (WRI, 2018)). In addition, China is, besides the United States, the country with the worldwide highest water usage for industrial purposes (FAO 2017). This is, inter alia, related to the large sizes of industrial parks in China with an average of 1,188 ha (concerning eight cities: Beijing, Shanghai, Shenzhen, Dialian, Tianjin, Xi’an, Chengdu, and Wuhan) (Zheng et al. 2017: 83). In comparison, the average size of industrial parks in Vietnam is approx. 300 ha (own investigation on 24 parks and MPI 2017).

Based on the investigations in China, Vietnam, and Germany, two typical industrial park systems regarding wastewater treatment (see figure 1) can be deduced. In both systems, the CWTP uses groundwater, surface water, or tap water as raw water source and usually provides three different water qualities: drinking, industrial, and deionized water. Wastewater from the different production plants is treated in a park-internal CWWTP, which, subsequently, discharges the treated water, e.g. into the receiving water body. In case of highly polluted wastewater, production plants have their own on-site pre-treatment. A decisive difference between the park systems is that the production plants discharge their wastewater either into one collective sewer (see industrial park system 1) or in separate sewers (see industrial park system 2) for conveyance to the CWWTP. System 2 enables a more precise control of the quality of wastewater inflows from each production plant to the CWWTP. Another advantage of separate sewer systems is the higher operational stability of the CWWTP in case of an accident in one of the production plants. Highly polluted or toxic wastewater can be separated immediately, thus avoiding production stoppage etc. at other production plants. However, at present, System 2 is rare in industrial parks. Obviously, the application of cross-company reuse water is currently also not common.

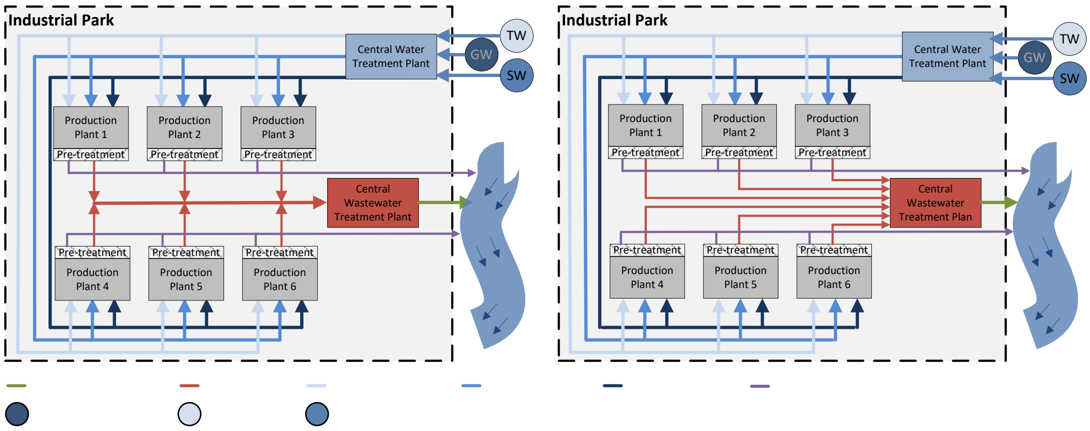

Fig. 1. Typical industrial park systems (Source: own figure - not to scale)

3. Results and Discussion: IW²MC→R as solution strategy for water-stressed regions for driving new industrial park developments, using China as case study

The development of the IW²MC→R is based on the results of the investigations (see chapter 2) and includes two different water-reuse approaches. The case study of China is particularly suitable due to the differences in the water-stress level investigated during the country comparison of China, Vietnam, and Germany (see chapter 2). Thus, Chinese data, e.g. guidelines and governmental regulations, serve as a basis for the following results. Table 3 The COD, Turbidity and color removal efficiency of three alternative (Yimrattanabovorn et al, 2018).

3.1 The general idea of the Industrial Waste Water Management Concept with focus on Reuse (IW²MC→R)

The development of the innovative sustainable IW²MC→R is based on the two existing industrial park water systems described above. The concept includes the sustainable treatment of wastewater in a CWWTP as well as the supply of reuse water for different purposes via a Water-Reuse Plant (WRP) (see figure 2). The IW²MC→R aims at the highest possible Industrial Park Reuse Factor (IPRF) (see chapter 1). Therefore, on the one hand, the IPRF includes the Infrastructure Reuse Factor (IRF), which relates to the infrastructural reuse applications, e.g. water for irrigation, street cleaning, and toilet flushing (see calculation in chapter 3.4). On the other hand, the IPRF includes the Production Plant Reuse Factor (PPRF), whereby it is possible to calculate the water-reuse applications for the Production Plants (PP), e.g. for process water.

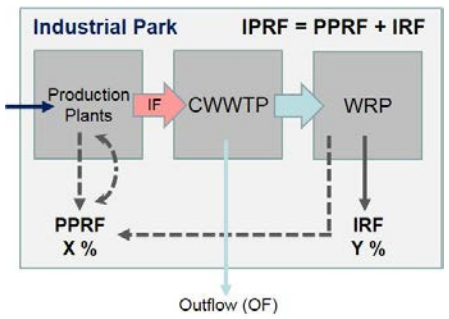

Fig. 2. IW²MC→R - Calculation of the IPRF (Source: own figure – not to scale)

3.2 The two water-reuse-approaches of the IW²MC→R

Referring to the typical industrial park systems, the IW²MC→R can be specified into two different water-reuse approaches. Both approaches are based on the current wastewater treatment systems in an industrial park including the existing layout of pipes and sewers.

Water-reuse approach 1 (see figure 3) is linked to the first typical industrial park system, where wastewater is discharged to the CWWTP in one joint sewer system. Regarding the CWWTP, this system only allows few options of optimization. Due to the combined collection of wastewater from different productions in one sewer system, treatment systems have to be diverse and flexible to enable the handling of changing wastewater volume flows resp. qualities as well as meet the required discharge qualities. In such a case, common treatment concepts for industrial wastewater mostly provide for a 4-step process chain. Step 1 includes the so-called head works, i.e. mechanical treatment processes, such as grates, sieves, and sand trap, etc. Step 2 consists of mixing and expansion tanks with the potential connection of a neutralization unit if need be. Precipitation and flocculation are carried out in Step 3. The biological wastewater treatment unit, Step 4, is the key component of the treatment chain. Worldwide, the activated sludge process still is the preferred process due to its robustness and adaptability. Caused by the mostly successive development of industrial parks, the number of treatment tracks often is identical to the number of development phases of the overall industrial park. Due to the joint sewer system of all productions and the resulting mixing of wastewater flows, treatment tracks normally are of identical design. Splitting the treatment steps, particularly the biological unit, into several tracks offers the advantage of increased flexibility and robustness in case of malfunction.

Water-reuse approach 2 of the IW²MC→R, based on the typical industrial park system 2 (see figure 3), discharges the wastewater from the several production plants within parallel sewers to the CWWTP. Compared to System 1, this design already enables an optimized operational management of the CWWTP. Optimization potentials start with the specific selection and mixing of wastewater partial flows. For example, alkaline and acidic partial flows could be neutralized when mixed. According to the IW²MC→R, the further classification of the wastewater flows depends on their biological treatability. Wastewater only loaded with organic compounds is treated in a biological treatment unit that is designed for carbon elimination only. Wastewater heavily polluted with nitrate, e.g. from fertilizer production, is treated in a treatment unit with denitrification only. In this case, wastewater partial flows heavily loaded with organic compounds can be used, if need be, as organic carbon source, dosed via a bypass. The same applies to wastewater partial flows loaded with ammonium resp. phosphorus. This way, the biological treatment unit as key process component of all treatment tracks and the step with the highest energy demand and costs, at the same time, could be optimized via a specific design concept. In case, wastewater partial flows cannot be treated biologically, they are treated in a separate treatment track. Such is the case for wastewater with (very) high salt concentrations resp. high concentrations of non- resp. poorly degradable compounds. They could be treated in a desalination unit (e.g. via reverse osmosis (RO)) or be incinerated, provided amounts and required efforts are in a reasonable relation. Further wastewater partial flows are to be treated in the respective treatment tracks according to their constituents. Thereby, the compliance with the required discharge qualities is top priority.

In addition, the IW²MC→R concept provides for the pre-treatment of wastewater partial flows in case of high pollution load, before being allowed into the CWWTP. For example, wastewater from paint and lacquer production often are highly loaded with heavy metals and/or non- resp. poorly degradable COD, and mostly contain high concentrations of inorganic solids. In such cases, heavy metals are removed by precipitation. Poorly degradable COD is pre-treated via oxidation processes (AOP process) before entering the biological treatment unit. Inorganic solids are usually removed via filters.

In both systems, the discharge from the CWWTP is further treated within separate units in the WRP. The treatment tracks differ in their composition depending on the different discharge qualities to be achieved, which in turn depend on the intended use of the water treated in the WRP and associated requirements, such as technical codes or legal guidelines (see chapter 3.3). Water for irrigation purposes, for example, could be treated via Anaerobic Membrane Bioreactor (AnMBR). Organic matter and solids are retained, while nitrogen and phosphorus, as essential nutrients for plants, are preserved. In this case, it is also conceivable to charge the AnMBR with the inflow of the CWWTP biological unit via a direct bypass. This way, the conventional aerobic treatment within the CWWTP is evaded, thus further reducing energy consumption and costs for nutrient elimination, which is unwanted here. In case, water is treated to be used for toilet flushing resp. street cleaning, thus requiring nutrient elimination, a conventional membrane bioreactor (MBR) might be applied. This process offers the advantage of the total retention of all solids and a (limited) disinfection effect while showing high process robustness, at the same time. In addition, this process module shows little land usage, caused by high potential biomass concentration and accompanying high volume turnover.

When looking at the requirements for the different water usages, one can identify different process technologies often to be used in the WRP, as well. Fine screens and sieves are crucial within the so-called head works. This mechanical equipment is necessary in order to protect the downstream process units against clogging/damage (especially MBRs). In addition, due to the mostly discontinuous loading of wastewater resp. withdrawal of treated water for respective applications, storage and expansion tanks are required at the inflow and outflow of each treatment track. As the application of the treated wastewater demands high standards regarding hygienic parameters, a disinfection unit is needed at the end of each treatment track within the WRP.

Figure 3 gives a conceptual overview of the two described water-reuse approaches whereby it should be remarked that the illustration is not to scale. Due to the low inflow loads from the CWWTP to the WRP, the dimension of the latter is assumed not to be more than an additional 10 % of the area of the CWWTP. With the opportunity of taking reuse water instead of treated raw water (e.g. drinking water) the needed size/capacity of the CWTP can also be reduced, at least those treatment steps, where dimensions are directly related to the water flow.

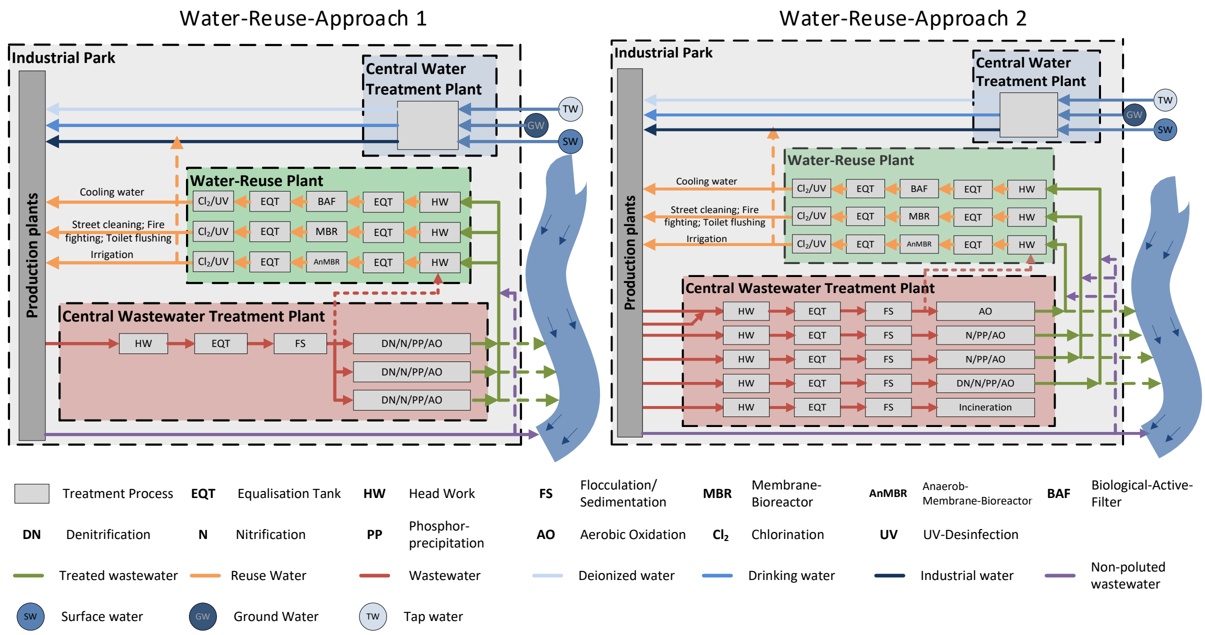

Fig. 3. Two different water-reuse approaches of the sustainable IW²MC→R
(Source: own figure – not to scale)

3.3 Guidelines and requirements for reuse applications in industrial parks in China

For the developed IW²MC→R, the principle "fit for purpose" plays an important role, i.e. reuse water should be provided in different qualities referring to the subsequent use. As the reuse water quality is a question of governmental regulation, this chapter will give a short overview of prescribed Chinese quality standards.

Generally, the central government of China has great ambitions to encourage water-reuse solutions throughout the country. This is why there are already many policies, regulations, and standards on water-reuse to enhance further developments in this field (Lyu et al. 2016; Rodrigues 2014).

As the IW²MC→R focusses on industrial parks and their internal infrastructures, two standards are particularly relevant. The "Water quality standard for urban miscellaneous water consumption" (GB/T 18920-2002) contains quality requirements for the purpose of toilet flushing, street cleaning, firefighting, irrigation, vehicle washing, and construction (extract see table 1). The standard addressing industrial usage, in particular, is the "Water quality standard for industrial water consumption" (GB/T 19923-2005). In this standard, requirements relating to reuse water qualities for cooling water, washing water, boiler feed water, and process/product water are prescribed. For calculating the IRF in this study (see chapter 3.1 and 3.4), three reuse purposes were taken into account. Their quality parameters are listed in table 1 and are the basis for the selection of the treatment processes in the WRP (see chapter 3.2).

Table 1 Overview of reuse water quality requirements due to potential reuse purposes in industrial parks as an example (Source: GB/T 18920-2002)

Parameter		Toilet flushing	Street cleaning	Irrigation
pH	≤		6.0 - 9.0	
Color	≤		30	
Olfactory			no odor	
NTU	≤	5	10	10
TDS [mg/L]	≤	1,500	1,500	1,000
BOD_5 [mg/L]	≤	10	15	20
NH_4-N [mg/L]	≤	10	10	20
LAS [mg/L]	≤	1	1	1
Fe [mg/L]	≤	0.3	---	---
Mn [mg/L]	≤	0.1	---	---
DO [mg O_2/L]	≤		1	
Total residual chlorine [mg Cl/L]			contact 30 min later ≥ 1.0, end point of pipe network ≥ 0.2	
Total coliforms [L^{-1}]	≤		3	

3.4 Calculation of the IRF for industrial parks in China

In order to initiate the described concept in industrial parks, the main task is to identify quantities and qualities of existing water flows (wastewater register and water demands) as well as suitable treatment technologies for linking these flows (see chapter 3.2). The use of an exemplary MIP offers, in contrast to the calculation of wastewater and water-reuse flows from real industrial parks, the possibility of modifying production types and allows using supplementary expansion areas to analyse the framework conditions that lead to the highest possible IPRF (see chapter 3.1).

The paper, in a first step, focusses on the calculation of the IRF, which is part of the IPRF, to estimate the potential of different infrastructural water-reuse applications. An MIP, including 6 different exemplary PP, serves as a basis for this calculation. As chemical, food, and beverage industries are among the industries with the worldwide highest water consumption rates, six production types from these sectors were chosen (see table 2) to determine the MIP's total wastewater quantity. Thus, the first calculation refers to an industrial park with different industries. On the basis of the European Best Available Techniques Reference Documents (BREFs) and other literature references (e.g. Rosenwinkel et. al. 2015) data was collected for the selected production processes with regard to their wastewater flows. The unit of the given data usually was m³/ ton of product resp. kg/ ton of product (see table 2). Thus, to get the wastewater flows in m³/d, production capacities of the exemplary production plants had to be determined. Therefore, real production facilities in China were investigated to provide these data. As sanitary wastewater is discharged into the CWWTP, as well, it is calculated with 50 L/employee×day according to the Chinese standard GB 50015-2003.

Table 2 Calculation of wastewater flows in the MIP, example of China (Source: own figure)

	Wastewater values	Production capacity due to example plants in China or data referring to the MIP	Calculated wastewater flows in m³/d
H_2O_2 production	1.5 m³/t product	230,000 t product/a	945
Polystyrene production (GPPS)	1.1 m³/t product	300,000 t product/a	904
Chlorine production	0.62 m³/t product	215,000 t product/a	365
Superphosphate production	1.25 m³/t product	850,000 t product/a	2,914
Production of soft drinks	1.56 m³/1000L product	600,000,000 L product/a	2,564
Butchery (cattle)	0.95 m³/cattle	100,000 cattle/a	260
Sanitary wastewater	50 L/employee×day	11,180 employees in the MIP	559
		Sum Wastewater flows	**8,511**

For the dimensioning of the MIP, average values for different parameters were taken into account from 12 investigated industrial parks in China. As the example plants in the MIP are mainly from the chemical sector, the parks were chosen according to the presence of chemical industry. Data on industrial park size, number of companies, number of employees and the percentage of road and green spaces were analysed for each park. To determine the park size of the MIP with 6 PP, the average site size per company (in ha) was calculated by dividing the park size of the investigated parks through the number of companies, assuming that the park areas are fully occupied by production plants (no free construction areas) and the area is evenly distributed. The achieved data should therefore be regarded as a first approximation to be verified via real production plant sizes with their respective capacities. The calculated average size was multiplied by the number of 6 PP for the MIP, resulting in a park size area of 260 ha. The number of employees in the different parks divided by the respective park size was the second essential average value (employees/ha) to be gathered from the investigated parks. The number of employees in the MIP was calculated by multiplication with the MIP park size. This value is needed for the calculation of the sanitary wastewater flow and the water demand for toilet flushing. The water demand for irrigation depends on the area of green spaces within the MIP in correlation to the specific water demand value. According to a governmental regulation, green spaces have to take up at least 20 % of the park area (MoHURD 1994). The Chinese standard GB 50282-2016 (average see table 3) states the typical water demand range for irrigation. Based on the mentioned governmental regulation, it is possible for municipalities to specify these regulations. For example, the municipality of Shanghai determines 20 % of green spaces as a minimum for industrial parks. In case, newly-built plants produce toxic resp. harmful gases, the area of green spaces must not be below 30 % of the total area of the industrial park (RSMGW 2007). Other municipalities have even more restrictive regulations. For example, the municipality of Changchun in general sets a minimum of 25 % of green spaces for industrial parks and in case, there is production of toxic resp. harmful gases, the percentage rises to 40 % (RCMGW 2014).

For calculating the water demand for irrigation, the average value of the indicated range given in GB 50282-2016, i.e. 2.0 L/m²×day, was taken into account. To determine the water demand for road cleaning, the overall area of roads and the required water demand per m² is relevant. Aerial photographs were analysed, resulting in an overall road space of ~ 9 % of the park area. The findings were verified by interviews with management staff of industrial parks. Regarding the water demand, the average value of the indicated range of GB 50282-2016 was taken into account as basis for the calculation, i.e. 2.5 L/m²×day. To determine the water demand for toilet flushing, 80 % of the estimated overall sanitary water (50 L/employee×day) are assumed to be toilet flushing water, whereas 20 % are assumed to be used for washing hands, tea kitchens, and occasional showers. Based on these analyses, the reuse water demand for irrigation of green spaces, street cleaning, and toilet flushing within the MIP were calculated (see table 3).

Table 3 Calculation of the reuse water demand in the MIP, example of China (Source: own figure)

	Water demand values	**Data referring to the MIP**	**Calculated reuse water demand in m³/d**
Toilet flushing	40 L/employee×day (= 0.8×50L)	11,180 Employees in the MIP	447
Street cleaning	2.5 L/m²×day	23 ha (= 0.09×260ha)	585
Irrigation of green spaces	2.0 L/m²×day	52 ha (= 0.2×260ha)	1,040
		Sum reuse water demand	**2,072**

Including the described indicators, calculations, and assumptions for the exemplary MIP with 6 PP in China, the result is an IRF of ~ 25 % (wastewater flows: 8,511 m³/d; reuse water demand: 2,072 m³/day; see table 4), considering the reuse water flows for irrigation of green spaces, street cleaning, and toilet flushing. This means, 25 % of the wastewater can be used to generate reuse water, thus reducing the raw water demand considerably. According to the considered treated raw water flows, an IRF of 25 % results in a water-saving potential of ~ 18 % (treated raw water flow: 11,279 m³/d; reuse water demand: 2,072 m³/day). In addition, the energy requirement of the CWTP can be reduced, as well (see Table 4).

Table 4 Exemplary calculation of the energy demand (Source: own figure)

Water flows	Units	Without Reuse	With Reuse
Treated raw water flow (drinking and deionized water)**	m³/d	11,279	9,207
Wastewater flow	m³/d	8,511	8,511
Reuse-water flow	m³/d	-	2,072
Energy requirement	**spec. values* (kWh/m³)**	**Total requirement (kWh/d)**	**Total requirement (kWh/d)**
CWTP			
Raw water conveyance	0.5	5,640	4,604
Raw water treatment	1	11,279	9,207
Treated raw water distribution	0.1	1,128	921
CWWTP and WRP			
Waste water treatment CWWTP	0.6	5,107	5,107
Reuse water treatment WRP	1	-	2,072
Reuse water distribution	0.1	-	207
Total energy requirement		**23,153**	**22,117**

*assumption according to Lazarova et al (2012)
**without industrial water e.g. for cooling

The findings described above illustrate the high potential of the IW²MC→R for China. By including only three water-reuse options, there is already a high water-saving potential. In case, further water-reuse options are taken into account (e.g. cooling resp. firefighting water), the IRF could be even higher. In China, especially in regions, where rainfall is very rare, the average water demand for irrigation and street cleaning is higher than the used average value, thus increasing the IRF. In regions with a lower water-stress level, differences between dry and rainy seasons have to be considered.

The calculation of the energy demand (see table 4) makes clear that by relieving the CWTP via a high IRF, the overall energy demand is reduced, despite a higher specific energy demand for CWWTP und WRP (1.7 kWh/m³) than for the CWTP (1.6 kWh/m³). When considering the specific energy demand for the treatment and distribution of reuse water in the WRP (1.1 kWh/m³), it becomes apparent that wastewater presents an attractive raw water source, which, in this case, is even more energy efficient than the production of water in the CWTP from sources outside the park. This means that with increasing IRP, the relative energy saving (currently ~ 4 %) increases further. These findings are in line with the general experience that wastewater often presents a cost- and energy-efficient source for raw water, this especially in case of natural raw water sources of poor quality resp. in case of long transport routes (Lazarova et al 2012).

4. Conclusion

The IW²MC→R, in general, represents a sustainable solution strategy for industrial parks by providing reuse water for different purposes. Considering the three water-reuse applications (irrigation of green spaces, street cleaning, toilet flushing), the calculated value of the **IRF** is **~ 25 %**, which is fairly high, especially in water-stressed areas. As a result, the water-saving potential is ~ 18 %. Considering the expansion of water-reuse applications towards cooling and firefighting water, IRF and water-saving potential will be even higher, further increasing the benefits of realizing/implementing the concept. A calculation of the energy consumption shows that energy can be saved by using reuse water. Savings even increase with increasing IRF.

Evaluating the two different water-reuse approaches and the consequently different designs of the treatment processes, advantages and disadvantages became apparent. The potential of optimization, seen from the perspective of industrial park operators resp. planners, regarding treatment processes, both in the CWWTP and in the WRP, increases enormously if the individual wastewater partial flows of the production plants are collected and conveyed in separate sewer pipes, compared to the approach with one sewer system, where all wastewater partial flows are mixed. In the first case, treatment tracks can be constructed to fit precisely, thus reducing energy and land requirements as well as the use of resources to a minimum.

Currently, systems with only one sewer to the CWWTP are the most common in industrial parks, which is why in this case the implementation of the first approach is probably more expedient as for avoiding higher investment costs. Both solutions provide reuse water according to the principle “fit for purpose”. Further analyses will be carried out to determine which of the two water-reuse approaches of the IW²MC→R is the most suitable for existing resp. new parks. In addition, the MIP can be used to investigate whether industrial parks with diverse industries and thus diverse wastewater flows and water demands or thematic parks with similar industries offer better framework conditions for the two reuse approaches.

Hence, due to the different water-reuse approaches, the IW²MC→R provides an adaptable sustainable solution strategy. Clear benchmarks for area and energy consumption have been defined for this purpose. Therefore, especially in fast-growing and water-stressed regions, the application potential of this concept is very high to enable the construction of new and the expansion of existing industrial park locations. For the successful implementation of these concepts in respective countries, a supportive government is essential as well as clear regulations for water reuse, e.g. regarding water quality requirements for different purposes. China therefore offers particularly suitable framework conditions.

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Wastewater Reuse in Turkey: From Present Status to Future Potential

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Abstract

Turkey is not a water rich country in terms of existing water potential. The amount of available water is about 112 billion m^3. While Turkey uses 32 billion m^3/year water for agricultural irrigation (73% of water use) but aims to reduce this ratio to 64% in 2023, along with agricultural water needs of 72 billion m^3/year. In addition, Turkey uses 5 billion m^3/year for industry in 2012, it is expected to use 22 billion m^3/year of water in industry in 2023. With the present water potential and sectoral water use rates, Turkey should perform key administrative and technical regulations in the coming years in the reuse of treated wastewater area. In 2017, the Ministry of Environment and Urbanization initiated an important project, "Reuse of Treated Wastewater in Turkey". With this project, all wastewater treatment plants (WWTPs) were investigated for determining the wastewater reuse purposes for the first time. According to the results from this project, although there are 26 WWTPs with the different capacities of reuse facility, only 15 of them realized reuse in 2017. The amount of water recovered and reused from domestic/urban WWTPs was determined as 29.6 million m^3. Accordingly, the reuse rate of domestic wastewater in Turkey is defined as 0.78%. This paper aims to give an overview of wastewater reuse activities from present status to future potential in Turkey and the opportunities and challenges in expanding water reuse. The status of wastewater treatment plants, the distribution of various treatment processes, treatment processes and their compliance with the WWTPs where reuse are carried out in Turkey, are evaluated in this study. The realization of the planned goals and challenges are discussed after regulatory changes for reclaimed wastewater and reuse targets in Turkey for 2023.

Keywords: Irrigation, Treatment Plants; Water Reuse; Wastewater

1. Introduction

Turkey is not a water rich country in terms of existing water potential. Approximately 1400 m^3 fresh water per capita is available annually for water consumption. Turkish Statistical Institute (TSI) has estimated that the population will reach 100 million and water availability in Turkey will fall 1120 m^3 per capita by 2030. The total, technically and economically usable surface and ground water potential of Turkey is around 112 billion m^3, with 96 billion m^3 (86%) coming from rivers located within Turkish borders, 3 billion m^3 (3%) from external rivers originating outside the country borders and 12 billion m^3 (11%) from groundwater resources. Water resource potential of Turkey is given in Table 1. Turkey is situated in a semi-arid region and water demand increases with population growth, industrialization, urbanization and rising affluence. Actual water consumption in Turkey is 73% of usage dedicated to agricultural irrigation, 16% of usage for domestic purposes and 11% of usage for industrial sectors (www.dsi.gov.tr).

Table 1 Water resources potential of Turkey (www.dsi.gov.tr)

Source	Value
The average annual rainfall	643 mm/year
Total land area of Turkey	783.577 km^2
Annual rainfall	501 billion m^3
Evaporation	274 billion m^3
Ground water infiltration	41 billion m^3
Surface water	
Annual runoff	186 billion m^3
Available surface water	98 billion m^3
Ground-water	
Annual amount of potable water	14 billion m^3
Total available water (net)	112 billion m^3
Development status	
Used in irrigation	32 billion m^3
Used in drinking water	7 billion m^3
Used in industry	5 billion m^3
Total water consumption	44 billion m^3

The sectoral distribution of water use according to the development levels and industrial water usage in Turkey in comparison with other countries are given in Fig. 1. While Turkey uses 32 billion m^3/year water for agricultural irrigation (73% of water use), but aims to reduce this ratio to 64% in 2023, along with agricultural water needs of 72 billion m^3/year. In addition, Turkey uses 5 billion m^3/year for industry in 2012, it is expected to use 22 billion m^3/year of water in industry in 2023. With the present water potential and sectoral water use rates, Turkey should perform key administrative and technical regulations in the coming years in the reuse of treated wastewater area.

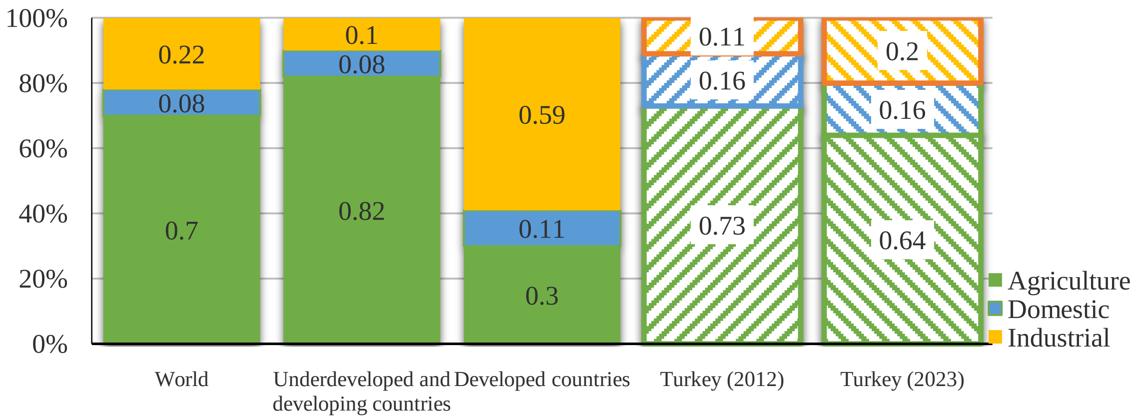

Fig. 1. Sectoral water use and distribution according to the country's level and Turkey's position.

The AQUAREC Project (2006), supported by the European Union (EU), has developed a model to estimate the reuse of treated wastewater in the EU. The current reuse of treated wastewaters in 2000 and potential reuse amounts in 2025 was determined with the model (TYPSA, 2013). According to the model results, it is seen that Turkey can take place in the ranking for potential reuse in number 4 after Spain, Italy and Bulgaria in 2025 with 287 million m^3 water reuse per year in the EU. When evaluating this potential, the execution of important projects and researches for the reuse of treated wastewater can be foreseen in the coming years in Turkey. Turkey has already launched two important projects after seeing this potential in the reuse of wastewater.

This paper aims to give an overview of wastewater reuse activities from present status to future potential in Turkey and the opportunities and challenges in expanding water reuse. The status of WWTPs, the distribution of various treatment processes, treatment processes and their compliance with the WWTPs where reuse are carried out in Turkey, are evaluated in this study. In addition, the current legislation in Turkey, and recent developments in the planned legislative changes are presented in this study. The realization of the planned goals and challenges are discussed after regulatory changes for reclaimed wastewater and reuse targets in Turkey for 2023.

2. Wastewater Treatment and Water Reuse Status of Turkey

Turkey's Ministry of Environment and Urbanization has carried out a major project in 2016 to determine the status of the wastewater treatment in the country including the efficiency and operational problems of domestic wastewater treatment plants in the whole country. Within the scope of "Determination of the Current Status of Domestic / Urban Wastewater Treatment Plants and Determining the Need for Revision (TURAAT)" project, it has been determined that Turkey has 1015 domestic wastewater treatment plants either in operation or under construction and 10.5 million m^3/day wastewater is treated daily (TURAAT, 2016). According to the TÜRAAT project, the proportion of treated wastewater is 82.9% generated by municipalities. In 2018, this rate increased to 85%. Turkey's target rate with municipality's wastewater treatment is 100% in the year of 2023. Fig. 2 shows the amount of wastewater treated in domestic / urban WWTPs in 2015.

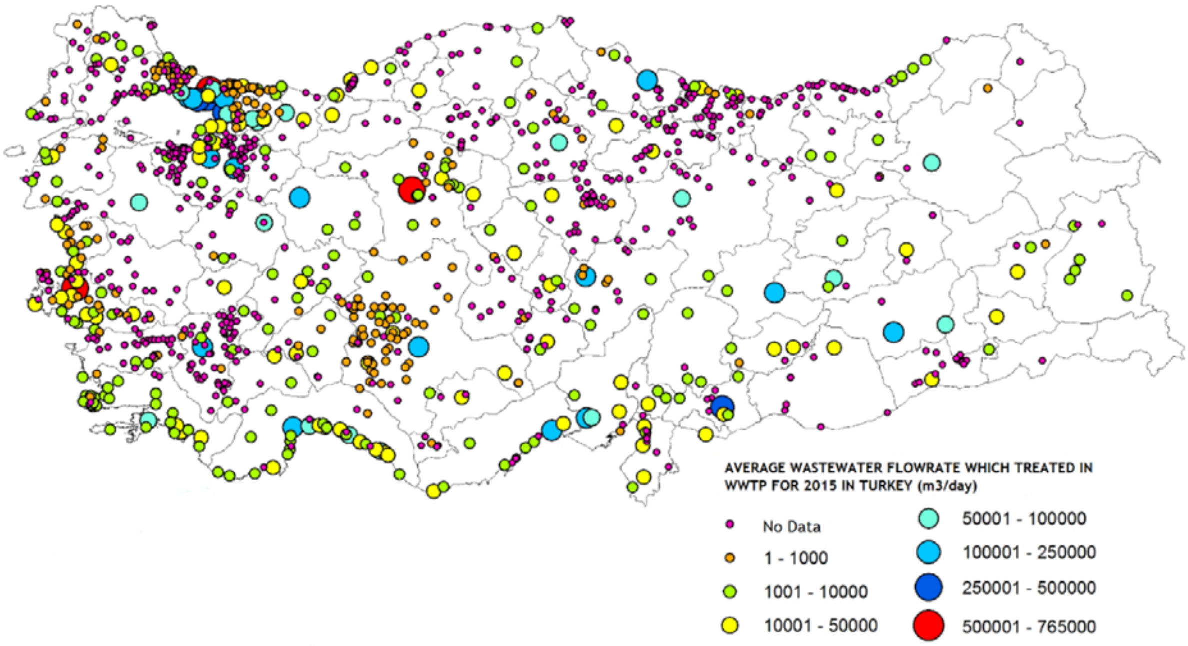

Fig. 2. Amount of wastewater treated in domestic / urban WWTP's throughout the country (TURAAT, 2016).

In 2017, the Ministry of Environment and Urbanization initiated the second important project, "Reuse of Treated Wastewater in Turkey". With the project, it is aimed to investigate the national and international practices and standards for the reuse of wastewater for urban and industrial wastewaters and to propose technical and administrative criteria for establishing the legal framework for the reuse of treated wastewater specific to Turkey. With this project, all WWTPs were investigated for determining the wastewater recovery and reuse purposes for the first time. According to the results from this project, although there are 26 WWTPs with the different capacities of reuse facility, only 15 of them realized reuse in 2017. The amount of water recovered and reused from domestic/urban WWTPs was determined as 29.6 million m^3. Accordingly, the reuse rate of domestic wastewater in Turkey is defined as 0.78%. In 2016, the province of Kocaeli has an important share in Turkey with a ratio of 57.8% according to the recycled water rates in WWTP's. Koceli is followed by İstanbul with a rate of 19.2%. The other provinces that have wastewater recovery are; Bursa, Antalya, Konya and Mugla (Fig. 3).

In Turkey, industrial reuse of treated domestic wastewater is the first with 56.8% ratio, followed by 16.3% environmental / ecological reuse, in-plant reuse with 6.4% (green area irrigation, processes, washing etc.) and urban reuse (green area irrigation) with 2.6% (Fig. 4). Wastewater reuse applications in agriculture are done rather indirectly by withdrawing river downstream or lake water from discharged effluent of WWTPs. Reuse of treated wastewater from the domestic WWTPs for planned agricultural irrigation purposes is not currently available. Reuse applications in water deficit industrial regions is the highest in Turkey due to water shortages and high-water rates compared to other areas.

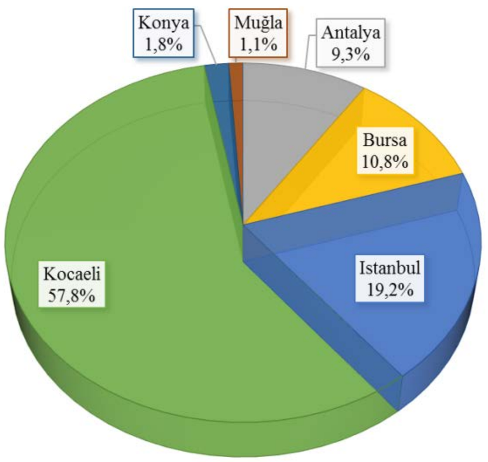

Fig. 3. The provinces which makes wastewater recovery in Turkey.

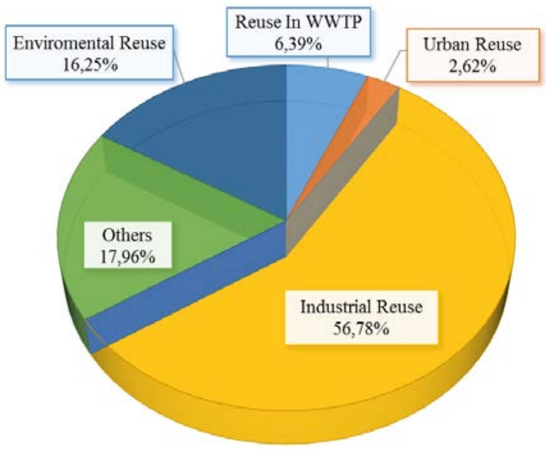

Fig. 4. The distribution of the treated wastewater reuse in Turkey

Fig. 5 shows the distribution of tertiary treatment process existed in 26 WWTP built for waste water recovery purposes in Turkey. When the recycling processes in the country are examined; there are 15 UV disinfection, 8 pressure sand filter, 7 chlorination, 5 rapid sand filter, 5 mechanical filter, 3 disc filter, 3 MBR, 2 active carbon, 2 ultrafiltration, 1 ozone disinfection, 1 multimedia sand filter, 1 cartridge filter.

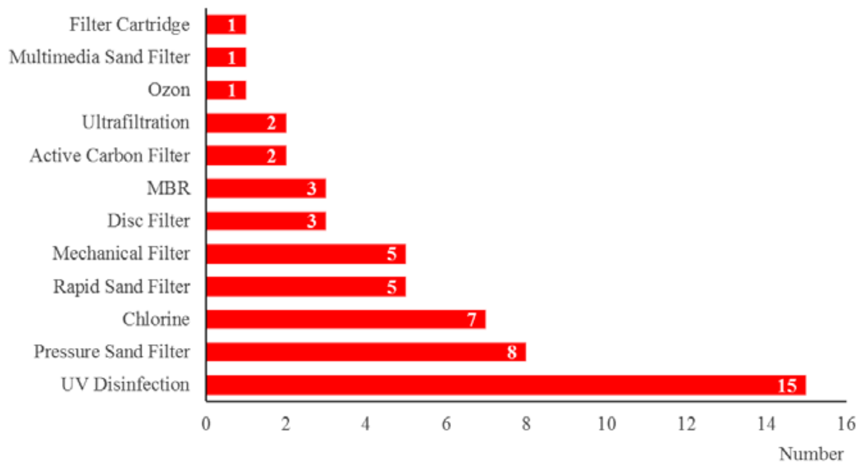

Fig. 5. The distribution of the 3rd stage treatment processes constructed to gain wastewater reuse across the country

In Turkey, the following processes for the purpose of reuse in the wastewater treatment plants can be seen.

- Pressurized multimedia sand filter + UV disinfection
- Pressurized multimedia sand filter + Chlorine disinfection
- Pre-chlorination + Pressurized multimedia sand filter + UV disinfection + Final chlorination
- Pressurized multimedia sand filter + Activated Carbon + UV disinfection
- Pressurized multimedia sand filter + Ultrafiltration + Chlorine disinfection
- Rapid Sand Filter + UV disinfection
- Rapid Sand Filter + Chlorine disinfection
- Mechanical Filter + UV disinfection
- Mechanical Filter + Ultrafiltration
- Disc Filter + UV disinfection
- Pre-chlorination + Pressurized multimedia sand filter + UV disinfection + Ozonation + Final chlorination
- MBR + UV Disinfection

Although there are 15 operating wastewater recycling plant in Turkey, only five of these plants can present additional operating cost of the recovery process. Wastewater recovery facilities with processes and unit treatment costs are given in Table 2.

Table 2 Unit treatment costs of reuse plants operating in Turkey

City	Plant	Recovery flow rate (m^3/day)	Process	Unit Treatment Cost* (TL/m^3)	Unit Sale Price (TL/m^3)	Reuse Area
Antalya	Gazipaşa WWTP	4.400	MBR	0,92	-	Environmental (Hacımusa stream, river flow)
Konya	Konya WWTP	3.600	Pre-chlorination + Pressurized sand filter + UV disinfection + Final chlorination	<0.2	-	Urban reuse (purple pipes network)
Antalya	Hurma WWTP	3.120	UV + Cartridge Filter	-	-	In-plant green area irrigation (Not active due to clogging of nozels)
			Coarse Filter + Mechanical Filter	0.12	-	In-plant thermal drying unit, cooling water
Kocaeli	Körfez WWTP	44.000	Rapid Sand Filter + Pressured Sand Filter	0,05	0,42	Reuse in industry
Kocaeli	Plajyolu WWTP	10.000	Rapid Sand Filter + UV	0,06	3,5	Reuse in industry
İstanbul	Paşaköy	75.000	Rapid Sand Filter + UV	0,04	-	In-plant reuse Transfer to Tuzla AAT for in-plant reuse Environmental (Riva stream, river flow)

* In the cost of unit treatment in 2017 year; electricity and chemical expense are included, maintenance, repair and personnel expense are excluded.

Examples of successful applications for the reuse of treated domestic wastewater throughout the country include:

- The Purple Pipe Network application, projected in Konya WWTP, has been in operation since 2013 with a new distribution network of 24 km for urban green area irrigation.
- Kocaeli Körfez WWTP, Kullar WWTP and Kocaeli Plajyolu WWTP are successful applications for the further treatment of treated wastewater.
- Istanbul Paşaköy WWTP is one of the successful applications for reuse as cooling water and in-plant use.
- Antalya Hurma WWTP is a successful application to produce cooling water from wastewater.
- Konacık WWTP in Muğla is selling the treated wastewater to be used in irrigation for the urban green area with the protocol made with Bodrum Municipality. In addition, the treated wastewater is sold to 120 subscribers as irrigation water.

3. Proposal of New Legislative Regulation for Reuse

Turkey began to apply wastewater reuse with the "Notification for Wastewater Treatment Plant Technical Procedures". In the seventh chapter of the Notification, prepared by the Ministry of Environment and Forestry, which entered into force on March 20, 2010, there are regulations regarding the recovery and reuse of wastewater.

According to the Notification, the requirements of the treated wastewater to be reused in irrigation, the chemical quality criteria for irrigation water, and the concentrations of the maximum heavy metal and toxic elements permissible in irrigation waters are given. The criteria contained in the Notification, published in 2010 were taken from the guidelines for water reuse by the US Environmental Protection Agency (US EPA), Guidelines for Water Reuse, 2004.

With the aim of updating the legislation applied since 2010, “Reuse of Treated Wastewater” project was carried out in Turkey.

During the preparation of legislative proposals for the reuse of treated wastewater in Turkey, below methodology has implemented.

- Examination of current national legislation,
- Evaluating the current wastewater treatment technologies, treatment efficiencies and water reuse experiences in Turkey,
- Evaluation of international experiences,
- Evaluation of developments in treatment technologies,
- Evaluation of the effects of pollutants in the wastewater on the environment and public health,
- Evaluation of legislation practices in the world (USA, EU, Singapore, Australia, Spain, Italy, France, Israel etc.),
- Detailed evaluation of the legislative arrangements of all states in the USA from Guidelines for Water Reuse, 2012,
- Determination of technical criteria for legislation specific to Turkey.

Alternative treatment technologies, water quality criteria and monitoring frequencies have been proposed for each of the different reuse categories (urban, agricultural, environmental, industrial, aquifer feeding) for the reuse of treated wastewater.

With the proposed legislative regulation, environmental reuse, industrial reuse, aquifer feeding has been discussed for the first time, in addition to the urban reuse and agricultural reuse included in the legislation introduced in 2010.

While determining wastewater recovery treatment alternatives, water quality criteria and monitoring frequencies, two matters were beard in mind. One was the promotion of Turkey's year 2023 target of 5% reuse and the other was the high-level protection of environmental and public health.

Since the criteria and values proposed by the project are still in the evaluation phase of the Ministry of Environment and Urbanization, more details cannot be given in this paper.

4. Conclusions

The Ministry of Environment and Urbanization, engaged in planning WWTP’s with the approach that WWTP’s are a source of raw materials, energy and a water recovery, has set the target of 2023 as 5% for reuse in agricultural irrigation, groundwater supply, irrigation for urban purposes, irrigation for wetlands and rivers, environmental/ecological use, as well as for prevention of saltwater interference at the seaside in Turkey. There are some obstacles to achieve this 5% target. These possible obstacles can be listed as follows.

Technical Barriers: The main driver and barrier of wastewater reuse in many regions of the world is the insufficiency of efficient collection and treatment systems for wastewater. According to the TÜRAAT project conducted in 2016, the wastewater treatment rate is 82.9% in Turkey. Although these rates are quite high, the rate of reuse is 0.78% due to the fact that wastewater cannot be treated at the desired level.

Social Perception/Educational Barriers: In the reuse of wastewater for agricultural irrigation, which is the most important area for the reuse, the perceptions of the public, which encourages a preference for the use of fresh water, are both socio-cultural habits and the afraid of dangers of food consumption, irrigated by wastewater.

Economic barriers: In order to make recycled water more attractive to potential users than the water obtained from fresh water sources, it should be cheaper and more suitable. An important obstacle for the reuse of wastewater is that the reuse projects in the short-term is expensive and it is only feasible in the long-term.

Corporate and Organizational Barriers: The responsibility of different institutions in water management and the fragmentation of authority is another obstacle that needs to be overcome in order for the re use projects to progress.

In Turkey, the following mistakes can be noticed when examining the current status of water reuse from the wastewater plants:

1. Failure to understand the legal regulations given in Annex 7 of the Notification on Wastewater Treatment Plants Technical Procedures,
2. The legal arrangements given in Annex 7 of the Notification on Wastewater Treatment Plants Technical Procedures were created by copying the guidelines given in EPA (2004),
3. Failure to adopt "Fit for purpose" approach to the treatment,
4. Priorities of wastewater treatment plants are on wastewater treatment, and not on recycling and reuse,
5. Design of re use units without customer analysis and the need,
6. No cost-benefit analysis for each treatment facilities,
7. Unpredictable water quality with existing technologies,

8. Non-regular operation and frequent failure of UV disinfection systems due to occasional operational problems in wastewater treatment plants,
9. Especially the pressure multimedia sand filters are not designed properly (the filter feeding speed is not selected correctly), the equipment is not selected correctly,
10. Lack of qualified personnel.

Suggestions for improving the wastewater reuse rate in Turkey can be listed as follows:

1. The uncontrolled and free use of groundwater, which is a strategic resource, by the industry should be legally prevented.
2. Incentive policies for the industry for using the wastewater again should be promoted.
3. In order to promote the use of treated domestic / urban wastewater for agricultural irrigation purposes, additional support and incentives should be given to farmers who produce by using the wastewater in the irrigation in the Agricultural Support program by the Ministry of Food, Agriculture and Livestock. Besides, in order to eliminate the existing negative public perception, the pilot projects should be carried out in the Research Institutes of the Ministry of Food, Agriculture and Livestock and the results of studies should be disseminated.
4. Policies should be developed to reduce initial investment costs by encouraging the domestic production of filtration, disinfection and membrane processes, which may be required for the reuse of treated urban wastewater.
5. In order for the wastewater to be discharged to the drinking water sources and to the groundwater and to reuse from these sources, it is necessary to adapt a new legislation in our national legislation and to facilitate the limit values and permits to ensure that the reuse is healthy and sustainable and widespread.
6. Water use in industry will increase in line with the targets of our country in 2023. In addition to the reuse of treated domestic / urban wastewater in industry, studies and arrangements should be made in order to increase the reuse of wastewater released in the industry after the production process.
7. Training / workshop activities about water reuse should be carried out.

Acknowledgement

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WR-A25

Application of membrane technology in water reuse in China

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Abstract

The growing water stress both in terms of water scarcity and quality deterioration promotes the development of reclaimed water as a new water resource use. Because of high efficiency and automation, membrane technology is increasingly shining in water reuse. This review mainly focused on commercial application status of membrane technologies (microfiltration, ultrafiltration, nanofiltration, reverse osmosis, forward osmosis, electrodialysis etc) in China. All kinds of membrane technologies have their expertise in the field of water reuse, which will occupy a large part of the future water reuse market in China. In addition, some research status also supports the future of membrane technology. In addition, the report surveyed the history of membrane technologies when they were applied to water reuse. It is supported that membrane technology is a better choice for wastewater treatment and reuse in the rural areas. After analyzing standard revolution and sustainability of membrane technology, it proved that membrane technology is potential and prospective in water reclamation in China. Constantly mature standards will greatly promote the development of membrane technology in the reuse of water. Based on the above, this report finally summarized the opportunities and challenges of applying membrane technology in the water reuse process and showed the priority of future development.

Keywords: Application; membrane technology; water reuse; China

1. Introduction

The world runs on water. Clean reliable freshwater is vital for human activity. However, freshwater availability in sufficient quality and quantity is one of the major challenges that society will face this century (Distefano & Kelly 2017). Colorado River that sustains 40 million Americans is dying(Stanley et al. 2018). In light of climate change and continued growth of urban populations, there is concern that the gap between the availability, supply and demand for fresh water will widen even further in sub-Saharan Africa (Dos Santos et al. 2017). Economic water scarcity is experienced in central and Latin America including the Caribbean region, South and central Africa, North India, some parts of China and some other Asian countries(Gude 2016). Water pollution is another major cause of the water crisis. The river Korotoa in Bangladesh is polluted by heavy metals and might create an adverse effect on this riverine ecosystem(Islam et al. 2015). Excessive emerging contaminants of concern (ECCs) that shuttle through water and soil seriously affect human health. It is globally recognized that humans are creating great pressure on the quality of our water resources by means of anthropogenic (man-made) pollutants entering freshwater systems(Archer et al. 2017).

When the global water crisis spreads, people are also suffering from severe water shortages and water pollution in China. Two-thirds of the global population (4.0 billion people) live under conditions of severe water scarcity at least 1 month of the year. Nearly half of those people live in India and China(Mekonnen & Hoekstra 2016). Rapidly urbanizing China will have a large number of cities with seasonal water shortage by 2050(McDonald et al. 2011). Continuous industrial growth, commercial development and contamination have been occurring in most cities around China, meanwhile, many rural residents are surrounded by the effluent of modern heavy industry, bringing tremendous challenges to sustainability in urban and rural planning(Zhuang et al. 2009; Chen et al. 2017). The groundwater over-exploitation is severe and has resulted in the partial drainage of the first aquifer in the Piedmont Plain area of Hebei and the deep confined aquifers in Beijing, and a large area of land subsidence in the plain areas(Huang et al. 2015; Shao et al. 2017). In addition, the depression of the seawater brackish surface has appeared in coastal cities, such as Cangzhou, Hengshui, Tianjin, Tangshan(Kong et al. 2016; Wang et al. 2017). To solve these problems in China, there are two solutions to water forced-intake and water reuse.

The water forced-intake includes groundwater extraction and long-distance water transfer. Groundwater exploitation in China experienced from sustainable prior to 1950s, rapid unsustainable expansion in 1970s and 1980s, peak in 1990s, and comprehensive ban since 2000(Shi et al. 2008; Wang et al. 2009; Yang et al. 2010; Shi et al. 2012). Excessive groundwater extraction leads to hydraulic head drawdown in aquifers and pore pressure decline in aquitards, or an increase of effective stress in aquifers and aquitards, which results in strata compression. Since 2000, many local governments have begun to ban groundwater pumping. Land subsidence and groundwater level decline were alleviated. It's shown that exploitation of cannot sustainably face water shortage. Only long-distance water transfer and water reuse are available to alleviate the water crisis (water scarcity and water pollution).

Water reuse is considered one of the stars to alleviate water shortage and water pollution. Hundreds of cities in northern China suffered frequent drought for years in the late 1980s. Due to sustainable use of water resources, water reuse has been highly appreciated by the state council of the People's Republic of China since the 1990s. The first municipal wastewater reuse demonstration project, Dalian chunliu river wastewater treatment plant, was operated in 1992. With the development of wastewater recycling technology, conventional water reuse technologies are gradually replaced by various advanced treatment technologies, such as advanced oxidation, adsorption, membrane filtration, denitrification biological filter. The technological revolution benefits from high demand for reclaimed water. In 2010, all wastewater treatment plants (WWTPs) of China (excluding the Special Administrative Region of Hong Kong, Macau SAR and Taiwan) only produce 0.015km^3 recycle water, but it amazingly increased to 48 km^3/yr in 2017. Although most of the reclaimed water was used for non-drinking purposes recently, this is indeed a very exciting number.

Admittedly, characteristics of Chinese water environment are different from those of other countries with developed water reuse. This review discusses the following questions: (1)the prospects of membrane technology in water reuse in China; (2)what kind of membrane technology may be focused on in the future; (3) the development barriers and solutions of membrane technology in China.

2. Water crisis and water reuse in China

2.1 Water crisis

Water reuse is of increasing relevance for water-stressed regions while often considered a contentious option. Compared to the annual average during 1956–1979, average precipitation in the 3-H basins (Huaihe, Haihe and Huanghe) decreased by 9.6%, runoff decreased by 23.8%, and flow to the ocean decreased by 58.6% (CAE, 2001). High demand for urban and agricultural water supply promoted the development of alternative sources such as rainfall harvest by small reservoirs, groundwater, and reuse of wastewater. Groundwater that has advantages of convenient access and low cost was widely used in household, industry and agriculture before 2000. Since the early of the 1980s, the groundwater overdraft volume increased year by year. There are 345 million pumped wells in the whole country until 1997, and total annual groundwater exploitation reached about 985.24 km^3. In 2000, groundwater was overexploited nearly 100 km^3(Shouhai 2003). Such abuse had forced local governments to issue relevant bans in China.

However, deteriorating groundwater quality also needs to be attention, currently. According to the MEP, the groundwater tested in 100 cities across China was not suitable for drinking water supply. Compared to the USA and EU, the groundwater from Beijing and Tianjin was more polluted by Pharmaceutical and Personal Care Products (PPCPs), perhaps due to irregulated intensive industrial and agricultural activities(Zhai et al. 2017). No obvious relationship was found between surface water and groundwater concentrations of chemicals (Kong et al. 2016). Groundwater NO− 3 has higher concentrations because of the infiltration of domestic sewage and industrial wastewater with rich NO− 3 into aquifers(Zhang et al. 2015). Groundwater is generally used in rural areas and suburban areas, where investments for centralized water treatment systems often unaffordable given the remote locations and lack of financial resources. And the centralized water treatment systems often fail due to unprofessional maintenance and management for rural areas(Lenton & Wright 2004). Therefore, it is difficult to compliance with water quality standards if the groundwater quality is not good in rural areas. Noncarcinogenic and carcinogenic risks of a part of the micropollutants via oral ingestion and dermal absorption are both in an acceptable scope at most Liaodong peninsula rural sites. While at a few areas, the groundwater used for drinking and cooking could pose certain carcinogenic risks to the residents. It is necessary to pay close attention to the health risks from using the groundwater and take effective action to control pollution of groundwater.

Water reuse, a sustainable concept, is an effective way to control wastewater discharge of human activities. Moreover, it is a green technology to alleviate the stress on drinking water supply. According to the survey, the degree of China's urbanization (percentage of urban population) will surpass 70% by 2030, which would be substantially greater than that in 2016 (57.3%) and about 4.2 times that in 1978 (17.9%) (National Bureau of Statistics of China 2018; United Nations 2018). In order to solve the contradiction between water supply capacity and high-speed urbanization, Chinese municipal organizations have tried long-distance water transfer and water reuse. The long-distance water transfer project which has good effluent quality, simple treatment process and high construction cost, expands the supply of drinking water. In addition, the water reuse which has cheaper water price, wide application but considered a contentious option, drop the demand for potable water.

Water-borne diseases are spread more widely by the polluted water, and water pollution also affects human health through the food chain enrichment and delivery of toxic substances, such as the transmission of resistance genes directly affecting the ecosystem. As announced in the Thirteenth Five-Year Plan (2016–2020), the rate of potable water use in rural areas will reach over 80% in China, and the centralized water supply popularization rate will reach 85% or more. But three water-related status in rural areas needs to be considered. Firstly, most of the rural wastewater is directly discharged, and treatment rate of total rural wastewater only reached 5.1% in rural areas(Chinese Academy of Engineering 2001). Secondly, simple potable water treatment technologies with unsatisfactory drinking quality are applied. Thirdly, the heavy industry moved from city to countryside, and aquaculture industry develops rapidly. The villager of China is facing severe water environmental challenges. Re-use of wastewater, to recover water, nutrients, or energy, is becoming an important strategy. Water reuse, a method for achieving wastewater useful and worthy, relieves water environment overload via controlling the discharge of pollution.

2.2 Water reuse

2.2.1 Standard revolution

The State Council of China has always attached great importance to China's water environment. The Leading Team for Environmental Protection was officially established in 1974. After a continuous reorganization, the State Environmental Protection Administration was upgraded to Ministry of Environmental Protection (MEP) in 2008, as an integral department of the State Council. And Ministry of Water Resources (MWR), the Chinese Government Department responsible for water administration, was founded in October 1949. Two ministries jointly manage water environment.

The water crisis has been driving government departments to continuously improve the discharge standard of pollutants. But the water recycling industry started late in China (excluding the Special Administrative Region of Hong Kong, Macau SAR and Taiwan). In the early stage, the application of reclaimed water technology is based on relevant foreign standards or advanced experience. After decades of technological development, the first industrial “Quality standard for reclaimed wastewater” was issued in 2000 under the name of CJ/T 95-2000, which was used to guide recycled water reused as scenic water. It then derived to a series of national standards in 2002, including GB/T 18919-2002, GB/T 18920-2002, GB/T 18921-2002. Moreover, the 2002 revision of national “Discharge standard of pollutants for municipal wastewater treatment plant” added Class I-A as a basic requirement of reclaimed water. Ever since then, GB/T 20922-2007, GB/T 19772-2005, GB/T 19923-2005 and GB/T 25499-2010 were issued, respectively listed water quality indexes on farmland irrigation, groundwater recharge, industrial uses and green space irrigation. National standards need to be reviewed every five years, but none of these national recycling water quality standards (RWQSs) have been revised. From 2002 to 2016, Gross National Income (GDP) grew 5.15 times to 740,59.87 billion RMB, and Sales Value of Industry (Present Value) of Industrial Enterprises increased to 1,151,95.01 from 108,58.58 (billion RMB). Total Waste Water Discharged just grow 0.62 times to 71.11 billion tons. The draft revision of “Discharge standard of pollutants for urban wastewater treatment plant” has been announced in 2015. These have shown that Chinese water environment has undergone significant changes, and it is unreasonable not to revise RWQSs. Recently, the new Beijing local standard of “Discharge standard of water pollutions for municipal wastewater treatment plants” (DB 11/890-2012). The main pollution control limits were improved to the class IV level of Environment quality standards of surface water (GB 3838-2002), which was stricter than most national reclaimed water standard. The development procedure of RWQSs is listed in Table 1, and the revised details are explained below.

The Beijing DB 11/890-2012 standard marks water reuse enters a new stage in China. The stricter discharge limits promote wastewater treatment plant upgrade their treatment process to add advanced process technologies. It will promote the revision of RWQSs. Stricter wastewater discharge standards foreshadow the bright future of water reuse in China.

2.2.2 Water reuse technology

The secondary treatment processes mainly remove suspended solids, biodegradable organic matter, and part of nutrient in wastewater. Secondary effluent (SE) remains a lot of colloids, dissolved organic matter, dissolved inorganic material and microorganisms, and the problems of safety, applicability and economy still exist. The water reuse treatment technology, as an advanced wastewater treatment process, is built after the secondary treatment process, and the purified water will be used for a variety of purposes. According to popular age, water reuse treatment technologies can be divided into traditional water reuse processes (TWRPs) and modern water reuse processes (MWRPs). TWRPs utilize from conventional drinking water treatment technologies (coagulation, sedimentation, sand filtration, etc.). Due to low treatment efficiency, these TWRPs are outdated. Based on function, MWRPs are divided into pre-treatment technology, main treatment technology and advanced treatment technology, as shown in Table 1. The filtration cannot easily avoid backwash, especially the media filtration has complicated backwash process and discharges a lot of backwash effluent. Limited dissolved matter removal of the surface filtration is difficult to satisfy strict RWQSs. The membrane filtration is usually defaulted to the pressure-driven membrane process, including microfiltration(MF), ultrafiltration(UF), nanofiltration(NF), reverse osmosis(RO), with better separation performance. These processes, based on physical and chemical mechanisms, don't worry about the lack of microbial carbon sources. Compared with the media filtration, the surface filtration and the biofilter, the pressure-driven membrane process has irreplaceable advantages. As is known, membrane technology also includes non-pressure-driven membrane processes, such as forward osmosis (FO), membrane distillation (MD), electrodialysis(ED), pressure retarded osmosis(PRO). At present, there are more than 300 membrane providers and nearly 1,000 engineering companies in China. In 2016, China's entire membrane industry market scale exceeded 140 billion yuan; it is expected that by the end of 2022, the value will reach 361 billion yuan(Gao 2017). The industry standard "Technical specification for membrane separation of municipal water supply (CJJ/T251-2017)" was announced in 2017, that is the first independent membrane treatment standard in China. Governments and companies would be attracted by membrane technology with confident application prospect thanks to its ability to simultaneously remove a broad range of contaminants.

3. Application of membrane technology

Membrane technology has been broadly applied in the treatment of wastewater, drinking water treatment and desalination (Cheng et al. 2017; Li 2017; Tay et al. 2018), regardless of decentralized wastewater, centralized municipal wastewater or industrial wastewater. Search results based on online databases, including Web of Science and National Knowledge Infrastructure of China (CNKI), might show that the concern of Chinese researchers (Figure 1) and businessmen (Figure 2) on membrane technology.

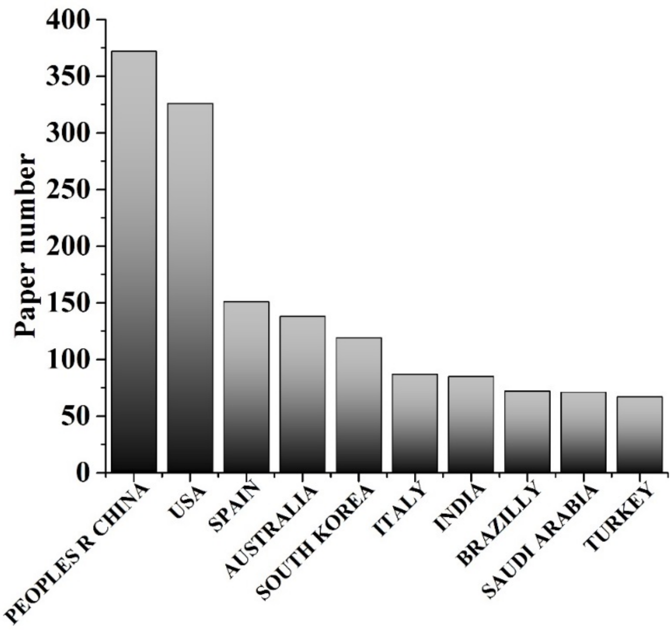

Fig. 1. Geographic distribution of papers on membrane technology in water reuse in recent five years

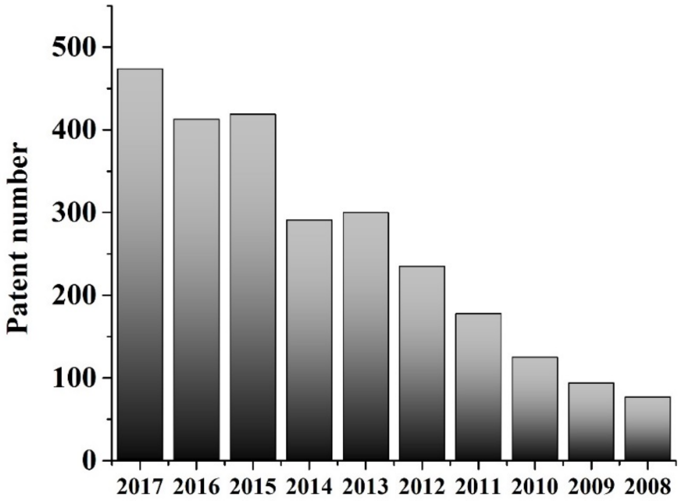

Fig. 2. Variations number of domestic patents on membrane technology in water reuse

However, the water crisis with Chinese characteristics makes application of membrane technology different from other countries. Application of membrane technology would be discussed: (1) alleviate water shortage based on application purpose; (2) solve water pollution based on membrane function.

3.1 Potable reuse of membrane technology

The United States, Singapore and Namibia are famous for the development of wastewater reuse for potable reuse (PR), while China is relatively slow on PR. China has experienced urban migration for thousands of years, most developed cities have a reliable water resource. With the limited exploitation of groundwater, most cities begin to use the surrounding river water. But not all river water can be easily purified. For example, the high turbidity water of the Yellow River is difficult to handle by traditional sediment process. This problem has been issued by Lihua Yan in the 1970-1980s. Geographical characteristics of China cause water crisis, not like the United States. California's economy is developed but extremely dry, which is almost non-existent in China. Especially, Beijing and Tianjin have a very high demand for water, but there are not enough reservoirs around. And most rivers are suffering serious pollution. With black-odor river water, it cannot be used for drinking. This indicates that local regions urgently need to improve the water quality by applying PR.

The desert covers the Midwest of the United States, such as California, Nevada, Arizona, with a dry climate and severe water shortage. Local government promotes direct potable reuse (DPR) and indirect potable reuse (IPR) to reduce demand for fresh water. Currently, RO is recommended to PR as the main process. In 2014, NEWater is sold to the public about 4.9 RMB/m^3 in Singapore. In the same year, Beijing purchase water from the South-to-North Water Transfer Project about 2.33 RMB/m^3, user price of the first step was 5 RMB/m^3, which include water volume about 180 m^3 /yr. That was a turning point for the South-North Water Transfer Project and PR, that indicate PR has potential in the Beijing region. Beijing and Tianjin have water recycling plants access RO process, with the ability to PR, but currently only for non-potable purposes. There are no cases of wastewater reuse for drinking in China recently. Delightly, there are already many wastewater reuse pieces of researches applying RO to water reclamation plants in Beijing, including pathogen, membrane fouling, genotoxicity, etc. This indicates that there is already employer trying to investigate the safety of PR, which also indicates that Chinese PR market scale will be expanded, so demand of membrane production and application technology exploration have a bright future.

The construction of WWTP under the wetland is a good solution to residents hating of living around WWTP. According to the survey, people want to live near WWTPs because of the beautiful scenery above wetlands. Therefore, the present social awareness will promote the realization of DPR operation in the next few years. Nanofiltration (NF), possessing advantages that high flux rates through the membrane, high rejection of divalent salts and organic molecules above 200 Da, and low maintenance and costs, is considered as a promising treatment method for ground, surface and wastewater. Compared with RO, NF can further cut down the price of DPR. NF effluent can be discharged into the wetland on the ground, waiting to be sucked into water treatment plant. However, NF is not good at monovalent ion rejection. If wastewater is constantly recycled in a city, the concentration of salt will continue to rise in the water body and infiltrate into the ground. In general, the groundwater nitrate pollution problem alleviates from the east region to the west region obviously in the mainland of China, which makes a visual response to human activities and social economy (Zhai et al. 2017).

Capacitive deionization (CDI) is considered to be one of the most promising technologies for the desalination of brackish water with low to medium salinity (Zhang et al. 2018). NF-CDI combination process will impact the RO wastewater reuse market.

Not only wastewater can be regarded as the source for water reuse, but also rainwater can. As we all know, rainwater is a lightly polluted water resource, which has low COD, nitrogen and phosphorus concentration, low hardness, and low metal ion concentration. However, the collection interface affects water quality, usually high particles, bacteria and viruses number (Ding et al. 2017b; Lin et al. 2018). Boiling rainwater with fuel, although not always be the optimal solution, is widely used in Chinese villages. Ultrafiltration seems more promising due to the small footprints, high removal performance of bacteria and reducing the dosage of chemical disinfectants during rainwater treatment for potable purpose. Gravity-driven membrane filtration (GDM) may be a better choice for decentralized rainwater reuse as long as installing ultrafiltration membrane.

In urban areas, it is also very suitable to collect rainwater for greening or flushing the toilet. An integrated non-power cyclone precipitation membrane filtration reactor was applied to Xi'an global trade central building for rainwater reuse. This system uses a 10μm filter cloth, so it has good COD and turbidity removal performance but unsatisfied pathogen retention. Although rainwater is easy to handle, the amount changes greatly monthly, which is not an ideal source of water compared to wastewater.

3.2 Non-potable reuse of membrane technology

Compared with DPR, people prefer to accept wastewater for non-drinking reuse (NPR). The inhabitants don't worry about pollutants in the water entering the organs through the mouth, thus affecting physiological activities. What's more, people have no psychological exclusion on NPR unless reclaimed water smells stinky. In the NPR field, it can be divided into greywater reuse, wastewater reuse and industrial wastewater reuse according to different wastewater sources, which are very important sources in NPR.

3.2.1 Greywater reuse

Most greywater is reclaimed in decentralized treatment and reuse. Grey water has been defined as wastewater originating from bathtubs, showers, hand basins, washing machines, dishwashers and kitchen sinks (Eriksson et al. 2009). Recently, a trend has emerged by which grey water is excluded from kitchen sinks and dishwashers (Oron et al. 2014). The advantage of recycled greywater is that it is a plentiful water source with a low pathogen and organic content. To illustrate, greywater represents 50–70% of total consumed water but contains only 30% of the organic fraction and 9–20% of the nutrients, thereby making it a good source for water reuse. Moreover, in an individual household, it has been established that greywater could potentially support the amount of water needed for toilet flushing and outdoor uses such as car washing and garden watering. Grey water varies regionally and over time. Water supply quality and activities in the house have an effect on the characteristics of grey water. Greywater originating from the bathroom and laundry includes mainly chemicals (detergents, soaps and salts) and several million pathogenic bacteria, which can cause a health hazard if this water is reused without proper treatment. Therefore, greywater must undergo certain treatments so that it can be made ready for reuse (Bani-Melhem et al. 2015). In China, there is no large-scale drainage system in which greywater and black water are discharged separately. Moreover, many local governments are trying to unset septic tanks so that manure is directly discharged into the urban drainage pipe to improve the influent biodegradability of the WWTPs. This suggests that greywater reuse as a centralized source of water is difficult to carry out in China. However, recent urban community buildings mostly separate blackwater and greywater via two drainage system until they cross the boundary of the community, which facilitates the development of decentralized greywater treatment and reuse in the urban community, and the recycled water could be reused for road cleaning and garden watering in the community. Ding et al. published an article on Gravity Driven MBR (GDMBR) for the first time in 2016. The GDMBR is driven by an ultra-low gravitational pressure (40-100 mbar) without any backwash or aeration shear(Tang et al. 2018). Flux stabilization at 2.0 L/ (m^2 h) occurred in the reactor applied 150kDa ultrafiltration membrane. Therefore, GDMBR is in a dilemma because of too low flux. For urban car washes that cannot accept public recycled water, GDMBR still has a price advantage now. Increasing the membrane flux by in-situ coagulation can decrease the membrane area and equipment footprint about 50% (Ding et al. 2017a). In-situ coagulation is a feasible method that users add a little coagulant to the reactor every day. But how to dispose of a large amount of chemical sludge. There may be better sustainable ways to improve the stable flux of GDMBR in the future.

3.2.2 Domestic wastewater reuse

The reuse of municipal wastewater for non-potable water is currently the most widely used in water reuse in China. Taking Beijing as an example, the recycled water in central urban areas mainly supply to industrial cooling, agricultural irrigation and scenic environment (Figure 3). Beijing qinghe WRP, huaifang WRP, lugouqiao WRP and beixiaohe WRP apply membrane filtration process (ultrafiltration or MBR), and the effluent is used for all DPR purposes. Reclaimed water consumption in northern China varies with the seasons recently, during the winter ice period, it is not advisable to replenish the scenic river with a large amount of reclaimed water. The green space and farmland do not need irrigation, so recycled water consumption is greatly reduced. Therefore, membrane treatment is more suitable in the north, WRPs need not worry about hindering the processing performance after changing the processing load.

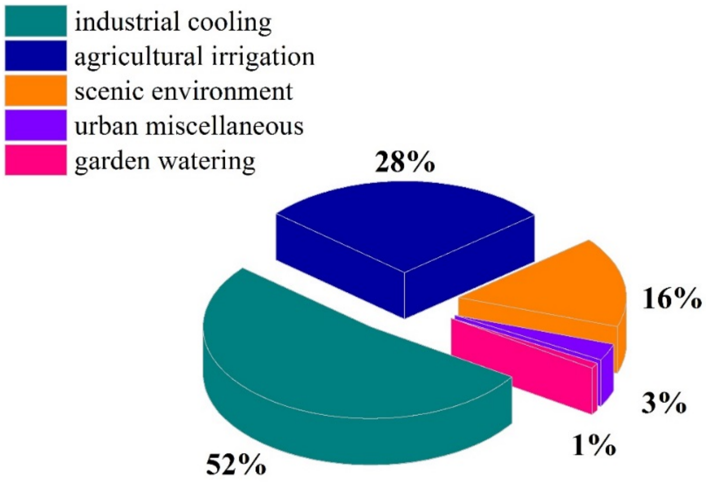

Fig. 3. Beijing reclaimed water consumption composition

4. Sustainability of membrane technology in water reuse

4.1 Lower chemical dose

The membrane treatment process utilizes the selective permeation function caused by physical and chemical forces, and some substances are separated according to the designer's intention, and the purification is achieved without secondary pollution caused by the addition of chemicals. Currently the use of the water treatment industry adding chemicals to remove contaminants, such as coagulation, advanced oxidation, resulting in more metal ions and non-metal ions in the effluent, also causing a large number of metal salts in the sludge and concentration during the treatment process. Not only will chemicals increase the cost of removal by-products, but also destroy the soil ecology, cause soil salinization and increase TDS in the water environment. The HOA, HOB and HIN not only accounted for 96% DOC, but also shared the genotoxicity of the whole RO concentrate (Sun *et al.* 2014). With the development of the water cycle industry, the daily water circulation coefficient (the ratio of total water consumption to fresh water every day) will go up constantly, which is positively correlated with the salt concentration. The ultrafiltration or microfiltration can remove colloids and particulates without the addition of chemicals at low-frequency chemical cleaning. And the nanofiltration and reverse osmosis processes often add polymer scale inhibitor to prevent salt from crystallizing on the surface of membrane. The polymer scale inhibitor could not leak into the effluent and can’t cause secondary pollution. We should note that the membrane process concentration is a kind of refractory wastewater, which is provided with high concentration of pollutants and poor biodegradability. It could be discharged directly into the sea in the coastal city. For the inland city of China, most concentration is to dry. Drying performance affected by the weather, the drying process cover a large area so that urban WRPs need high costs to handle concentrate. On the one hand, this problem can be solved by FO-MD(Zhou *et al.* 2018). On the other hand, OMBRs offer unparalleled advantages over conventional MBRs in terms of the excellent product water quality and possibly low energy consumption, making the technology highly promising for wastewater treatment and reclamation (Krzeminski *et al.* 2017). Apart from the removals of trace organic compounds, removals of heavy metals and nanoparticles from wastewater might be another potential application of OMBRs.

4.2 Healthier water quality

Human health problems caused by water reuse include pathogen, chemical pollutants and disinfection by-products and other potential risks. Ultrafiltration is an attractive method for removing pathogen, reducing addition dosage of disinfectants and reducing disinfection by-products. As new antibiotics continue to be discovered, super bacteria and super viruses constantly challenge human physiological resistance, and conventional disinfectants kill viruses at risk of leakage. Ultrafiltration membrane rejects most viruses, such as SARS (80-140 nm) and adenovirus (70- 90nm), enterovirus (10~30nm). Ultrafiltration has unsatisfactory ability to remove dissolved organic matter so that the predecessor of disinfection by-products is difficult to alleviate. Therefore, it is necessary to apply to nanofiltration or reverse osmosis, which can reduce low molecular organic substances and reduce the concentration of disinfection by-products exhaustively. Potable reuse is becoming a feasible option to cope with water shortages, that requires stricter water quality than indirect potable reuse, including lower limits and more comprehensive indicators. Thus, promoting the development of NF and RO membrane for the high rejection of biological toxic substances ensure that the drinker has enough confidence in the PR system.

4.3 Better economic suitability

4.3.1 Compared with water transfer project

The supply time characteristics of water reuse and water transfer projects are stepwise. In other words, the increase in supply capacity is stepwise. Since different minimum effective scale between water reuse and water transfer projects, their ladder sizes are also different. As seen in Figure 4, the investment step-to-curve effect makes it possible to achieve significant cost savings in water reclamation. In the presence of the gap between supply and demand of water resources, due to economies of scale considerations, taking into account the long-distance water transfer usually takes decades later the demand for water, and in order to determine the scale water diversion project. Then, it will cause a part of the water supply capacity to be idle in the initial application period. The supply capacity of water recycling projects is relatively small and the project cycle is also short, that also saves water resources and delays the investment. Both have economized the cost of water reuse. The proportion of water supply in the metropolis of China indicates that water reuse is currently not dominant (Figure 5). However, Beijing is the capital of China, and water policy of Beijing government will lead the future water reuse to flourish.

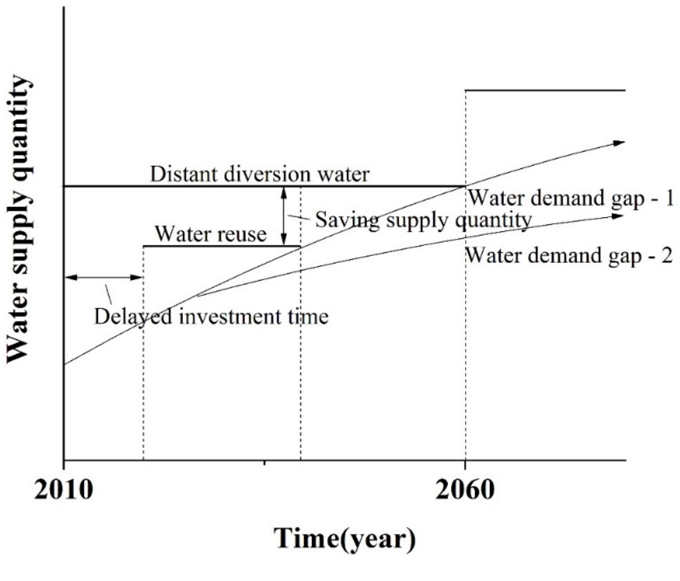

Fig. 4. Step-curve effects of wastewater reuse and distant water transfer projects

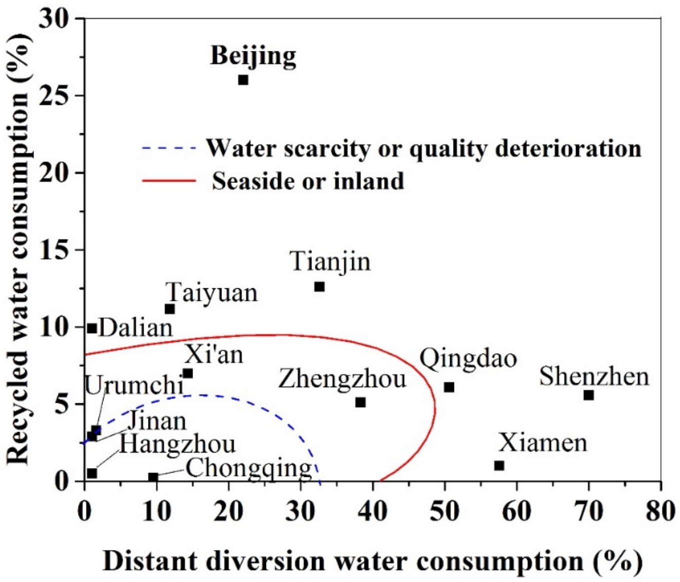

Fig. 5. The relationship between recycled water and distant diversion water in the metropolis of China. (The left side of the red line: inland city, the right side of the red line: seaside city; the left side of the blue line: water quality deterioration city, the right side of the blue line: water scarcity city)

4.3.2 Compared with conventional processes

Table 1 Economic comparison of 4.3.2 Compared with conventional processes different WRP processes under the same scale

Reuse process	Invinvestment (RMB/m^3)	Operating costs (RMB/m^3)	Total costs (RMB/m^3)
Direct filtration	450-500	0.25-0.27	0.32-0.36
Coagulation + filtration	500-550	0.26-0.32	0.35-0.42
Coagulation + sediment + filtration	550-600	0.28-0.34	0.38-0.45
Coagulation + MF	1900-1980	1.10-1.25	1.48-1.55
Coagulation + sediment + MF	1950-2000	1.15-1.32	1.50-1.57
Coagulation + sediment + MF + RO	2900-2970	1.70-1.85	2.39-2.45
Coagulation + MF + RO	4300-4400	2.55-2.73	3.50-3.55

Conventional processing large area, the wastewater treatment plant is generally difficult to meet the space requirements, but significantly less than the traditional process investment membrane treatment processes. Based on the initial investment, the conventional process is the most cost-effective recycling process. Generally, the conventional process requires the investment of 800~1000RMB per ton, but the membrane reuse process needs 3000~4000 RMB per ton, with the order of microfiltration ≈ ultrafiltration <double membrane process. For the WRPs over 10,000-ton, the investment of MBR requires 2000~3000RMB per ton. Operating conventional process costs only 0.50 RMB per ton, microfiltration and ultrafiltration membrane reuse process needs to be increased to 1~2 RMB, but the total cost of a membrane reuse process based on reverse osmosis totally costs more than 2 RMB. From Table 1, it is shown that applying conventional process as pretreatment may reduce the cost of high-pressure membrane filtration. Despite being affected by strict emission standards, the conventional process cannot play an important role in the future, but it is essential in cutting the cost of operating the membrane process. In addition, nanofiltration could operate only 50% of the RO membrane cost cause of larger flux and better anti-pollution performance. Nanofiltration is expected to significantly improve effluent quality on condition that the operating cost can be controlled within 2 RMB per ton.

5. Challenge and prospect

In China, the most promising process for water reuse is nanofiltration, which has challenge currently that nowhere to discharge concentration. It is urgent to develop a single or combined process to weaken the harm of concentrate with high stability and low cost. At the same time, although Chinese high-pressure membrane providers can manufacture high-performance membranes, few manufacturers can control production quality well, and rarely pay attention to optimize the structure and material in membrane components. The high cost of membrane treatment caused by membrane fouling still needs to be focused for engineering applications.

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WR-B10

Reduction of CO_2 emissions in sewage treatment systems by removing oil and fat from wastewater and using it for power generation

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Abstract

Wastewater containing of oil and fat (WCOF) may worsen water environment by declining performance of sewage treatment systems (STP) especially in urban areas, like Tokyo, which depend on combined sewerage. Since oil balls with combined sewer overflow (CSO) in rainy season have got a problem in Tokyo, Japanese government suggests three goals to improve combined sewerage. Grease-trap (GT), for the third goal, must be installed to remove oil/fat in WCOF from kitchens discharging much WCOF in Japan. Although GT efficiently eliminates oil/fat in WCOF as grease, collection of intercepted grease (IG) is onerous because IG is removed by hand with papers. A new technology, named Kankichikun-Jr (K-Jr), to automatically collect IG from GT has been developed to effectively utilize IG as a biofuel for power generation (FPGS), which is expected to reduce burden to sewage treatment systems as well as generation low carbon electricity, in Japan. Thereat, this study aims to quantitatively evaluate environmental effects with reduction of burden to STP for Tokyo by FPGS using a bottom-up model. As a result, 111 thousand t-CO_2, corresponding to 15% reduction in STP of Tokyo Metropolis, is annually reduced at sewage treatment systems by installing K-Jr at GT in Tokyo.

Keywords: Energy recovery; oil/fat-contained wastewater; grease-trap

1. Introduction

Wastewater containing oil and fat (WCOF) discharged from community often causes water pollution and declines performance of sewerage and sewage-treatment system. Especially WCOF is argued in an urban area, like Tokyo, with a combined sewer overflow (CSO) in the rainy season. Indeed Japanese government has published a report on countermeasures to improve combined sewerage in urban areas since oil balls which has a possibility to come from WCOF with CSO were cast ashore at a seaside park in Tokyo Bay (MLIT and JIWET, 2000). The report suggests three present goals: 1) reducing water pollutants, 2) ensuring sanitation and 3) removing inert matter (including oil balls). The concrete measures of the third goal are not only improving screening functions at outlet of combined sewerage and facilities for oil balls with CSO but also restraint to flush WCOF down the drain from restaurants (Nakazato, 2006).

Grease-trap (GT), which contributes to the third goal above, is the prevalent equipment to remove fat, oil and grease (FOG) from WCOF and must be installed at a kitchen which discharges much WCOF in Japan (Kusakari et al., 2012). GT can easily intercept FOG in WCOF as grease, but the intercepted grease (IG) should be constantly collected and disposed of in order to keep the removal efficiency of GT. However, the collection process is high maintenance, so more effective collection methods are necessary to improve removal efficiency of GT.

An innovative power generation system, named as Food-green Power Generation Systems (FPGS), using IG is developed in Japan (NEDO and TBM Co. Ltd, 2017). The FPGS is a low-carbon technology because IG is utilized as biofuels for power generation. Meanwhile, the systems is expected to reduce burden to sewage treatment systems by decrease of flushing WCOF down the drain by an original technology named Kankichikun-Jr. (K-Jr) which automatically collects accumulated grease in GT, for maximizing of feedstocks procurement. Thus K-Jr can keep functions to eliminate FOG from WCOF in GT at higher level constantly. As the results, discharge of WCOF from GT, it is considered, is decreased and contribute to reduce burden to sewage treatment systems. Thereat, this study aims to quantitatively evaluate environmental effects with reduction of burden to sewage treatment systems for Tokyo by FPGS.

2. Materials and method

2.1 Functions and issues of GT

Grease-trap (GT) consists of three layers (SHASE, 2016). The first layer interrupts vegetable scraps and such floating on WCOF by a basket. The second layer eliminates FOG from WCOF with specific gravity differences between water and FOG and finally store them as IG. The third layer discharges wastewater meeting criteria (low FOG concentration) to a drain.

The theory of GT, as above, is simple and effective to remove FOG in WCOF, but GT usually has a maintenance issue, namely clean-up of IG, for keeping high performance to remove FOG because the removal efficiency is worsened if much IG accumulates in the second layer. Generally IG is cleaned up with specific papers by hand, which is hard work and time-consuming for workers of restaurants. Therefore, management of IG is a very important issue to operate GT.

2.2 Food-green Power Generation Systems (FPGS)

Food-green Power Generation System (FPGS; Fig. 1) is a new and unique power generation system using IG (Sahara, 2017). FPGS consists of four processes: collection, transformation, power generation and supply.

In the collection process, IG is efficiently collected by a vacuum separator which sucks not only grease but also sludge with wastewater in GT into its tank and returns only water to GT after grease is separated from sludge in the tank. Next, the collected IG is transformed to biodiesel, named Straight Mixed Oil (SMO), for diesel generators.

The developer, TBM Co. Ltd., operates two types of power generation systems. The first system is a fixed power generation. TBM Hanamidai Green Power Plant (100 kW) is certified as a renewable energy (biomass) power generation facility by Ministry of Economy, Trade and Industry, Japan in 2016 and supplies electricity via power supply networks of electric power companies. The second system is a mobile power generation and two power generation vehicles, whose capacity of generators are 100 kVA and 60 kVA, are operated. At the same time, these vehicles can supply electric power independently, and have been supplied green power for festivals and events of local communities and municipalities.

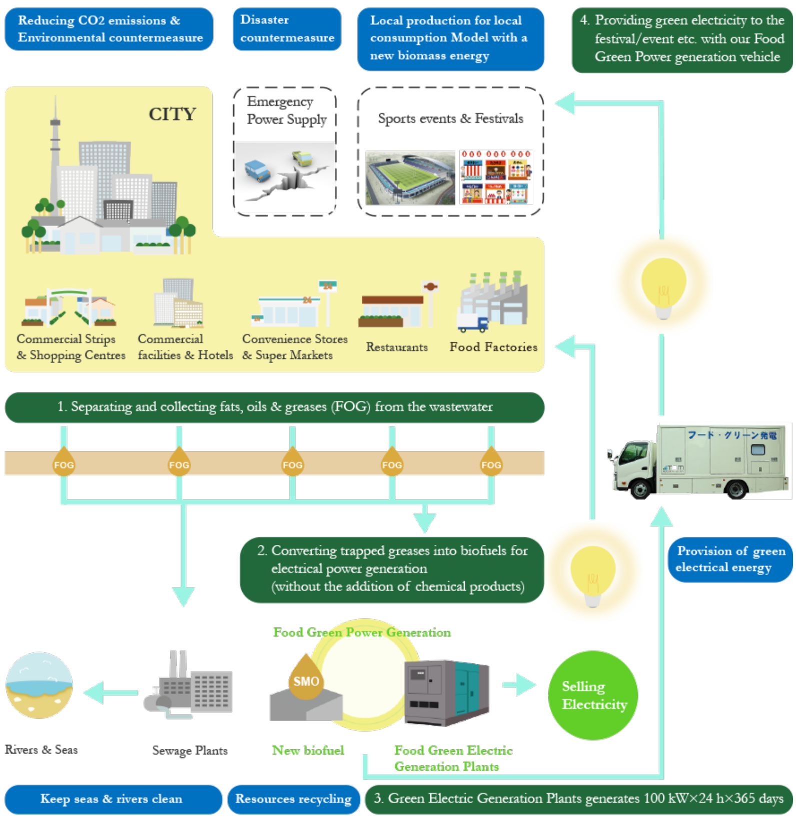

Fig. 1. Framework of FPGS using IG as an urban biomass (TBM Co. Ltd., 2018)

2.3 Environmental effects of FPGS and a target of this study

Food-green power generation system (FPGS) is expected to bring three kinds of positive environmental effects (Fig. 2). First, FPGS possibly decrease impacts to water environment, because it is possible to reduce water pollutants which is the cause of a clogged drainpipe and oil ball with CSO due to efficient collection of FOG in WCOF.

The second effect is reduction of volume of solid waste. Trapped grease is usually incinerated with cleaning papers for GT, but these waste can be disappeared due to transforming trapped grease to fuels for FPGS.

The third effect is reducing CO_2 emission by power generation with biomass (biodiesel). At the same time, FPGS can reduce CO_2 emission to dispose of clean-up papers with IG. Furthermore, FPGS possibly contribute to reduce CO_2 emission of wastewater treatment process, which this study focuses on. This is because electric power consumption may decrease by reducing input of FOG to sewage treatment plants (STP) due to promoting more IG collection for FPGS.

Thus this study accounts reduction of the CO_2 emission by estimating reduction of electric power consumption of sewage treatment process with high collection efficiency of IG using a bottom-up approach (please see “Calculation” section) .

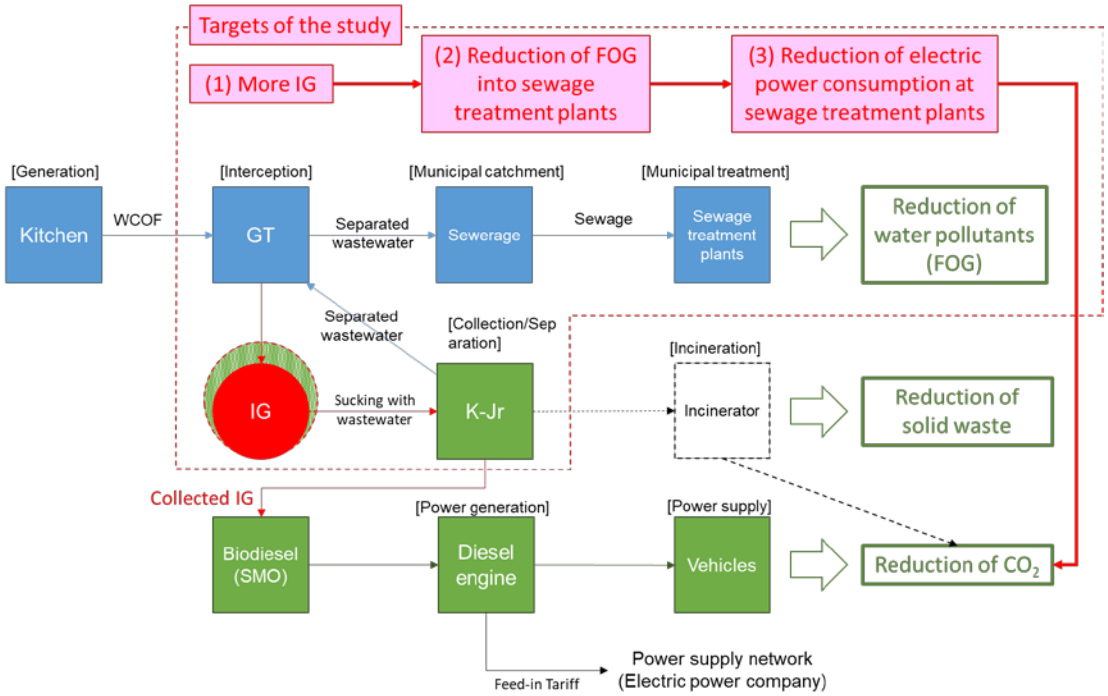

Fig. 2. Environmental effects of FPGS and a target of the study

2.4 Description of a study area

Tokyo is the capital of Japan and approximately 14 million residents live in the administrated area of 2,191 km^2 (BoGATM, 2018). The administrative area consists of 4 regions: Metropolitan area, city area, rural area and islands area. 77 billion kWh of electric power, which reaches at 30% of total electric power supply from Tokyo Electric Power, is annually consumed. Sewerage systems cover almost all areas in Tokyo and approximately 2 billion m^3 of wastewater is treated at STP. In addition, sewer is collected by combined sewerage systems whose influent includes runoff originate from precipitation. Food manufacturing shares 9% of the total manufactured goods shipments of Tokyo. Tokyo has 45,361 restaurants, which 437 thousand people work at and whose annual sales reach 2.2 trillion yen (20 billion USD) (MIAC, 2014).

2.5 Calculation

Amount of increase of IG by K-Jr can be calculated by subtracting amount of IG in GT with K-Jr from that of the existing GT (without K-Jr). IG is estimated with influent of WCOF into GT, its effluent from GT and amount of n-hexane extract (n-Hex) in the influent and effluent. Therefore, we collected these compiled data based on results of 160 sites in Tokyo contracting with the developer of K-Jr. (TBM Co. Ltd). Furthermore the data is categorized into 10 sectors: processed food retails, retails of other food and beverage, general restaurants, Japanese restaurants, Chinese restaurant, barbeque restaurants, other special food restaurants, Japanese noodle shops, bars/beer halls and hamburger shops; whose WCOF, it is assumable, include much FOG and set parameters of per site amount of collectable IG with or without K-Jr by sector. Meanwhile, number of sites (restaurants or shops) in Tokyo is compiled by sector from statistical data (MIAC, 2015).

Reduction of burden to sewage treatment systems is defined as reduction of COD-based influent, which is calculated by covert amount of increase of IG by K-Jr to COD-based value using a conversion factor (g-COD/g-IG) under the assumption that all amounts of FOG in effluent from GT go into STP. The conversion factor is finally set as 2.874g-COD/g-IG, which is a mean value of conversion factors of palmitic acid, oleic acid and linoleic acid under the assumption that they are main components of FOG in WCOF. Furthermore, reduction of CO_2 emission by diminishing the inflow of COD is accounted by multiplying avoided electric power consumption by CO_2 emission factor. The avoided electric power consumption is estimated as the product of reduction of COD-based influent and electric power requirements for the unit removal of COD, which is estimated as averaged value (2.61 kWh/kg-COD) of sewage treatment systems of Tokyo (JSWA, 2015). In addition, CO_2 emission factor refers to reported value (0.474 kg-CO_2/kWh) of a power provider for Tokyo (TEPCO, 2017).

3. Results and discussion

Tokyo annually generates 67 thousand tonnes of FOG at 10 sectors and especially Chinese and barbeque restaurants share 31% and 16% of the total respectively. Then GT intercepts approximately 43%, and it is expected to double the removal rate by installing K-Jr. Then, it is calculated that 31 thousand tonnes of FOG into STP can be decreased by installing K-Jr at GT of 10 sectors in Tokyo, and installation to Chinese and barbeque restaurants whose shares 30% and 16% of the total reduction is effective.

As the results, it is accounted that 111 thousand t-CO_2 is annually reduced at sewage treatment systems by installing K-Jr at GT of 10 sectors in Tokyo. Furthermore that is corresponding to 15% of CO_2 emission (730 thousand t-CO_2) of STP in Tokyo (BoSTM, 2015).

For verification of calculated results, a past study says 45 thousand tonnes of grease is generated and 35 thousand tonnes is trapped in GT in Tokyo (Kuramochi et al., 2011). However, the sector classification is different from this study, so the results of the common 7 sectors are reaggregated and compared with our results (Table 1). Our results of generation of FOG may overestimate, though amount of IG is the same almost. This error causes 21% differences of removal ratio, thus our results on reduction of FOG into STP by FPGS has possibility to overestimate by approximately 45%. In addition, because the current model cannot take account of leakage of FOG from sewerage, such as oil ball with CSO, an issue of uncertainty on practical input of FOG into STP remains. Thus practical reduction may become less than the results.

Table 1 Comparison of calculated results with a past study

	This study	**Kuramochi et al. (2011)**
Generation of FOG (tonnes)	54,138	38,456
IG (tonnes)	23,903	25,096
Removal ratio in GT (%)	44%	65%
Reduction of FOG into STP by FPGS	46%	25%

4. Conclusion

This study evaluates effectiveness for reduction of CO_2 emission at sewage treatment system by implementation of FPGS in Tokyo and the result shows 111 thousand t-CO_2 reduction. Although the result has a possibility of overestimation, it is concluded that FPGS may indirectly contribute to decrease CO_2 emission of STP of Tokyo Metropolis by 8-15%.

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WR-B11

Comparative Environmental Impacts and Economic Benefits of Different Wastewater Management for Cassava-Based Ethanol Production in Thailand

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Abstract

This research investigated the environmental impacts and economic benefits of cassava-based ethanol production when wastewater treatment system was modified for the purpose of water reuse and biogas production. This study experimented with three different wastewater management schemes in cassava ethanol production, i.e. open lagoon, Upflow Anaerobic Sludge Blanket (UASB) with biogas recycle for steam production (biogas-steam), and UASB with biogas recycle for electricity generation (biogas-electricity). The ethanol production data was collected and analysed for input and output inventories. The environmental impacts i.e., the potential water reuse, the greenhouse gas (GHG) reduction and the economic benefits i.e., the payback cost and the capital reduction of ethanol production were investigated. The findings revealed that both UASB schemes reduced water consumption by 79% (415449 m^3/year). Moreover, the biogas-steam scenario decreased GHG by 83.25% of the total GHG in base case that was slightly higher than those decreased by biogas-electricity scenario (82.76%). The payback cost of biogas-steam and biogas-electricity was 0.14 and 4.48 years, respectively. The capital reduction of ethanol production was 1.39 and 1.07 THB per L-ethanol for biogas-steam and the biogas-electricity, respectively. Based on the environmental impact and the economic costs, the biogas-steam was the most preferable choice.

Keywords: annual cost; cassava; greenhouse gas; open lagoon; payback cost; UASB

1. Introduction

The current effects of climate change around the world are the increasing surface temperature, melting glacier, and extreme weather (IPCC 2013). The greenhouse gases (GHGs) are important key driver for the climate change (IPCC 2013). Human activities, especially the using of fossil fuels, are the main source of emitted GHGs. EPA (2018) reported that the electricity and heat production sector are the majority of the global GHG emission. The climate change has been resulting in unusual weather and affecting the hydrologic cycle, for instance the strong El Niño in 2015 boosted the hottest global temperature (IPCC 2013). For Thailand, it was predicted that the daily maximum temperature will slightly increase and the duration of the warm period (temperature exceeding 35°C) will extend by approximately 2–3 months (Chidthaisong A. 2010). Therefore, GHGs should be reduced by using alternative energy in particular biogas as well as promoting the water reuse in order to decrease the water stress in El Niño period.

In Thailand, Department of Alternative Energy Development and Efficiency has promoted the using of renewable energy sources especially ethanol to replace methyl tert-butyl ether (MTBE) and to reduce gasoline price (Thailand Environment Foundation 2007). Currently, the ethanol supply is more than the ethanol demand such that the ethanol stock was 94.46 million L in November 2017, while ethanol is employed only 3.94 million L per day (Department of Alternative Energy Development and Efficiency 2017). In addition, this ethanol cannot be exported because Thai ethanol price (24-25 THB) is more expensive than the Philippine ethanol price (16-17 THB) in 2017 (Thai Ethanol Association 2017). Therefore, the capital reduction of the ethanol production in particular by using cassava as raw material was significant. Sorapipatana C. et al. (2011) reported that utility cost, i.e. steam and electricity in the cassava-based ethanol production factory is the highest annual expense. Additionally, the stillage that is effluent of the ethanol distillation process contains high concentration of organic matter, i.e. COD around 40,000–60,000 mg/L (Thailand Environment Foundation 2007), is generally treated in the open lagoon (Silalertruksa T. et al. 2009). The stillage has potential to produce biogas that is employed as energy source for steam production or electricity generation in the ethanol factory (Kasetsart

Agricultural and Agro-Industrial Product Improvement Institute 2006, Thailand Environment Foundation 2007, Moriizumi Y. et al. 2012). Hence, the pervious wastewater treatment process such as open lagoon should be replaced with Upflow anaerobic sludge blanket (UASB) that has higher treatment efficiency for the stillage with characteristic and can generate biogas (Tchobanoglous G. et al. 2003). Moreover, the effluent after treated by UASB should be recycled to the simultaneous saccharification and fermentation (SSF) processes.

Previously, Moriizumi Y. et al. (2012) study five different types of the cassava-based ethanol productions that varied the percentage of using biogas for steam boilers and gas engine powered electricity generator. The results showed that using biogas for stem production could reduce more GHG emissions than using it for gas engine powered electricity generator. While Wang K. et al. (2014) showed that effluent from anaerobic digestion could be used for the ethanol fermentation process. The outcomes of reusing effluent were reduced energy consumption and to get value-added products.

This research provides information of the two main issues, i.e. the environmental impacts and the economic benefits. The former consists of water reuse and GHG, while the latter is the payback cost and the reduction cost of the ethanol production. Moreover, this study intends to find the most preferable options for wastewater management and biogas utilization in terms of the environmental impacts and economic benefits of various schemes.

2. Method

The functional unit of this study was the annual quantity of anhydrous ethanol. The assumption was that an ethanol factory generated 150,000 L of ethanol per day and the working day was 330 days per year. Therefore, this factory produced 49,500,000 L or 49,500 cubic meters of ethanol per year. For biogas production, this paper estimated biogas yield in the steady state. Additionally, the system boundary included ethanol production, wastewater treatment, steam process, and electricity generation.

In this study, there were a total of three scenarios (Fig. 1), i.e. 1) base case (scenario 1) that wastewater was treated by open lagoon system, using natural gas as energy source for the steam production and using electricity national grid mix; 2) biogas-steam (scenario 2) that wastewater was treated by UASB, using biogas (methane) and natural gas for steam production and using electricity national grid mix; and 3) biogas-electricity (scenario 3) that wastewater was treated by UASB, using biogas for electricity generation and using residual biogas and natural gas for the steam production. The differences of the three scenarios were indicated in Table 1.

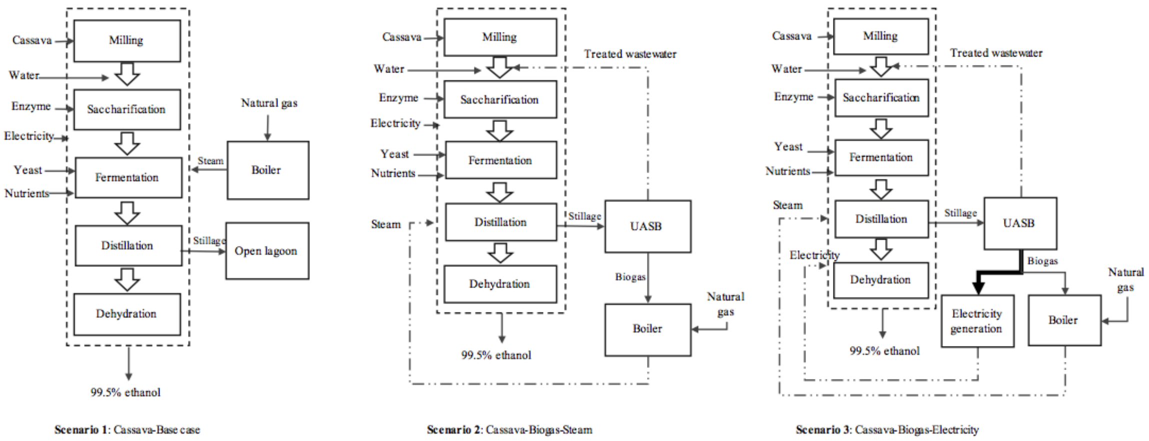

Fig. 1. Flow chart of various cassava ethanol production schemes

Table 1 The differences of three scenarios in terms of the wastewater treatment system and energy sources.

Scenario	Type of wastewater treatment plant	Volume of biogas production (Tons/year)	Using Biogas		Using Natural gas	Using electricity national grid mix (GWh)
			Steam production (GJ/year)	Electricity generation (GJ/year)	Steam production (GJ/year)	
1. Base case	Open lagoon	-	-	-	532999.61	16.06
2. Biogas-steam	UASB	5021.54	226722.38	-	294497.34	16.06
3. Biogas-electricity	UASB	5021.54	61498.73	165223.65	471500.88	-

The information of cassava-based ethanol production was gathered from the secondary data, such as published articles and governmental reports in Thailand between 2006 and 2017. The average input and output data were employed in this paper. The assumption of water reuse in the ethanol industry was such that the industry recycled all treated wastewater into SSF. In addition, this research assessed direct and indirect GHG excluded CO_2 from fermentation process. The former was produced from WWT processes and combusted energy fuel i.e. biogas and natural gas that were analysed base on IPCC (2006b, 2006a) methods. In addition, Thai National Life Cycle Inventory Database (2009) was employed for indirect GHGs particular electricity national grid mix and provincial water supply.

Finally, the payback cost was divided into building cost and annual expenses. The former encompassed the UASB construction cost that modified from Bernal A.P. et al. (2017), and using Purchasing Power Parity (PPP) and Gross Domestic Product (GDP) for changing currencies and base year, respectively (The World Bank 2016), or/and the electricity generation that adjusted from Department of Alternative Energy Development and Efficiency (2014) and also employed PPP and GDP (The World Bank 2016). The latter consisted of the electricity cost (Provincial Electricity Authority 2017), the energy cost especially natural gas (Energy Policy and Planning office 2015) and the water supply expense (Provincial Waterworks Authority 2016). The price of the electricity, the natural gas and the water supply was 1.97 THB/kWh (Provincial Electricity Authority 2017), 0.25 THB/MJ (Energy Policy and Planning office 2015) and 29 THB/m^3 (Provincial Waterworks Authority 2016), respectively. Additionally, this research excluded the depreciation and the maintenance cost of UASB, boiler and the electricity generation. Therefore, the payback period that the building cost divided by the saving cost that equalled the yearly expenses of scenario 1 minus the yearly expenses of scenario 2 or 3. Besides the reduction cost of ethanol production was assessed saving cost after the payback period that the ethanol production cost based on the principle of calculated ethanol price from Energy Policy and Planning office (2011).

3. Results and discussion

3.1 Inventory information

The input and output of inventory data of cassava-based ethanol production in Thailand were presented in Table 2. The production of 1 litre of ethanol employed fresh cassava, water, yeast, enzyme, diammonium hydrogen phosphate, sulphuric acid, sodium hydroxide, electricity and steam on the average of 5.94kg, 10.63L, 0.42g, 2.66g, 7.50g, 2.84g, 1.25g, 0.27kWh and 3.37kg, respectively. In addition, by products of ethanol production were carbon dioxide (CO_2), Distiller's Dried Grains with Solubles (DDGS), and fusel oil that were generated on the average of 0.73kg, 1kg and 3g per L of ethanol produced, respectively. The stillage contained COD and BOD approximately 60,835 and 25,000 mg/L, respectively (Kasetsart Agricultural and Agro-Industrial Product Improvement Institute 2006, Thailand Environment Foundation 2007, Mangmeechai A. et al. 2013, Moriizumi Y. et al. 2012, Silalertruksa T. et al. 2009). According to treatment of stillage by UASB, the average input were 8.39 L stillage/L ethanol, 0.063 kWh electricity/L ethanol, 7.59g sodium carbonate/L ethanol and 1.50g ammonium chloride/L ethanol and the average output were 8.39 L effluent/L ethanol and 4.58 MJ biogas/L ethanol.

Table 2 Inventory information of cassava ethanol production and treated wastewater system.

Inventory information	Unit	Sources					Average	
		Kasetsart Agricultural and Agro-Industrial Product Improvement Institute (2006)	**Thailand Environment Foundation (2007)**	**Silalertruksa T. *et al.* (2009)**	**Moriizumi Y. *et al.* (2012)**	**Mangmeechai A. *et al.* (2013)**	**Unit/L ethanol**	**Unit/year**
Ethanol production								
Input								
Cassava (fresh)	kg	5.71	6.12	6.21			5.94	297693000
Water	L	9	9.08	10.16	11.25	13.64	10.63	525937500
Yeast	ml (*g)	0.33*	0.17		0.75		0.42	20680000
Enzyme	g	2.73	2.74		2.51		2.66	131642500
$(NH_4)_2HPO_4$	g				7.50		7.50	371250000
H_2SO_4	g				2.84		2.84	140580000
NaOH	g				1.25		1.25	61875000
Other chemical reagent	g	20	5.50				12.75	631125000
Electricity	kWh	0.24	0.28	0.30	0.26		0.27	13470188
Steam	kg	2.67	4.07				3.37	166608750
Output								
Ethanol	L	1	1	1	1	1	1	49500000
CO_2 (fermentation)	kg	0.73					0.73	36300000
Stillage	L	7.67	9.67		8.64	7.6	8.39	415449375
COD	mg/L	50000			71670		60835	
BOD	mg/L	25000					25000	
DDGS	kg	1					1	49500000
Fusel oil	g (*ml)	3*	3				3	148500000
UASB								
Input								
Stillage	L	7.67	9.67		8.64	7.6	8.39	415449375
Electricity	kWh				0.06268		0.063	3102660
$NaHCO_3$	g				7.59		7.59	375705000
NH_4Cl	g				1.50		1.50	74250000
Output								
Treated wastewater	L						8.39	415449375
Biogas	MJ						4.58	226722377

3.2 Water reuse

Normally, the ethanol factory consumed water approximately 525,938 m^3/year and the main water consumption was the SSF process. In case of open lagoon (scenario 1), treated wastewater could not be reused as water supply in SSF processes because of the quality of treated wastewater (Wang K. et al. 2014). In general, stillage was treated by open lagoon system in the Thai ethanol industry and there is no direct discharge of this wastewater to the waterway (Mangmeechai A. et al. 2013). The treated wastewater might be used as liquor fertilizer (Moriizumi Y. et al. 2012) or watering trees near the ethanol plants (Mangmeechai A. et al. 2013). This system is the cheapest option (Wei Y.-a. et al. 2004), whereas the hydraulic retention time (HRT) of this system is one or two month (Wei Y.-a. et al. 2004), which is longer than the typical HRT of the UASB system. In this article, the HRT of the UASB is 3.56 days. Hence, the open lagoon system employed area for storage more than UASB system when the organic loading and flow rate of both system were similar.

For the treatment efficiency, UASB (85-90% COD removal) is better than the open lagoon (60% COD removal) (Wei Y.-a. et al. 2004). Therefore, COD of effluent from UASB was lower under the same conditions and treated stillage from UASB can be reused as raw water including nutrients (Wang K. et al. 2014). Additionally, scenario 2 and 3 could reuse effluent up to 100% after being treated by UASB, which were around 415,449 m^3/year. Both scenarios could reduce around 79% of total water consumption. Water reuse could reduce the resources depletion especially raw water and save the water cost (mention in section 4.).

3.3 Greenhouse gas

According to scenario 1, the total yearly released of GHG was around 178,676 Tons CO_2eq and the open lagoon was the main contributor of GHG which produced about 75% of total GHG. For scenario 2 and 3, the stillage was treated by UASB and biogas was used as energy source, therefore GHG from wastewater treatment was not emitted. Additionally, scenario 2 and 3 released GHG approximately 29,923 and 30,812 Tons CO_2eq per year, respectively, and both scenarios had using natural gas that was the majority of GHG contributor. The emitted GHG of biogas-steam and biogas- electricity decreased by 83.25% and 82.76%, respectively due to the unreleased GHG from wastewater treatment and the reduction from using natural gas for steam production or/and electricity generation. Figure 2 provided the yearly emitted GHG for each process under the various scenarios.

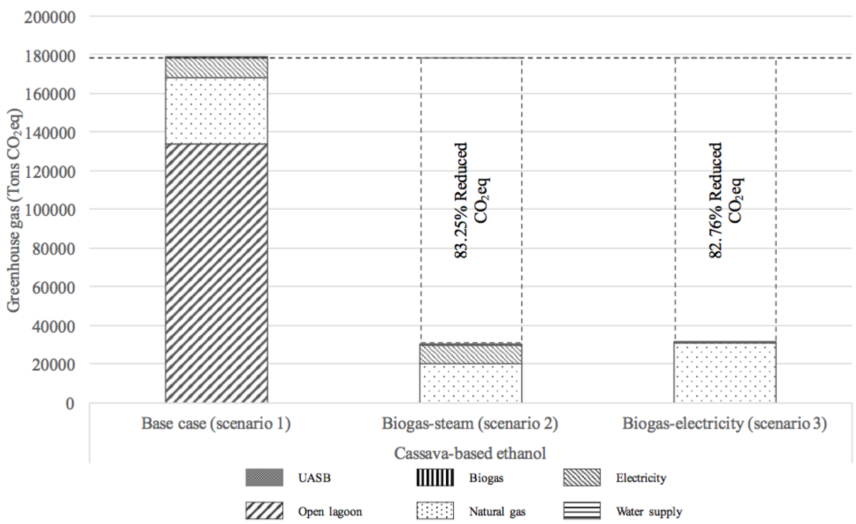

Fig. 2. Annual emitted GHG under the various cassava-based ethanol schemes.

The results of Moriizumi Y. et al. (2012) indicated that stillage treated by the open lagoon system, treated by UASB and using biogas for steam production, and treated by UASB and using biogas for electricity generation, releases the total GHG of 82,665, 34,254 and 47,619 Tons CO_2eq/year, respectively. These results were higher than those from this research except the open lagoon scheme. The GHG that emitted from the open lagoon in this study was higher than Moriizumi Y. et al. (2012) because the energy source in Moriizumi Y. et al. (2012) research were coal and biogas, while this research use biogas and natural gas as energy sources. Nevertheless, this research conformed to Moriizumi Y. et al. (2012)'s study that using biogas for steam generation is more effective in decreasing GHG discharge than for electricity generation.

3.4 Economic benefits

According to payback cost, the building cost of UASB was 2,217.50 THB per m^3 in 2016 hence, the UASB construction cost of scenario 2 and 3 was about 9.99 million THB. While the electricity generation cost around 113 million THB in 2016 per 7.92 GWh/year (one engine). In addition, the cassava ethanol production should employ 2 engines to produce enough electricity for this industry. Therefore, total building cost of the electricity generation was approximately 226 million THB in 2016. Consequently, total building cost of the scenario 2 and 3 was approximately 9.99 and 236.19 million THB, respectively.

In accordance with the annual saving cost, the yearly expenses of scenario 1 equalled 175.57 million THB including the electricity, the natural gas and the water supply cost of 26.56, 133.76 and 15.25 million THB, respectively. While the annual cost of scenario 2 and 3 was 106.62 and 122.84 million THB, respectively. The former consisted of the electricity, the natural gas and the water supply that cost of 26.55, 76.86 and 3.20 million THB, respectively. Additionally, the latter was composed of the natural gas and the water supply that was valued 119.64 and 3.20 million THB, respectively. The annual cost and building cost of all scenarios were provided in Figure 3. Therefore, scenario 2 could save 39.27% of total annual cost of base scenario that was higher than scenario 3 (30.03%) because using biogas for steam production reduced the yearly expenses especially the natural gas cost more than using biogas for generating electricity. The payback period of scenario 2 and 3 were 0.14 years (1.74 months) and 4.48 years (53.76 months), respectively. The starting up UASB maybe take several months to develop the granulated sludge and the biogas yield was low (Tchobanoglous G. et al. 2003). This paper assumed the biogas production when the granulated sludge was in the steady state. Hence, the real payback period might be longer than the calculated payback period.

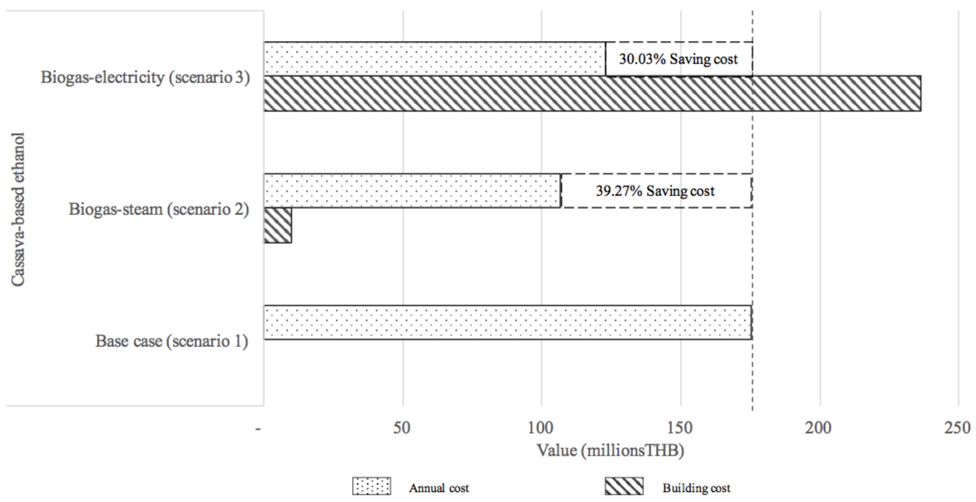

Fig. 3. Annual cost and building cost under the various cassava-based ethanol schemes.

The production cost of cassava-based ethanol is controlled by Energy Policy and Planning office (2011), which is equal to 7.017 THB per L ethanol. The results of annual saving cost in scenario 2 and 3 could decrease the production cost after the payback period. For scenario 2, the production cost reduced 1.19 THB per L ethanol in the first year and 1.39 THB per L ethanol in the second year. While the production cost of scenario 3 dropped 0.55 THB per L ethanol in the fourth year and 1.07 THB per L ethanol in the fifth year. Other way for reducing the production cost was to increase the efficiency of SSF that can increase bioethanol concentration up to around 5% on a w/w basis and consume fresh cassava only 5.56 kg/L ethanol produced (Balat M. et al. 2008).

4. Conclusion

This study investigated and compared the environmental impacts especially the water use and GHG, and the economic benefits particular the payback period and the reduction cost of ethanol under three cassava-based ethanol production schemes. The base case (scenario 1) could not reuse water to SSF process, and was the highest in terms of the GHG released and the annual expense. However, the ethanol industry should reduce the environmental impacts and expenses by replacing the open lagoon with UASB that could produce biogas for steam production (scenario 2) or electricity generation (scenario 3). Both schemes could reuse water approximately up to 79% of total water consumption. In addition, the emitted GHG of scenario 2 and 3 dropped by 83.25% and 82.76% of the base case, respectively. For the economic benefits, scenario 2 invested about 9.99 million THB for UASB, while scenario 3 spent around 236.19 million THB for UASB and the electricity generation. The payback period of both schemes was 0.14 and 4.48 years, respectively. Additionally, the reduction cost of ethanol production was 1.39 and 1.07 THB per L ethanol of scenario 2 and 3, respectively after the payback period. Overall, the cassava ethanol production with biogas for steam production scheme was the most preferable choice due to their environmental impact and economic benefits.

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Modeling Coastal Water Quality in Danang Bay, Vietnam: Models and adjusted parameters

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Abstract

The development of coastal areas recently has paved the way for the new opportunities in Vietnam, when more investments and projects have been approved, promising a bright future of prosperous development. However, apart from those benefits, rapid development causes negative impacts on surrounding environment. Urbanization has unintentionally put a great pressure on infrastructure and ecosystems, coupled with pollution rooted from upstream streams, resulting in the expansion of polluted areas which causes great damage on living standards of those households living in coastal areas. With the purpose of evaluating imbalanced impacts of wastewater treatment plants on causing pollution in Danang Bay, this study applies the MIKE 21 model for evaluating different scenarios. Outcomes from the models will help assess the level of pollution associated with the pollutant volume of waste sources. Calibration, verification for hydrodynamics (HD) and advection – diffusion (AD), Ecolab models have been implemented to ensure the reliability of this study.

Keywords: Coastal water quality, Hydrodynamics, Ecolab, Calibaration, Waste water, MIKE21.

1. Introduction

It is undeniable that the sea is an extremely important source of human resources for the sake of economic and social development (Costanza & al, 1997), (UNEP, 2006), (Barbier, et al., 2011), urbanization and industrialization along the coast have developed rapidly over the past few years worldwide (Wu & Clark, 1983), (Jones & Kaly, 1996), (Wepener & Degger, 2012), (Alexander, et al., 2015). On the other hand, river estuaries and coastal areas often concentrate on urban areas with high population density because they have great potential for economic development such as aquaculture, harbors and tourism activities (Kennish, 2002) (Dias, et al., 2013). Since then, recent decades, coastal areas, near estuaries around the world have been severely affected by rapid population growth leading to urbanization and encroachment. Sea is not controlled (Lindeboom, 2002), (Elliot & Quintino, 2007). Due to the rapid development of domestic wastes, the source of domestic waste is also increasing, causing imbalance in the environment, affecting the water quality of the sea and coastal waters (Hasler, 1947). Finally, pollution in coastal cities has threatened the environment, altering the nature and ecology of the marine environment through direct or indirect methods (Caric, et al., 2016). In addition, Vikas and Dwarakish (2015) also pointed out that pollution of coastal water caused mainly sewage, river discharge or direct discharge to the sea. Sea pollution has a significant impact on ecosystems and also causes health problems in neighboring populations by pathogenic microorganisms (WHO, 1998). The world, as in Kuwait, has also studied the effects of pollutants and the effects of flow, storage time and temperature (Ghobrial, et al., 1987), (Tomar, et al. 1995), (AI-Muzaini, et al., 1991), or the migration process, the effects of waste on the Kuwait coastline (Salem & Salama, 1979), and Litherathy, 1987) and the self-purification in this sea area. A number of studies have shown that each of the areas of the sea capable of self-purification, such as Bhargava, 1983 and Gupta et al, 2003, have estimated the waste water abstraction capacities of Indian waters and waters. As for M.T. Babu et al., 2006, the objective is to estimate the absorption capacity of Kochi coastal waters for urban and industrial wastewater using a two-dimensional water quality model.

With the development of science and technology, the application of evaluation models and spreading simulations is increasingly being used. The use of simulation and prediction of waste generation is essential. According to Li et al., 2003, a model of water quality assessment combined with Delft3D was used to simulate the spread of pollutants in dry and flood seasons or S. Davies et al, 2009 using software Mike 21 for hydrodynamic simulation, water quality and sediment transport for the river and coastal areas of Australia. In Vietnam, there are also studies on the spread of estuaries from the estuary to the nearby coastal area using the

Mike software. 21 (Cong, et al., 2012).

Given the importance of coastal and estuarine waters, the EPA also regulates coastal water quality divided into five classes for other uses (EPA, 1986), Southeast Asia (ASEAN) in general as well as Vietnam in particular have strict regulations with specific indicators (AusAID, 2008). Water quality modeling requires four main input types, topography, water levels, and source information (Kulkarni, 2013).

In particular, topography and water levels affect flow simulation, hydraulic quantities of the study area (Frank, et al., 2011). MIKE model has many different modules, MIKE 21 FM is one of the modules widely used.

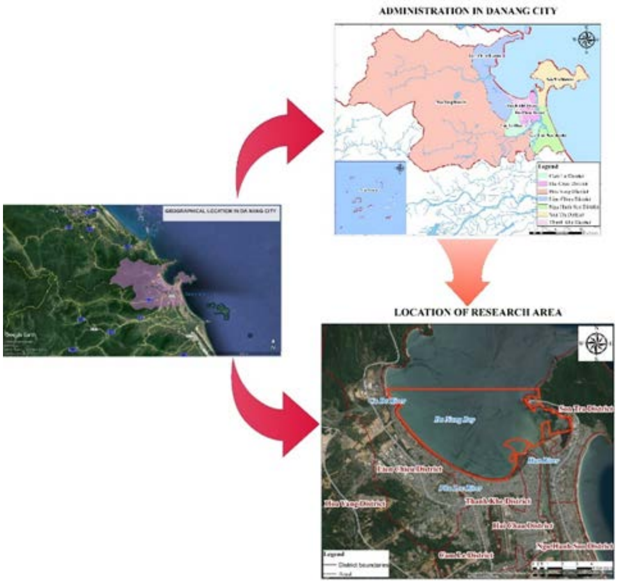

Fig. 1. Study area location and boundary

Danang Bay has high biodiversity, including coral reefs distributed along the coast from Hon Chao to the south of Son Tra Peninsula (Tuan, 2002), (Tuan, et al., 2005). The problem of pollution by organic matter in coastal water has been happening quite popular in the coastal provinces of Vietnam.

The level of monitoring parameters such as Coliform, $NH_4{}^+$ in the period 2011 - 2015 in most of the areas are high levels exceeding the threshold of Vietnam standards, especially in the northern and southern seas, the level of Coliform and NH4 + over the 6 years from 2010-2015 always exceed 1-1.5 times. Tho Quang boat (Da Nang) is one of the hot spots of marine pollution in recent years (General Department of Environment Viet Nam, 2016).

Fig. 2. Picture the actual study area

The results of this work will provide an insight as well as an approach in the study of coastal water environment in the lagoon areas, support for project proposals, and subsequent tasks. This paper presents the initial results of applying the MIKE 21 simulation model to simulate coastal water pollution from domestic wastewater, thus identifying the parameters that affect the process of propagation and Diffuse pollutants in seawater. The study area was identified as part of the Danang Bay

2. Research method

2.1 Hydraulic and water quality modeling

2.1.1 Hydrodynamic module

The Hydrodynamic module is based on numerical solution of the depth integrated incompressible flow Reynolds-averaged mass conservation and Navier-Stokes momentum equations (DHI, 2014).

The governing equations include:

Mass conservation:

$$\frac{\partial \zeta}{\partial t}+\frac{\partial p}{\partial x}+\frac{\partial q}{\partial y}=\frac{\partial d}{\partial t}$$

Momentum conservation:

$$\frac{\partial p}{\partial t}+\frac{\partial}{\partial x}\left(\frac{p^2}{h}\right)+\frac{\partial}{\partial y}\left(\frac{pq}{h}\right)+gh\frac{\partial \zeta}{\partial x}+\frac{gp\sqrt{p^2+q^2}}{C^2.h^2}-\frac{1}{\rho_w}\left[\frac{\partial}{\partial x}(h\tau_{xx})+\frac{\partial}{\partial y}(h\tau_{xy})\right]-\Omega q -fVV_x+\frac{h}{\rho_w}\frac{\partial}{\partial x}(p_a)=0 \quad (1)$$

$$\frac{\partial q}{\partial t}+\frac{\partial}{\partial y}\left(\frac{q^2}{h}\right)+\frac{\partial}{\partial x}\left(\frac{pq}{h}\right)+gh\frac{\partial \zeta}{\partial y}+\frac{gq\sqrt{p^2+q^2}}{C^2.h^2}-\frac{1}{\rho_w}\left[\frac{\partial}{\partial y}(h\tau_{yy})+\frac{\partial}{\partial x}(h\tau_{xy})\right]+ \Omega p-fVV_y+\frac{h}{\rho_w}\frac{\partial}{\partial y}(p_a)=0 \quad (2)$$

The following symbols are used in the equations: h(x, y, t) – water depth (=ζ - d, m); d(x, y, t) – time varying water depth (m); ζ(x, y, t) – surface elevation (m); p, q(x, y, t) – flux densities in x – and y – direction ($m^3/s/h$) = (uh, vh), (u, v)- depth averaged velocities in x – and y – directions; C(x, y) – Chezy resistance ($m^{1/2}/s$); g – accelerations due to gravity (m/s^2); f(V) – wind friction factor; V, V_x, V_y (x, y, t)- wind speed and components in x – and y – direction (m/s); Ω(x, y) – Coriolis parameter, latitude dependent (s^{-1}); p_a(x, y, t) – atmospheric pressure ($kg/m/s^2$); ρ_w – density of water (kg/m^3); x, y – space coordinates (m); t – time (s); τ_{xx}, τ_{xy}; τ_{yy} – components of effective shear stress.

2.1.2 The model MIKE21 ECOLAB

The module is mostly used for modelling water quality as part of an Environment Impact Assessment (EIA) of different human activities of estuary, creek and open ocean area with MIKE21, MIKE3, MIKE11 hydrodynamics. The strength of this tool is the easy modification and implementation of mathematical descriptions of ecosystems into the hydrodynamic software (DHI, 2017). The 2D depth-averaged transport equation for a non-conservative pollutant is given as:

$$\frac{\partial C}{\partial t}=Dx\frac{\partial^2 C}{\partial x^2}+Dy\frac{\partial^2 C}{\partial y^2}-U\frac{\partial C}{\partial x}-V\frac{\partial C}{\partial y}-\lambda C+..... \quad (3)$$

Where D_x, D_y are the dispersion coefficients in x and y direction; U, V the depth mean velocities in the x and y directions, respectively (m/sec); λ id the decay coefficient (s^{-1}). This equation is numerically solved by an explicit finite difference scheme using MIKE21. The model outputs are evaluated using the performance criteria described in the next section.

2.2 Set up the model

2.2.1 Study area

In this study, the geographic location of the area is shown in Fig. 1, Fig. 2. The water level is defined along the open boundary for the flow calculation model , in the study area the authors split into two boundaries As shown in Fig. 5, the second boundary is the East Sea (water level data) and the one containing the discharge (flow data). Items 2.2.2, 2.2.3, 2.2.4 will explain in detail the input data model.

2.2.2 Terrain and water level data

With this model data input, Danang Bay's seafloor data shown in Fig. 3 is taken from the General Bathymetric Chart of the Oceans (GEBCO) web site: https://www.gebco.net/ The most reliable, publicly available ocean data set available (GEBCO, 2016).

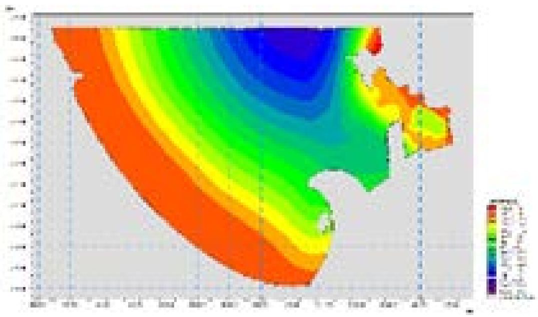

Fig. 3. Regional area

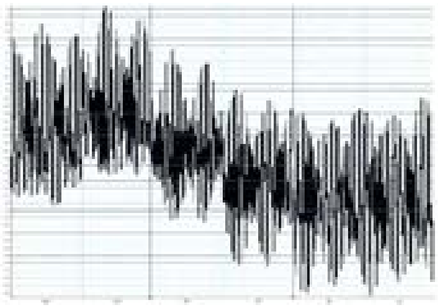

Fig. 4. Water level data

The water level data is derived from the MIKE Tide prediction tool set, the boundary values taken along the boundary line along the regional terrain calculated from the date of calculation from January 1, 2016 to June 30. / 2016, the data is shown in Fig. 4 (DHI, 2017). In addition, the meteorological data is taken from the meteorological observation station of Da Nang Airport in 2016.

2.2.3 Climate data

The meteorological information is taken from meteorological records at Da Nang airport, the data in the form of statistical files should be handled according to the requirements of the model. Extract the data of wind speed (m/s) and wind direction (degree) into Time series file for inclusion in MIKE model (DHI, 2014).

2.2.4 Emission data

Danang Bay with the development of tourism, the sea encroachment area became more and more popular. In this study, five major sources of waste are considered, as shown in Fig. 4. In this source, the source is divided into two main areas: the direct source of the bays from Cu De, Han and Phu Loc rivers.

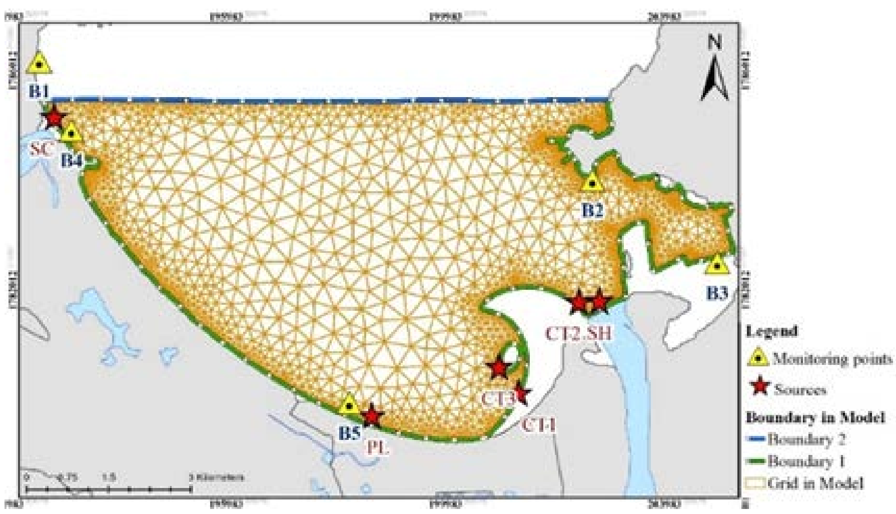

Fig. 5. Emission of location, monitoring points, and model boundaries in the study area

The research team will consider the source of discharged into the river and after the completion of the new Da Phuoc urban area, there will be 3 sewages pouring into the bay, location of waste sources.

Coastal water quality data for the baseline data is the average data from the monitoring stations in the Gulf from the Danang Technical Center. The location of monitoring stations is shown in Fig. 5.

3. Results

3.1 Scenarios description

Through the field survey, the synthesis and processing of data in the study area affect the coastal water environment. The main source of pollution is sewage from inland residential areas along the rivers flowing into the area, the aquaculture of coastal households contributes to these activities. This contributes to the impact on coastal ecosystems (Hiep, et al., 2012). In recent years, coastal cities have developed rapidly, putting more pressure on the coastal environment. From the above problems, the team has created two simulation scenarios as follows:

- Scenario 1: Simulation of pollutant concentration in case the urban area is operating in the future.
- Scenario 2: Simulating the impact of environmental incidents from Phu Loc's domestic wastewater treatment plant in the period of urbanization has not yet been put into operation.
- Scenario 3: Simulating the impact of environmental incidents from Phu Loc's domestic wastewater treatment plant in the urban phase has been put into operation.

In addition, the aim of the research team was to achieve, in addition to assessing the spread of the substance in the study area, but also to derive the ecological parameters of the Ecolab module which influenced the simulation process. Coastal waters.

Calibration and validation of hydraulic models

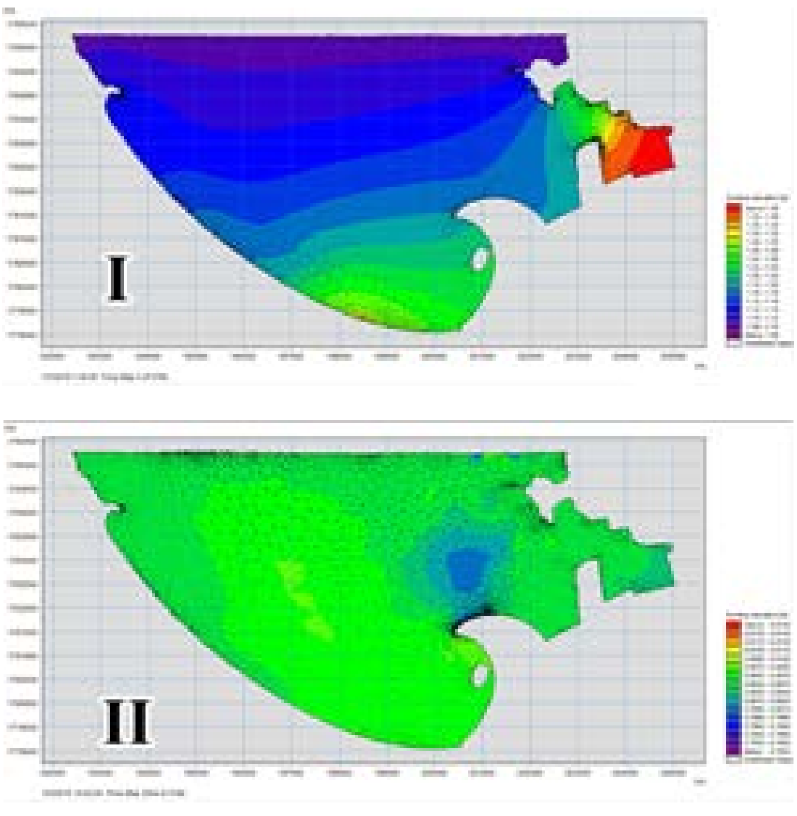

Fig.6. Water levels simulated in the area from January 1, 2016- (I) and March 3, 2016- (II)

Table 1 Nash coefficient and correlation coefficients for calibration and validation

	Correlation coefficients	**Nash coefficient**
Calibration results	0.99	0.789
Validation results	0.99	0.871

The model is calibrated and validated according to the water level data at coordinates (Long: $108^0 13$ 'E, Lat: $160^0 7$'N) at the main port of Da Nang in the tide of 2016 (General Department of Sea and Islands Viet Nam, 2016). The calibration parameters were then tested with water levels from DHI global data from May 1, 2016 to May 31, 2015. Fig. 7, Fig. 8 below shows the water level variables computed and measured when calibrated and validated in the study area. The results show that there is a high degree of similarity in phase and water level between simulation results of the model and data in both calibration and calibration.

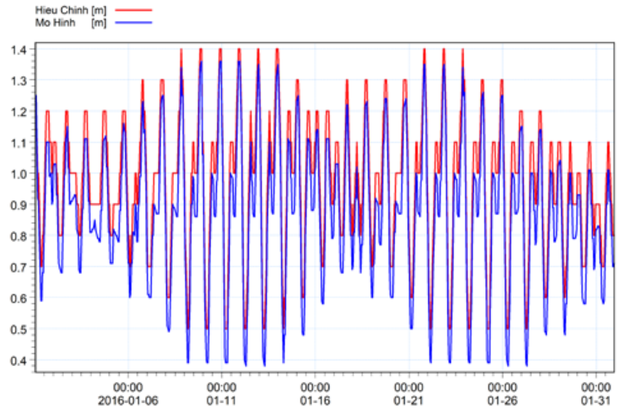

Fig.7. Regional area

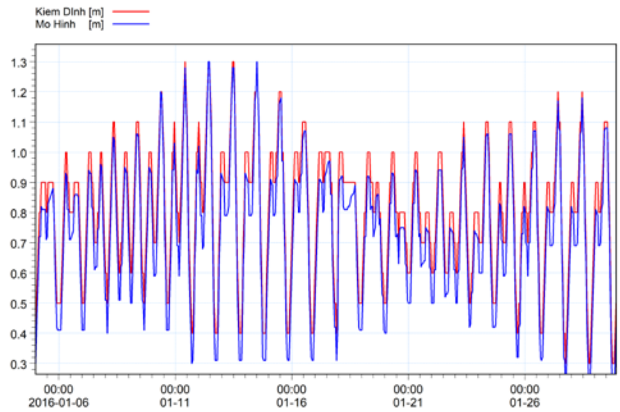

Fig.8. Water level data

From the process of calibrating and validating the model results with actual data, a number of typical parameters determining hydraulic results in this study were drawn. Table 2 shows the value of the hydraulic model input setting.

Table 2 Input calibrated parameter into hydraulic model

No.	Coefficient	Value
1	Running time	01/01/2016 – 30/06/2016
2	Viscosity coefficient	0.3
3	Manning (M) coefficient	33 $m^{1/3}/s$
4	Time step	30s
5	Triangle area	50.000.000 m^2
6	Wind data (direction + speed)	01/01/2016 – 30/06/2016
7	Water level	01/01/2016 – 30/06/2016

3.2 Calibrated Ecolab module in MIKE21 FM

Since the data collection is still difficult, it is only possible to correct and determine the relevant coefficients of the two indicators, NH_4^+ and Coliform. Modification of the parameters in the Ecolab module in MIKE was carried out at three sites located along the Danang Bay. The correction period was two days for the measurements on 02/02/2016 and 04/03/2016. City Monitoring Center Danang.

The correction position and NH_4^+ concentration at the time of calibration are also shown in Fig. 8, where Fig. 9-A illustrates NH_4^+ concentrations as of 02/02/2016 and Fig. NH_4^+ day 04/03/2016. Similarly, Fig.s 10-A and B also illustrate the concentration of coliforms in the study area on 02/02/2016 and 04/03/2016.

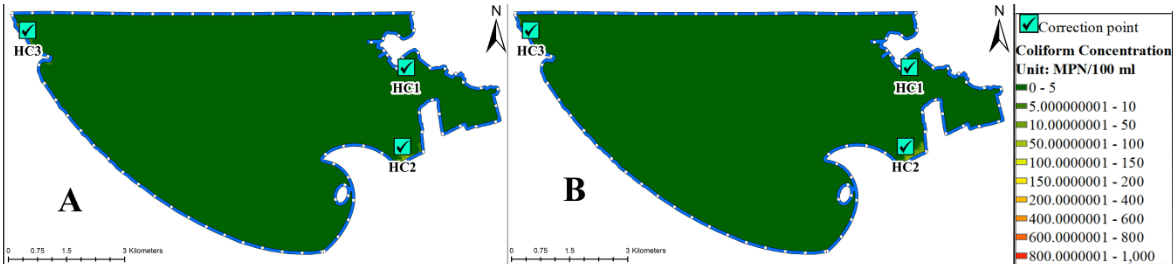

Fig.9. Location and concentration of NH_4^+ at the time of calibration

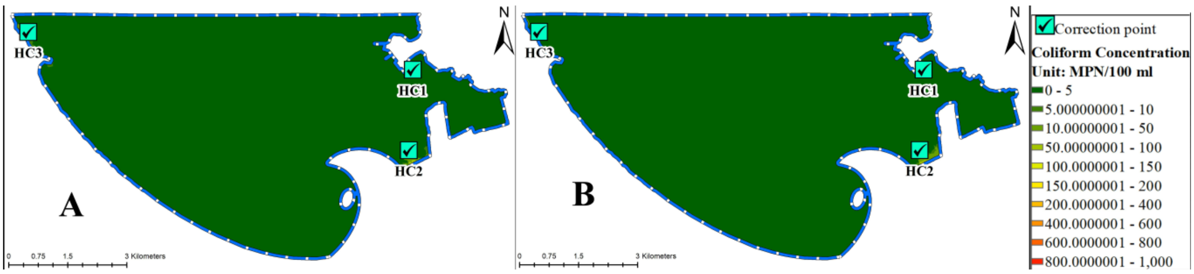

Fig.10. Location and concentration of coliform at the time of calibration

Table 3 Results of the Nash coefficient check during parameter modification of the Ecolab module

No.	Location	Nash coefficient of NH_4^+	Nash coefficient of Coliform
1	Cu De River estuary	0.743	0.74
2	Han River estuary	0.761	0.76
3	Tien Sa port bridge	0.828	0.846

Because nitrification in nature consists of several stages and is governed by various parameters and intersections (DHI, 2012). According to the study (English, 2017), some parameters have been shown to affect the concentration of emulsifiers.

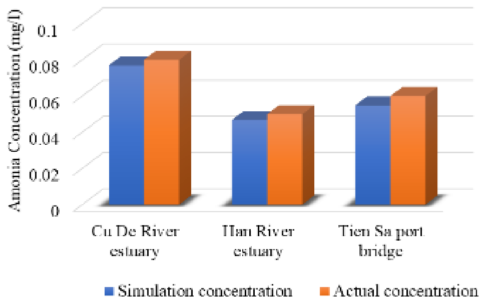

Fig.11. Simulation and actual concentration of NH_4^+ in 02/02/2016

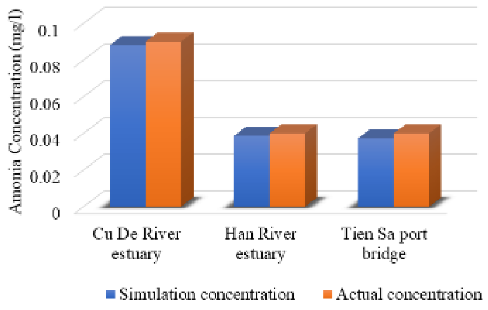

Fig.12. Simulation and actual concentration of NH_4^+ in 04/03/2016

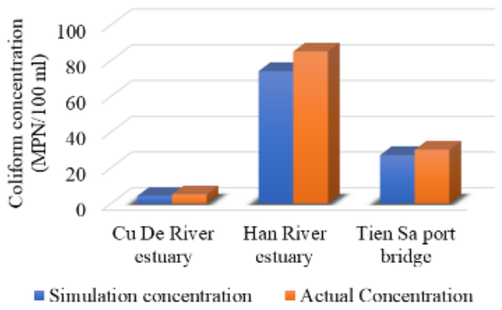

Fig.13. Simulation and actual concentration of Coliform in 02/02/2016

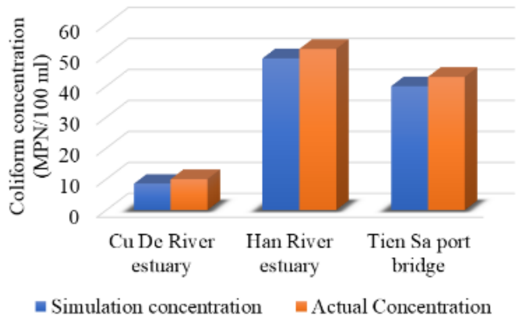

Fig.14. Simulation and actual concentration of Coliform in 04/03/2016

This study has also identified a number of parameters that affect the biology of substances in the study area. Fig. 11, Fig. 12 shows the concentrations between the model and reality on 02/02/2016 of the two NH_4^+ and Coliform species, Fig. 13 and Fig. 14 shown for April 3, 2016.

Table 4 Parameter values in the Ecolab module

No.	Parameter calibrated	Value	Unit
1	Coliforms: 1. Order decay Faecal coliforms	1,7	Per day
2	Coliforms: 1. Order decay Total coliforms	1,8	Per day
3	Coliforms: Arrhenius temperature coefficient	1,09	Dimensionless
4	Coliforms: Salinity coefficient of decay rate	1,2	Dimensionless
5	Coliforms: Light coefficient of decay rate	7,6	Dimensionless
6	Coliforms: 1. Order decay Faecal coliforms	1,09	1/m
7	Nitrification: Ammonia decay rate at 20 deg	1,78	/day
8	Nitrification: Temperature coefficient for nitrification	1,16	Dimensionless

3.3 Simulated scenarios results

Based on the revised set of parameters with independent data to assess the suitability of the model parameters. The authors simulate the three scenarios mentioned in 3.1. The following is the results of the propagation simulation, the concentration and area of two NH_4^+ and Coliform.

Scenarios 1

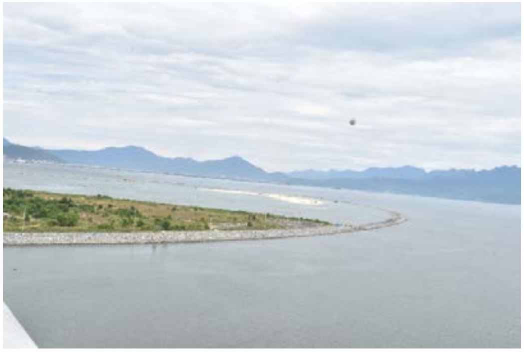

Fig.15. Location of new urban area

The level of NH_4^+ in scenario 1 is relatively low, not exceeding column 2 of QCVN 10-MT: 2015 / BTNMT on coastal water quality. Although there are 3 more wastewater treatment plants in Da Phuoc new urban area, the NH4 + concentration in the surrounding areas is still not much higher than before the operation. The concentration around the plants is in the range of 0.05 mg / l to 0.1 mg / l, much lower than column 2 of QCVN 10-MT: 2015 / BTNMT.

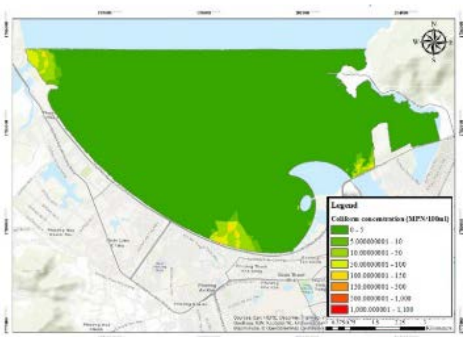

Fig.16. Coliform concentrations in scenario 1 at 9 o'clock on January 14 th for the whole area

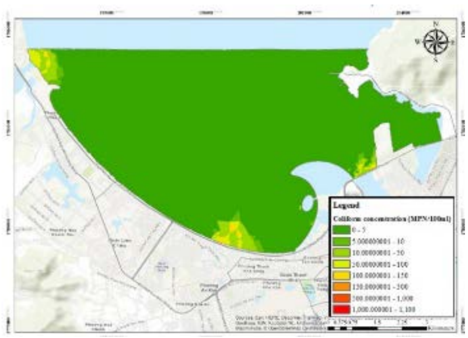

Fig.17. Coliform concentrations in scenario 1 at 9 AM on January 14 th in new urban area

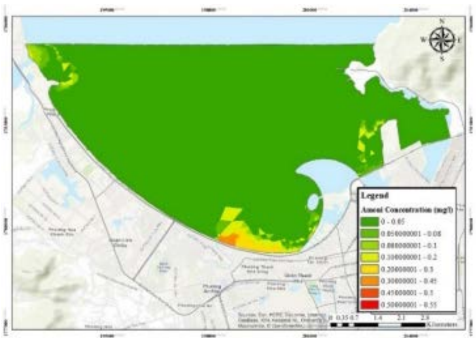

Fig.18. NH_4^+ concentration in scenario 1 at 9 o'clock on January 14 th for the whole area

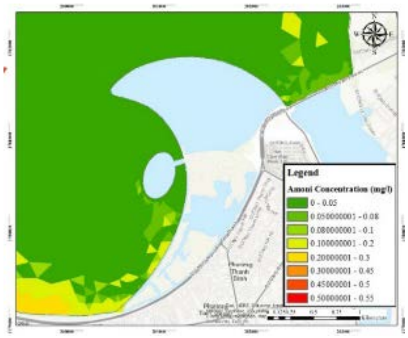

Fig.19. NH_4^+ concentration in scenario 1 at 9 AM on January 14 in new urban area

Fig.s 16 to 17 show the concentration of NH_4^+ in the study area and the specific location where the new urban area is located. Fig.s 18 to 19 show the concentration of Coliform in the study area and the specific location where the new urban area is located.

Scenario 2

Concentration of NH_4^+ in scenario 2 is always high, crossing column 2 of Vietnam Standards on coastal water quality. High concentrations, over the standards mainly concentrated in the area of the Phu Loc River, where the incident and the trend of spread along the coast in the direction of flow.

At the time of the occurrence of the 14-day incident, the NH_4^+ concentration remained high, exceeding the second column of the Vietnam Standards by 2 to 5 times. The concentration in excess of the standard (over 0.5 mg / l) is approximately 1,315,388,779 m^2 (≈1.3km^2), concentrated areas in the area of Phu Loc River and tend to spread along the coast toward where New urban area Da Phuoc. The concentration distribution is shown in Fig. 18.

At the time of the occurrence of the 14day incident, the concentration of Coliform remained high, surpassing column 2 of the Vietnamese Standards approximately 1.2 times. The concentration in excess of the standard (over 0.5 mg / l) is approximately 984,403.44 m^2 (≈ 9.84 km^2), concentrated areas in the area of Phu Loc River and tend to spread along the coast toward where New urban area Da Phuoc. The concentration distribution is shown in Fig. 19.

Scenario 3

Concentration of NH_4^+ in scenario 3 is always high, beyond column 2 of QCVN 10-MT: 2015 / BTNMT on coastal water quality. The high concentration in the Phu Loc River, where the incident occurred and the trend along the coast in the direction of flow. Although this scenario has considered the operation of three domestic wastewater plants but did not contribute too much to the concentration of pollutants in the event of an incident.

At the time of the occurrence of the 14 days incident, the NH_4^+ concentration remained high, exceeding the 2nd column of the Vietnam Standards by 2 to 6 times. The concentration in excess of the standard (over 0.5 mg / l) is approximately 1,315,488,779 m^2 (≈1.3km^2), concentrated areas in the area of the Phu Loc River and tend to spread along the coast toward where New urban area Da Phuoc. The concentration distribution is shown in Fig. 20.

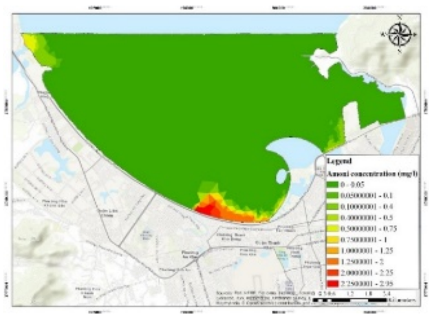

Fig.20. NH_4^+ concentration in scenario 2 at 9 o'clock on January 14th

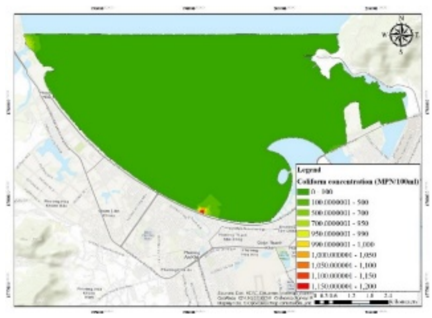

Fig.21. Coliform concentration in scenario 2 at 9 o'clock on January 14th

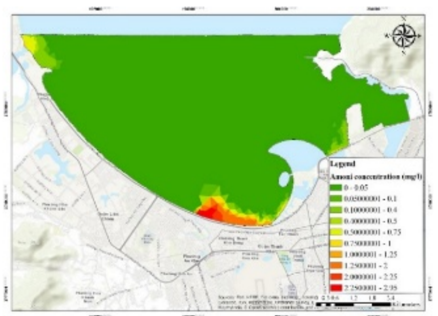

Fig.22. NH_4^+ concentration in scenario 2 at 9 o'clock on January 14th

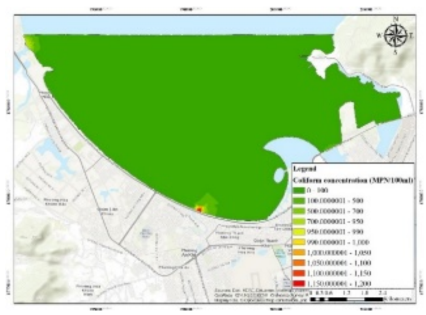

Fig.23. Coliform concentration in scenario 2 at 9 o'clock on January 14th

At the time of the incident 14 days, the concentration of Coliform remained high, exceeding column 2 of QCVN 10-MT: 2015 / BTNMT approximately 1.3 times. The concentration in excess of the standard (over 1000

MPN / 100ml) is approximately 1,002,403.44 m^2 (≈ 1 km^2), concentrated areas in the area of Phu Loc River and tend to spread along the coast toward where New urban area Da Phuoc. The concentration distribution is shown in Fig. 21.

4. Conclusions

Based on the data collected on meteorology, navigation, terrain and monitoring results from the waste source area, the authors have developed a set of hydraulic parameters including: coefficient of roughness, coefficient of viscosity and net area in the MIKE 21 FM HD model. Parameters were calibrated and verified with high correlation coefficient (R^2> 0.9), reliable NASH coefficient (NSE> 0.78) for hydraulic model.

In addition, the result of modifying the Ecolab module is also reliable when the NSE factor is greater than 0.74. Based on the above results, the team has identified a set of coefficients that affect the $NH_4{}^+$ and coliform spread in the study area. The parameters determined are as follows: Order decay Faecal coliforms and Total coliforms, Arrhenius temperature coefficient, Salinity and Light coefficient of decay rate for Coliform and Ammonia decay rate at 20 deg , Temperature coefficient for nitrification for $NH_4{}^+$.

The authors also applied a set of parameters to simulate three scenarios assessing water quality in the study area. For scenario one, the urban area put into operation in the future, the concentration of NH4 + and coliform will not change much compared to water quality in 2016. On the other hand, in scenario two and scenario three, the occurrence of environmental incidents at Phu Loc's domestic wastewater treatment plant at present and in the future has shown enormous impact on the environment and tourism development. However, in order to improve the accuracy and reliability of the model it is necessary to collect, measure and monitor additional quality data at bay in long time series as well as to update the terrain details area.

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WR-B14

Impact of flow rate on adsorption column capacities of different pore size distribution on activated carbons.

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Abstract

The impact of flow rate on adsorption columns with different pore size distribution have not been imprecise and unclear. Therefore, clarification of this impact on activated carbon adsorption columns that are Bituminous coal base (BAC) and Coconut-shell base (CAC) were interested to study. By experiments of Brunauer–Emmett–Teller (BET) method, adsorption isotherm, and adsorption kinetic, similarity of sorption site, adsorption capacity, and adsorption rate were found to indicate the same adsorption properties of CAC and BAC on dissolved organic matters in surface water. However, adsorption column experiments reveal higher adsorption capacities of CAC at 60 mL/min of flow rate and when the flow rate was increased to 120 mL/min higher adsorption capacity of BAC was found. This behavior could be described due to the increase of flow rate reduce liquid film resistance which contributed to increase of Thomas model adsorption rate constant. In contrast, the lower proportion of mesopores of CAC results in increasing of adsorption rate but was not enough to retain the adsorbates. The results indicate that flow rate on adsorption columns with different pore size distribution effect to adsorption mechanism even through the other properties of CAC and BAC is similar.

Keywords: Activated carbon adsorption column; Dissolved Organic Carbon; Flow rate variation; Granular activated carbon; Pore size distribution; Surface Water treatment

1. Introduction

Activated Carbon adsorption process is wildly used to retain hydrophobic pollutant in water such as solvents, pesticides, and color from humic substances, odor, and other dissolved organic matter (Benjamin & Lawler, 2013). Granular activated carbon (GAC) and powdered activated carbon (PAC) have been used to adsorb the pollutant in fixed bed column and contacting basin, respectively. The adsorbent transportation system is divided in to three mechanisms, first the bulk solution transport mechanism that the adsorbate diffuses from bulk solution to edge of boundary layer surrounding the activated carbon particle (liquid film), second external diffusion which the adsorbate is diffused across liquid film by concentration difference as driving force under liquid film resistance, and third intraparticle diffusion which pore and surface diffusion are occurred before adsorption (Tchobanoglous et al., 2003; Cecen & Aktas, 2012).

BET method is the typical method that use to estimate physical characteristics of activated carbon such as specific sorption site and pore-size distribution. The specific sorption site indicates adsorption capacity. In addition, adsorption isotherm is used to examine adsorption capacity. The value of BET specific adsorption surface area of activated carbons always reacts in the same way with the adsorption capacity which obtain from adsorption isotherm experiment due to the capability to adsorb of adsorption site surface (Bansal & Goyal, 2005). Nevertheless, the difference of pore size distribution also effects to the intraparticle diffueion mechanism of activated carbon. The ASTM international classified pore size (base on the assumptions that the pore is cylindrical and have no intersection) in three types macropores the pore that the diameter higher than 50 nm, mesopores that the diameter are 2 to 50 nm and microspores which are defined by less than 2 nm in diameter. On mesopores and micropores surface the adsorption sites are found due to high adsorption energy especially in micropores. On the contrary, there are much lower adsorption site on macropore due to low adsorption energy. This reason contributes to neglect of macropores sorption site (Cecen & Aktas, 2012). Although lower sorption site on macropores and mesopores decrease sorption sites as adsorption capacity of activated carbon but their broader pores can reduce diffusion path of adsorbent to be adsorb at high energy adsorption site on micropores surface inside activated carbon (Hsieh & Teng, 2000; Cecen & Aktas, 2012).

Flow rate is important factor of the adsorption column of GAC that impact to adsorption rate of the column. The film diffusion resistance of liquid film can be reduced by increase of flow rate that contribute to higher adsorption rate. This behavior was found in the case of phenol (as organic adsorbate) adsorption (Omri & Benzina, 2014) and percolate (as inorganic adsorbate) adsorption (Radhika et al., 2018) that the adsorption rate constant was increased by the increase of flow rate. Nevertheless, the film diffusion is not only a mechanism that dominate adsorption rate. As far as we know, although the impact of flow rate on adsorption column was investigate but the impact on different pore size distribution (that effect to the others adsorption mechanism) GAC column is still imprecise.

This study focused on the investigation of the impacts of flow rate on different pore size distribution adsorption columns with the similar results that obtained from adsorption isotherm and adsorption kinetic studies (batch adsorption properties) of CAC and BAC columns. The study conduct with the adsorption of DOC as representative of dissolved organic carbon (DOC), 254 nm ultraviolet absorbance (UV_{254}) as representative of humic-like substances, and color in Pt-Co unit in surface water by CAC and BAC. The activated carbons physical characteristics and batch adsorption properties were obtain from BET, Adsorption Isotherm, and adsorption kinetic study. After the batch properties had been studied, the adsorption column studies were proceeded through adsorption breakthrough curves at flow rate of 60 and 120 mL/min to find the adsorption properties of the columns. In addition, the Thomas adsorption model which fit to adsorption behavior of CAC and BAC was used to identify adsorption rate and adsorption capacities to investigate their change at different flow rate.

2. Materials and Methods

2.1 Activated carbons and raw water characteristics

Two types of commercial activated carbon (HRO 8x30 as CAC type and GB 1000 8x30 as BAC type at appearance density of 0.48 g/cm^3 and 8x30 ASTM Mesh size 2.36 to 0.60 mm) that are used for drinking-water treatment applications was obtained from Carbokarn Co., Ltd., Bangkok, Thailand. CAC and BAC were rinsed by deionized (DI) water to avoid ash until the supernatant was clear before use. As adsorbate solution, surface water from Prapa canal at entrance of water treatment plant of Metropolitan waterworks authority during rainy season (between May to October) in year 2016 and 2017 was immediately used to characterize within 6 hours. The average value of DOC, UV_{254}, and color are varied between 4.955 to 7.053 mg/l, 0.157 to 0.214 cm^{-1}, and 15.14 to 30.8 Pt-Co unit, respectively.

2.2 Activated carbons characteristics and raw water parameters analysis methodology

The specific surface area, total pore volume, external surface area and average pore diameter of CAC and BAC were identified by BET method on 3Flex surface physisorption and catalyst characterization from Micromeritics Co., Georgia, USA with N_2 adsorption. The samples were prepared by degasification at 300 ºC. Furthermore, scanning electron microscope; Quanta 450 FEI, Fisher Scientific Co., New Hampshire, U.S.A. The model was used to illustrate external surface area of CAC and BAC.

Before analysis, adsorbed water samples were filtered through 0.45 µm acetate cellulose membrane. DOC was analyzed by Total Organic Carbon Analyzer from Shimadzu TOC-L, Shimadzu Co., Tokyo, Japan. In addition to analyze UV_{254} and color (follow the APHA 2120C method) by Material Spectrophotometer; Hitachi U-2800 from Hitachi Co.,Ltd., Tokyo, Japan. Furthermore, specific ultraviolet absorbance (SUVA) was used to indicate humic substances, molecular mass, and hydrophobicity in water. SUVA can be obtained from percentage ratio between UV_{254} (cm^{-1}) and DOC (mg/L) as shown in Equation (1). When SUVA value is 4 or higher indicate mainly of humic, high molecular mass, and high hydrophobic substances in water. On the other hand when the value is 2 or lower indicate non-humic, low molecular mass, and low hydrophobic substances. SUVA value between 2 and 4 indicate mixtures of humic and non-humic, molecular mass, and hydrophobicity (Yapsakli & Cecen, 2010; Shen et al., 2016).

$$SUVA = \frac{UV_{254}}{DOC} \times 100 \tag{1}$$

2.3 Batch adsorption studies

BAC and CAC were prepared to 0.8, 1.6, 4, 8, 16, 40, and 80 g with 800 mL of raw water and mixed by Jar-test at 110 rpm at 30.7 ºC for 24 hours. After 24 hours of mixing DOC, UV_{254} and color were analyzed and plotted in Freundlich and Langmuir adsorption isotherm equations to determine proper adsorption behavior as shown in Equation (2) and (3), respectively.

$$q = K_F \cdot C_e^{\frac{1}{n}} \quad (2)$$

$$\frac{1}{q} = \frac{1}{K_L \cdot q_m} \cdot \frac{1}{C_e} + \frac{1}{q_m} \quad (3)$$

Where q is adsorption capacity that is the adsorbed adsorbate quantity on activated carbon adsorbent (mg/g, cm^{-1}/g and Pt-Co unit/g), K_F and n are Freundlich isotherm constants which are corresponded to adsorption capacity and adsorption intensity, respectively. C_e is equilibrium adsorbent quantity (mg/L, cm^{-1} and Pt-Co unit), K_L and q_m are Langmuir isotherm constants that related to the energy of adsorption and maximum adsorption capacity.

2.4 Kinetic adsorption studies

Optimum dose of CAC and BAC were selected from batch adsorption study mix with 800 mL of raw water by Jar-test at 110 rpm at 30.7 ºC. Then, 20 mL of total volume of GAC and adsorbed water at 0.5, 1, 1.5, 2, 3, 4, 5, 7 and 10 minutes were taken to analyze residual DOC, UV_{254} and color changing within 10 minutes of contact time to observe adsorption reaction order and adsorption rate identification.

2.5 Adsorption column study

Raw water was fed through 4 cm diameter and 37.9 cm height of GACs adsorption column at flow rate of 60 and 120 mL/min. The adsorbed water was taken by 250 mL to every 4 litres throughput volume to analyze residual DOC, UV_{254} and color. The fraction of residual adsorbate quantity at t minutes (C_t) and initial adsorbate quantity (C_0) was plotted against breakthrough volume to identify adsorption capacity (area above breakthrough curve), breakthrough volume (V_b) that is the volume at turning point of C_t/C_o, exhausted volume (V_e) that is the volume at C_t is 95% of C_0 and sorption zone (H_z) that obtain from Equation (4).

$$H_Z = H_T \cdot \left(\frac{V_T - V_b}{V_T - \left(\frac{1}{2}(V_T - V_b)\right)}\right) \quad (4)$$

Where H_z is sorption zone height (cm), H_T is total adsorption bed height (cm), and V_T is total throughput volume (mL).

2.6 Thomas Model

The Thomas adsorption model is widely used to predict the adsorption process among others most general models where Langmuir adsorption isotherm and second-order reversible reaction as adsorption order are the model conditions. This model is based on the relationship between C_t/C_o and breakthrough volume which is described by Equation (5).

$$ln\left(\frac{C_0}{C_t} - 1\right) = \left(\frac{K_T q_0 m}{Q}\right) - \left(\frac{K_T C_0}{Q}\right) V \quad (5)$$

Where K_T is the Thomas constant; indicate to adsorption rate (L/h-mg), q_0 is maximum column adsorption capacity (mg/g), m is GAC adsorption quantity (g), Q is flow rate (L/min), and V is throughput volume (Khraisheh et al., 2010).

3. Results and discussion

3.1 Pore size distribution and pore characteristics

The pore size distribution and pore characteristics of CAC and BAC were characterized by using the BET method, as shown in Table 1. The BET result shows similarity of BET surface area of the CAC and BAC as

849.4 and 901.6 m^2/g, respectively these are well known as adsorption sites. Furthermore, the total pore volume between CAC and BAC were compared and show similar value of 0.48 and 0.52 cm^3/g, respectively. The results contribute to similar adsorption capacity and similar average pore diameter. Although the BET surface area and the total pore volume of both kinds of GAC were similar, the proportions of mesopores and micropores are different (the volume of macropores are negligible because of their very low adsorption potential). Micropores comprise the main proportion of CAC (64%). On the contrary, mesopores comprise the main proportion of BAC (56%). Furthermore, the higher proportion of external surface area of BAC (55%) reflects its rougher surface compared to CAC (32%).

Table 1 Pore size distribution and pore characteristics of CAC and BAC.

Carbon type	BET surface area (m^2/g)	Total pore volume (cm^3/g)	Pore volume distribution		External surface area (m^2/g, %)	Average pore diameter (mm)
			Mesopores volume (cm^3/g, %)	Micropores volume (cm^3/g, %)		
CAC	849.4	0.48	0.18 (36)	0.30 (64)	276.3 (32)	2.26
BAC	901.6	0.52	0.29 (56)	0.23 (44)	498.4 (55)	2.28

3.2 Adsorption isotherm

The adsorption isotherms of CAC and BAC were characterized to ensure the similarity of adsorption capacities. The experimental adsorption curves showed higher fit to the Langmuir model than Freundlich model in all case of adsorbent: DOC, UV_{254}, and color (root mean square value; RMS of 0.9927, 0.9918, 0.9984, respectively) which the same adsorption behavior were found according to study of Hsieh et al. (2000) and Khraisheh et al. (2010). Similar values of q_m in both cases of DOC (CAC; 7.027 mg/g and BAC; 10.526 mg/g) and UV_{254} (CAC; 0.231 cm^{-1}/g and BAC; 0.322 cm^{-1}/g) adsorption obviously approve the similarity of adsorption capacity, as shown in Table 2. On the other hand, the color adsorption, around 3.3 times higher of q_m of BAC were found but in normally the total quantity of color always be described by UV_{254}. Although at 456 nm absorbance is normally used to represent color in Pt-Co unit but only yellow-brown color is measured. The measurement is not cover the others kinds of color such as light-yellow dark-brown (Stevenson, 1982). Therefore, UV_{254} absorbance which indicates aromatic functional group of humic substance (the cause of aquatic color) is more appropriate to represent the color (Lagos et al., 2009).

Table 2 Langmuir adsorption isotherm equation constants of DOC, UV254 and color adsorption by CAC and BAC.

Adsorbate	q_m (mg/g)		K_L	
	CAC	BAC	CAC	BAC
DOC	7.027	10.53	0.039	0.076
UV_{254}	0.231	0.322	35.6	9.919
Color in Pt-Co unit	46.08	151.5	0.013	0.003

3.3 Adsorption Kinetic

Adsorption kinetic experiments were conducted with 10 minutes contact time. The results demonstrated that DOC, UV_{254} and color adsorption rates between CAC and BAC were in common with negligible higher of BAC adsorption rates (see Fig. 1). Nevertheless, the analysis to identify reaction order and reaction rate constant of DOC adsorption revealed the highest fit to second-order adsorption reaction with the similar adsorption rate constant of 0.24 and 0.3 L/mg-h at RMS value of 0.996 and 0.9954 of CAC and BAC, respectively (see Fig. 2). The plots of SUVA against contact time within ten minutes reflected the similar trend of SUVA influence reduction between CAC and BAC (see Fig. 3). The SUVA reduction indicates capability of CAC and BAC to adsorb humic substance and hydrophobic substance that are the precursor of absorbable DOC and color in water.

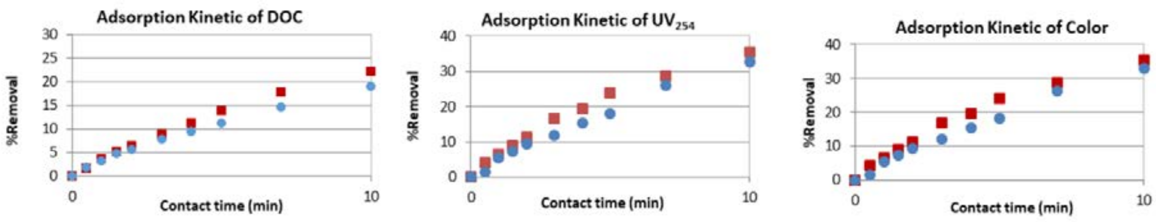

Fig. 1. DOC, UV_{254} and color removal kinetic by CAC (●) and BAC (■) within 10 minutes contact time and 31ºC at 110 rpm jar test mixing.

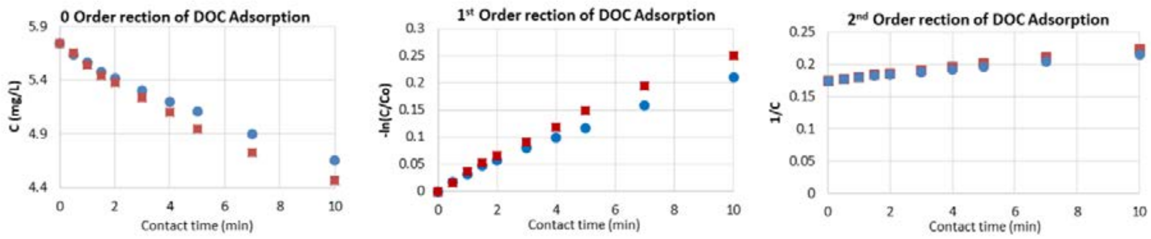

Fig. 2. Zero order, first order and second order reaction plot of DOC adsorption by CAC (●) and BAC (■) within ten minutes contact time and 31ºC at 110 rpm jar test mixing.

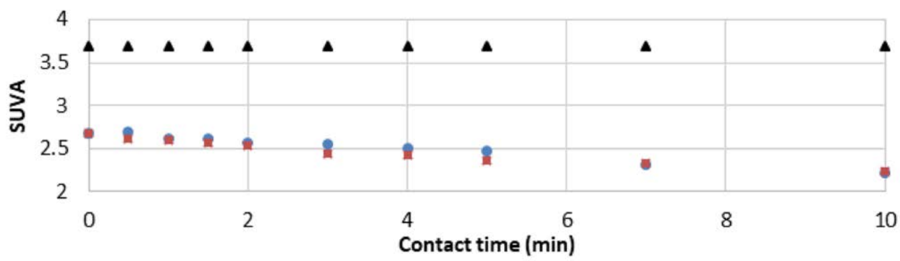

Fig. 3. SUVA of Adsorption Kinetic of CAC (●) and BAC (■) within 10 minutes contact time and 31ºC at 110 rpm jar test mixing (▲ is influent SUVA).

Adsorption isotherm and adsorption kinetic experiments results obviously approved the similarity of adsorption properties of CAC and BAC in term of equality of q_m that corresponding to similar adsorption site GAC from BET analysis and similarity of adsorption rates as equality of reaction order and adsorption rate constant.

3.4 Adsorption Column

Experiments in continuous columns were conducted with CAC and BAC at flow rate of 60 and 120 mL/min corresponding to contact time around 8 and 4 minutes, respectively. The breakthrough curves of BAC and CAC at 60 and 120 mL/min were plotted (see Fig. 4), when the flow rate was increased from 60 to 120 mL/min total adsorption capacities of CAC were decreased from 1.09 to 0.74 g DOC/g CAC, and 0.03 to 0.028 cm^{-1} (UV_{254} absorbance)/g CAC. On the contrary, adsorption capacities of BAC were increased from 0.67 to 0.97 g DOC/g BAC and 0.24 to 0.28 cm^{-1} (UV_{254} absorbance)/g BAC. Although the color adsorption capacities of CAC and BAC were deceased (from 3.21 to 2 Pt-Co/g CAC and 2.92 to 2.28 Pt-Co/g BAC), but be ignored by the reason that mentioned before. Consequently, the behavior of CAC and BAC total adsorption capacity on DOC and UV_{254} also affects to exhausted volume of all type of GAC, the extension of BAC and the reduction of CAC exhausted volume (see Fig. 5). Although UV_{254} adsorption capacities was tend to similar (less change) in all adsorption conditions but the difference of adsorption capacity on DOC disagree the result that obtain from adsorption isotherm that approved similarity of DOC adsorption capacity between CAC and BAC.

Furthermore, at 60 mL/min flow rate breakthrough curve (see Fig. 4) tendency of DOC adsorption by CAC and BAC are reversed as decreasing of residual DOC in effluent at before 24 and 40 litres breakthrough volume, respectively. After the reversion, DOC residual of CAC adsorption is constant between 24 to 32 litres breakthrough volume and shift up until the exhaustion of CAC. One the other hand, DOC residual of BAC is immediately increased after the decrease. While UV_{254} residual tend to be constant at initial until 16 and 8 litres breakthrough volume of CAC and BAC, respectively. After the stability, the UV_{254} residual in CAC and BAC column tend to slightly increase until the exhaustion. The reversion of DOC residual also found in the study of Khraisheh et al. (2010) that the initial DOC residual (DOC influent is 6 to 7 mg/l) of 55% dropped down to 35% along the beginning until 20 hours operation time of fixed bed GAC column whit the same behavior of UV_{254} breakthrough curve. The behavior may attribute to the necessity of accumulating DOC in column to reach high enough concentration gradient to reach maximum adsorption efficiency. By the way, when flow rate is increased to 120 mg/l the breakthrough of UV_{254} adsorption by both kinds of GAC and breakthrough of UV_{254} adsorption by BAC were immediately found at the initial. In contrast, DOC residual breakthrough curve of GAC has the same revere behavior as its DOC breakthrough curve at 60 mL/min flow rate with longer accumulation time to reach maximum adsorption efficiency and higher DOC residual during the initial until 56 litres breakthrough volume.

The sorption zone (see Fig. 6) reveals longer sorption zone at 120 mL/min flow rate in all conditions except the condition of DOC adsorption by BAC that the sorption zone is reduced from 69.7 to 29.15 cm which lower than adsorption bed height. By the reduction of BAC sorption zone, the different trend of DOC breakthrough curve of BAC at 120 mL/min flow rate is supported.

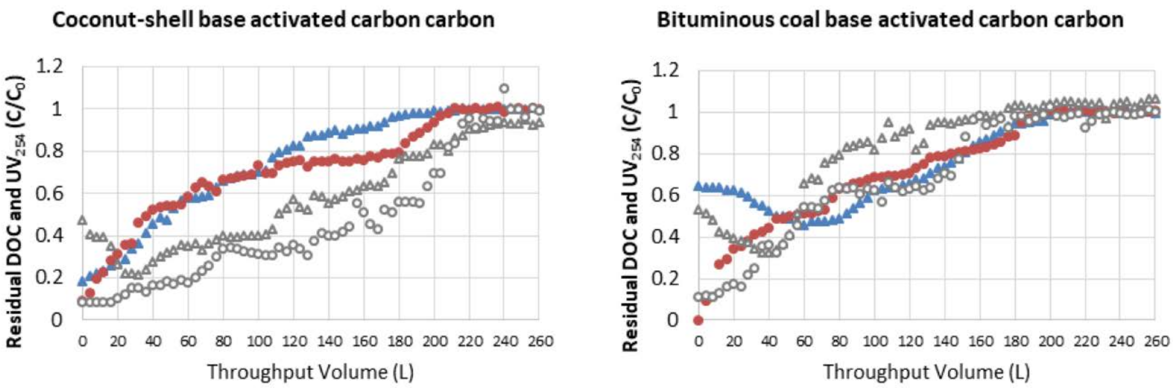

Fig.4. Breakthrough volume of CAC and BAC on DOC (Δ), UV_{254} (○) at 60 mL/min flow rate and DOC (▲), UV_{254} (■) at 120 mL/min.

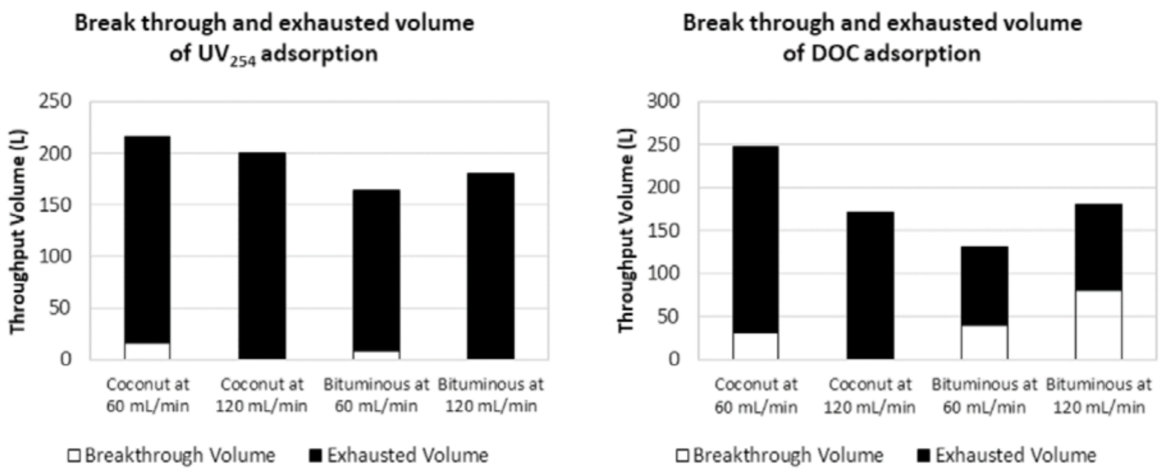

Fig.5. Breakthrough volume and exhausted volume of DOC and UV_{254} by CAC and BAC at 60 and 120 mL/min flow rate.

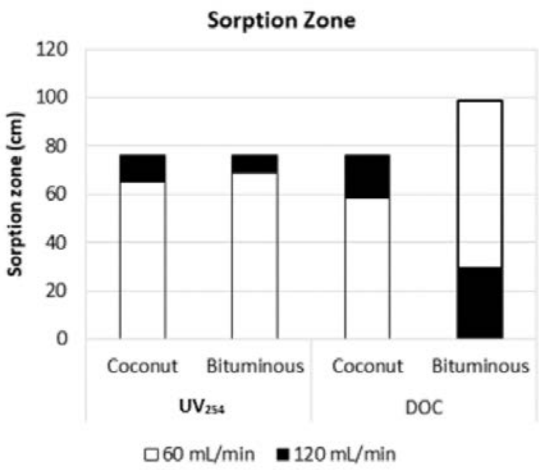

Fig.6. Sorption zone of DOC and UV_{254} adsorption breakthrough curves by CAC and BAC at 60 and 120 mL/min flow rate.

3.5 The Thomas model

The Thomas adsorption model was derived from Equation (5) in the range of V_b to V_e of DOC breakthrough curve. As shown in Table 3, the model is well fit with all breakthrough curves at RMS value by 0.9254 to 0.9875. The increase of K_T values were found after increase of flow rate to 120 mL/min with higher K_T values of BAC in all flow rates. The reduction of liquid film resistance after increase of flow rate contributes to higher adsorption rate and increase of q_0 of BAC. Even though K_T of CAC is increased at 120 mL/min flow rate but q_0 is dropped down in the same way with the calculation of maximum adsorption capacity according to the section of adsorption column. The reduction of q_0 of CAC agrees with extension of CAC sorption zone. Thus the increase of K_T of CAC may not higher enough to retain DOC at 120 mL/min flow where the contact time is twice shorter. This behavior also found in studies of Omri and Benzina (2014) that the adsorption rate constant of phenol adsorption by almond-shell activated carbon was increased while the decrease of adsorption capacity were occurred due to the increase of adsorption rate was not high enough to retain the adsorbent at shorter contact time. Radhika et al. (2018) found that when the flow rate was increased from 1 to 5 mL/min and 5 to 10 mL/min the increase of K_T with decrease of q_0 in case of percolate adsorption by coconut-shell base activated carbon occurred. On the contrary, K_T and q_0 were increased simultaneously when flow rate was increased from 10 to 15 mL/min. This behavior is due to adsorption rate order change from first to second order when the flow rate was increase which high enough to retain percolate.

Table 3 Thomas model constant and RMS of correlation.

Adsorption condition (mL/min)	K_T (l/h-mg)	q_0 (mg/g)	RMS
CAC, 60	0.01096	2.559	0.9525
CAC, 120	0.0272	1.420	0.9875
BAC, 60	0.02185	1.326	0.9254
BAC, 120	0.03219	2.002	0.9286

3.6 SEM surface characteristic and pore formation on GACs external surface

BET analysis is appropriate method to analyze sorption site of GAC but it cannot visualize surface characteristic and pore formation of GACs that may affect to adsorption behavior. SEM analysis was conducted to illustrate surface characteristic and pore formation at magnification 100 times and 2,000 times (see Fig. 7). At magnification 2,000 times SEM images reveal broader macrospores and longer distance between the edges of pores at external surface of BAC. In contrast, the narrower external pores with shorter distance between the edges of pores were found on CAC external surface. Consequently, the magnification 100 times SEM images clearly reveal rougher surface of BAC. Moreover, the longer distance between the edges of pores at external surface area of BAC contributes to larger external surface area. The larger external surface area agrees with higher external surface area of BAC that obtained from BET analysis, as shown in Table 1.

By the explanation that broader external pore and higher proportion of mesopores tend to make adsorbent is easier to desorb (Cecen and Aktas, 2012; Aschermann et al., 2018), the lower DOC adsorption capacity of BAC in adsorption column experiment at 60 ml/min flow rate might be uncovered.

At 120 mL/min flow rate the film resistance would be reduce by increase of flow rate as mention before. By the reduction of film resistance the concentration gradient in liquid film as adsorption driving force is increase which interrupt the desorption process. By the increase of the driving force, the K_T of DOC adsorption by CAC and BAC were increase. Consequently, by the higher concentration gradient the solvent are forced to diffuse into the pores with lower desorption that contribute to increase of adsorption capacity which found in case of DOC adsorption by BAC. On the contrary, the reduction of DOC adsorption capacity by CAC was found. The reduction support the studies of Cecen and Aktas, 2012 and Hsieh & Teng, 2002 which found that the broader external pores and mesopores have had the capability to reduce length of diffusion path to narrow and high adsorption energy pore inside GAC. Thus, by the narrow external pore and lower proportion of mesopores of CAC, the potential of adsorption rate to retain DOC inside the column of CAC is obstructed. Although the K_T of CAC was increased at 120 mL/min flow rate but the adsorption rate might be not enough to retain DOC at the twice shorter of contact time due to the narrower pores. However, to verify this phenomenon another experiment should be conducted in further study.

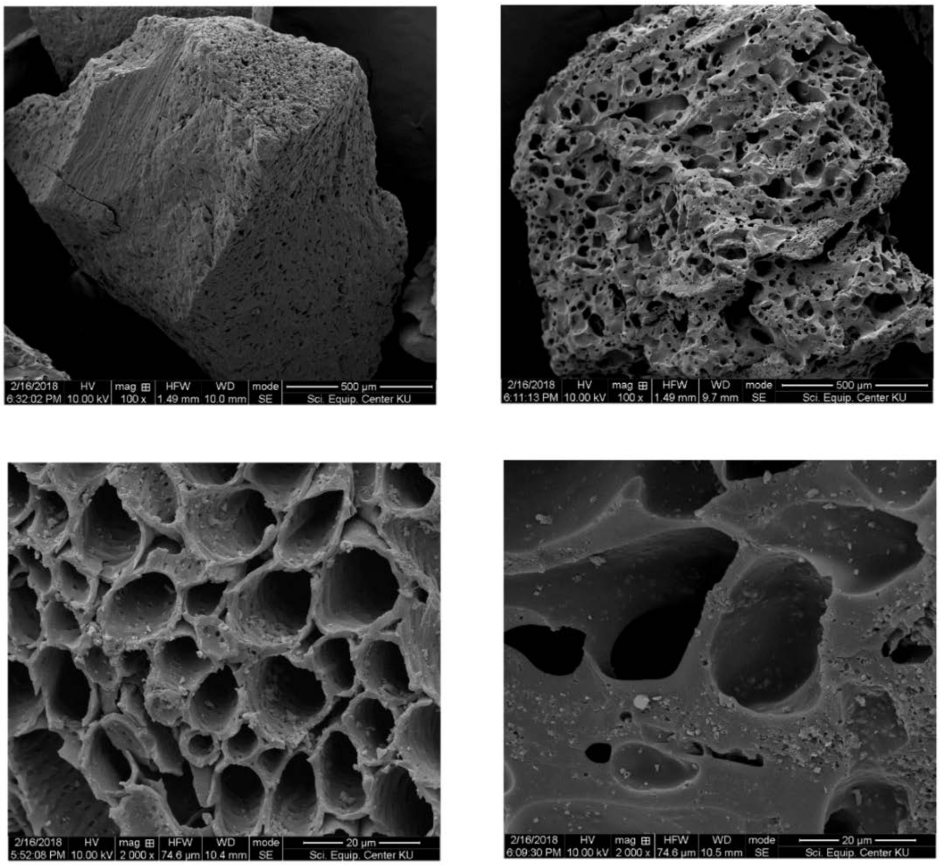

Fig.7. SEM image at magnification 100 times of CAC (top-left) and BAC (top-right) and at magnification 2,000 times of CAC (bottom-left) and BAC (bottom-right).

4. Conclusion

BET is a typical method to illustrate adsorption capacity of activated carbon. The similar BET adsorption site of CAC and BAC indicate similarity of adsorption capacity that can be confirmed by adsorption capacity constant of adsorption isotherm. On the contrary, in the case of adsorption column, the flow rate was varied the change of adsorption capacity of CAC and BAC in each flow rate. At 60 ml/min flow rate the lower DOC adsorption capacity of BAC was found due to the broader external pore and higher proportion of mesopores tend to make adsorbent is easier to desorb. When the flow rate was increased from 60 to 120 mL/min the K_T of CAC and BAC were increased due to the reduction of film resistance that contribute to higher concentration gradient which interrupt desorption. Higher DOC adsorption capacity of BAC was found due to lower desorption and higher K_T. In contrast, the DOC adsorption capacity of CAC was decreased. By the narrow external pore and lower proportion of mesopores of CAC, the potential of adsorption rate to retain DOC inside the column of CAC is obstructed that contribute to not enough adsorption rate to retain DOC at the twice shorter of contact time. However, further study should be conduct to clarify this phenomenon

All of the results from this study are clearly demonstrated that DOC adsorption capacities of different pore size distribution of CAC and BAC in adsorption columns tend to be differently impacted when flow rate is change. Nevertheless, the system designer and the researcher of activated carbon adsorption process might be gained useful information by this study results. Variable impact of flow rate on activated carbon adsorption column could be the evidence for adsorption column designer to use appropriate activated carbon under each flow rate. Importantly, by this study results, flow rate and pore size distribution could be taken into account as the couple factor that impacts to activated carbon adsorption capacity.

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Evaluation of Nitrification and Denitrification Performance of Down-flow Hanging Sponge System for High-Strength Domestic Wastewater Treatment

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Abstract

The main objective of this study is to confirm the nitrification and denitrification process of the pilot-scale Down-flow Hanging Sponge (DHS) system for high strength sewage treatment. The DHS reactor has been fed with high strength domestic wastewater discharged from apartment for more than one year. The process performance of the DHS reactor under the HRT of 4 hours and 5 hours was evaluated. DHS reactor effectively eliminated COD at about 85% even under flow rate fluctuation condition. Ammonia removal efficiency was achieved 86% and total nitrogen removal efficiency was 37%. The oxygen uptake rate of nitrifying bacteria was at 0.143 gO_2/gVSS/day. In addition, the sponge can accumulate sludge highest at 19.5 gVSS/L-sponge with the denitrification activity of 3.8 mgN/gVSS/day.

Keywords: DHS; Nitrification; Denitrification; On-site wastewater treatment; Trickling filter; Sponge

1. Introduction

Eutrophication or plankton bloom have been occurred from excessive amounts of nitrogen and phosphorus compounds according to human activities such as agriculture, residential and industry. Thailand is one of the countries experiencing eutrophication or plankton bloom. From previous researches, Eutrophication phenomena were occurred in nationwide, such as Songkhla lake (Sompongchaiyakul et al., 2004), Gulf of Thailand (Stuhldreier et al., 2015). In Bangkok, there is no Eutrophication phenomena. Owing to, the BOD concentration in canal water has been found to be approximately 4-20 mg/L. Thus, algae cannot grow in high BOD canal water. Moreover, the TKN from observed canal water was at about 9 mg/L and ammonia was at about 5 mg/L (Unpublished data from Department of Drainage and sewerage, 2016). From this information, it illustrates that wastewater treatment plant cannot serve effectively.

In order to make environmental sustainability, it is necessary to remove both organic matter and total nitrogen from wastewater. However, most developing countries have limited space and budget for construction (Onodera et al., 2014). Therefore, providing innovative wastewater treatment that satisfied both organic and nitrogen removal with low cost and less space for sustainability in the field of wastewater treatment.

In recent years, an aerobic trickling filter system called Down-flow Hanging Sponge (DHS), polyurethane sponge has been used as packing material, has been successfully applied for sewage treatment. The advantages of DHS system are less space for construction, no requirement oxygen supply and small amount of excess sludge production (Uemura et al., 2010). Moreover, DHS system can treat ammonia at about 88 %, 77 % of TKN (Tawfik et al., 2006) and 51% of total nitrogen (Miyaoka et al., 2017) under sufficient oxygen supply condition (Yoochatchaval et al., 2014). Therefore, DHS is an interesting technology for treating domestic wastewater especially in Bangkok.

2. Menials and Methods

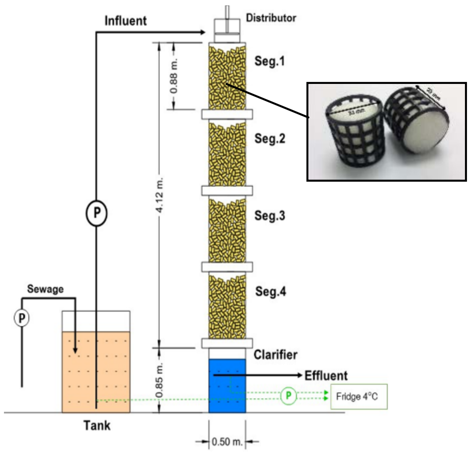
2.1 Reactor setup and configuration

The DHS reactor shown in Fig. 1 was installed and operated at Bongai community in Bangkok. The DHS reactor was constructed at area of 2 x 3 m^2 with a height of 5.5 m. High-strength sewage wastewater discharged from apartment house in Bongai community was fed directly to the DHS reactor. The DHS reactor was made from 5 segments of polyvinyl chloride (PVC) column. In segment 1 to 4 were consisted column 0.5 m long, 0.5 m wide, and 0.88 m in height, packed with 4,000 sponges, totally 16,000 pieces polyurethane sponge media with a polyethylene net ring (Ø33 mm and 33 mm height). The segment 5 was clarifier tank. The reactor volume is 350 L, based on sponge volume. Influent wastewater was pumped into reservoirs tank then it was fed to top portion of DHS reactor. It was gravidity flow down through the sponge media to clarifier tank.

2.2. Operating condition

The DHS reactor fed high-strength sewage wastewater was operated under the HRTs of 4 hours (246 days) or 5 hours (42 days). Furthermore, the process performance under flow rate fluctuation condition as follows; the HRT was set to 7 hours during 0:00-5:59, 10:00-17:59 and 22:00-23:59 or 3 hours during 6:00-9:59 and 18:00-21:59 in a day, had been investigated HRT at 3 hours at high flow and 7 hours at low flow (159 days).

(A)



(B)

Fig. 1. The DHS reactor setup and configuration at Bongai in Bangkok;
(A) DHS reactor setup at Bongai, (B) Schematic diagram of the DHS reactor

2.3 Sampling water and water quality profile along wastewater flow length

Spot sampling method had been used for analysis of temperature, pH, dissolved oxygen (DO) and oxidation-reduction potential (ORP) of influent and Effluent on site. Total nitrogen (T-N), Ammonia (NH_4^+-N), Nitrite (NO_2^--N), Nitrate (NO_3^--N) concentrations and Chemical oxygen Demand (COD) concentration were analysed by using a spectrometer DR-2800 water quality analyzed (Hach, Loveland, CO, USA) in order to confirm the nitrification and denitrification performance of DHS reactor. The influent and effluent sample collected by composite sampling method (6 minutes sampling per every hour) were used for the above analysis parameter. By the way, influent, effluent and the effluents of each segment were collected by spot sampling to determine water quality profile.

2.4. Tracer experiment

In this study, actual wastewater retention time (HRT) of the DHS reactor was evaluated by using saturated sodium chloride (35 gNaCl/100 mL-tap water) a solution, which contains high electronic conductivity (EC), as tracer substrate. The tracer experiment is conducted as following steps. At the first, drained DHS effluent in clarifier in order to evaluate retention time of the sponge media accurately. Then add sodium chloride to distributer at top portion and EC of the effluent discharging from segment 4 was recorded every 5 minutes with a conductivity meter. Finally, made plot graph and determine actual retention time.

2.5 Sludge concentration

5 or 10 pieces of sponge media were randomly selected for determination the amount of sludge concentration and sludge activity. Firstly, accumulated warms on the surface of sponge media was removed and then squeezed completely with BOD dilution water. The sludge concentration of bulk was determined by using glass fiber filter (GB-140, Advantech Co. Ltd, Japan).

2.6 Specific Oxygen Uptake Rate (SOUR)

The specific oxygen uptake of retained sludge mentioned above was determined in order to confirm the activity of nitrifier group and heterotrophic group. The squeezed sludge had been aerated overnight for elimination residual substrates then distributed sludge, BOD dilution water and substrate to the BOD bottle control and incubated at 2530°C by using water bath. DO concentration had been immediately recorded every minute continuously. The experiment conducted at least 15 minutes then plot graph of the changes DO to calculate OUR.

2.7 Denitrification activity

Denitrification potential of the retained sludge collected on day xx had been evaluated by nitrate consumption rate under the anoxic condition. 122 mL of serum vial bottle was used for the assay. Retained sludge, (nutrient solution) and substrates, sodium acetate (yy mgCOD/L in vial) as electron donor, potassium nitrate (zz mgN/L in vial) as electron accepter, were added to vial bottle with the total liquid phase of 50 mL and then replaced gas phase with pure nitrogen gas then closed cap, incubated at 30 °C and shook with 120 rpm (use water-bath). Before adding substrates, sludge was pre-incubated for 3 hours to remove residual substrates 2 mL of liquid sample was collected every 1-2 hours by syringe and filtrate soon and then nitrate (and nitrite) concentration(s) was (were) determined by HPLC (high performance liquid chromatography) unit.

3. Results and discussion

Table 1 Summary of water quality and removal of DHS effluent.

Parameter		Influent			Effluent									BMA Standard
					246 Days			42 Days			159 Days			
					HRT 4 hours.			HRT 5 hours.			HRT 3 hours and HRT 7 hours (flow rate fluctuation)			
Water Quality														
Temperature	°C	30	±	1	29	±	1	30	±	1	30	±	1	–
pH	–	7	±	0	8	±	0	7	±	0	7	±	0	5–9
DO	mg/L	4	±	8	6	±	1	5	±	1	5	±	1	> 5
ORP	mV	-251	±	54	85	±	27	82	±	16	71	±	20	–
Total COD	mg/L	240	±	112	39	±	9	31	±	11	27	±	16	–
Soluble COD	mg/L	119	±	26	30	±	10	29	±	15	20	±	10	–
Total Nitrogen	mgN/L	50	±	12	31	±	13	30	±	11	21	±	11	≤ 10
Ammonia	mgN/L	37	±	6	7	±	5	3	±	1	3	±	2	< 5
Nitrite	mgN/L	0	±	0	0	±	0	0	±	0	0	±	0	–
Nitrate	mgN/L	0	±	0	15	±	8	17	±	8	9	±	3	–
% Removal														
Total COD	%				86	±	4	89	±	7	77	±	16	
Soluble COD	%				70	±	13	83	±	13	71	±	41	
Total Nitrogen	%				35	±	21	36	±	24	58	±	16	
Ammonia	%				80	±	15	90	±	5	93	±	5	

3.1 Process performance

The summary of water quality of influent and effluent were shown in Table 1. DHS reactor was fed with high-strength sewage wastewater under various operational conditions, at the constant HRT of 4 or 5 hours, and fluctuated HRT (3 hours as high flow and 7 hours as low flow) condition. The average temperature, pH DO and ORP were 30 °C, 7.0, 4.0 mg/L of DO and -251 mV, respectively. For 447 days of operation, the influent total COD of 240 mg/L, soluble COD of 119 mg/L, total nitrogen of 50 mgN/L and ammonia of 37 mgN/L (in average) concentrations were higher s as compared with sewage in general area in Bangkok. (The influent was not affected strongly by rain water because of collected by separated sewer system.)

At the operational HRT of 4 hours, DHS reactor was effectively eliminated Total COD at about 86% and Soluble at about 70%. However, total nitrogen and ammonia removal rates were remained at about 35 % and 80%, respectively and it resulted insufficiency of the standard for effluent in Bangkok metropolitan administration (BMA). Furthermore, nitrate was detected in the effluent, it indicated nitrification was occurred by DHS reactor. The HRT of 4 hours was not appropriate for the treatment of domestic wastewater due to the high loading in the DHS system. Then, the HRT was increased 5 hours in next operation period.

As soon as, the HRT was extended to 5 hours, the process performance became better. The removal of Total COD and Soluble COD were increased to 89% and 83%. Moreover, the average of effluent ammonia concentration was at 3 mgN/L. It was achieved elimination at 90% which lower than BMA standard (NH_4^+-N < 5 mgN/L). On the other hand, total nitrogen removal rate was at about 36%. At the operational HRT of 5 hours was the appropriate condition for the sufficient organic removal and nitrification, however some modification is needed for enhancement denitrification by DHS reactor.

After that, process performance under flow rate fluctuation condition (HRT 3 hours as peak flow and 7 hours as normal flow, total flow in a day equals at HRT 5 hours) has been investigated depending on water consumption period. The result showed that total COD removal was at 77% and soluble removal was at 71 %. The nitrification process was highly achieved effluent discharging standard of below 5 mgN/L with an average ammonia removal rate of 93 %. Additionally, 51% of total nitrogen removal, denitrification, rate was confirmed.

In conclusion, the DHS reactor could eliminate both organic matter (COD) and ammonia without any pre-treatment under an operational HRT of 5 hours even though it was operated at a fluctuation flow condition. As compared to previous work about the direct sewage treatment by DHS reactor (Miyaoka et al., 2017), our DHS reactor also showed sufficient process performance as an innovative wastewater technology which enable wastewater treatment with low cost (no requirement oxygen supply) and less space (short retention time).

3.2 Tracer experiment

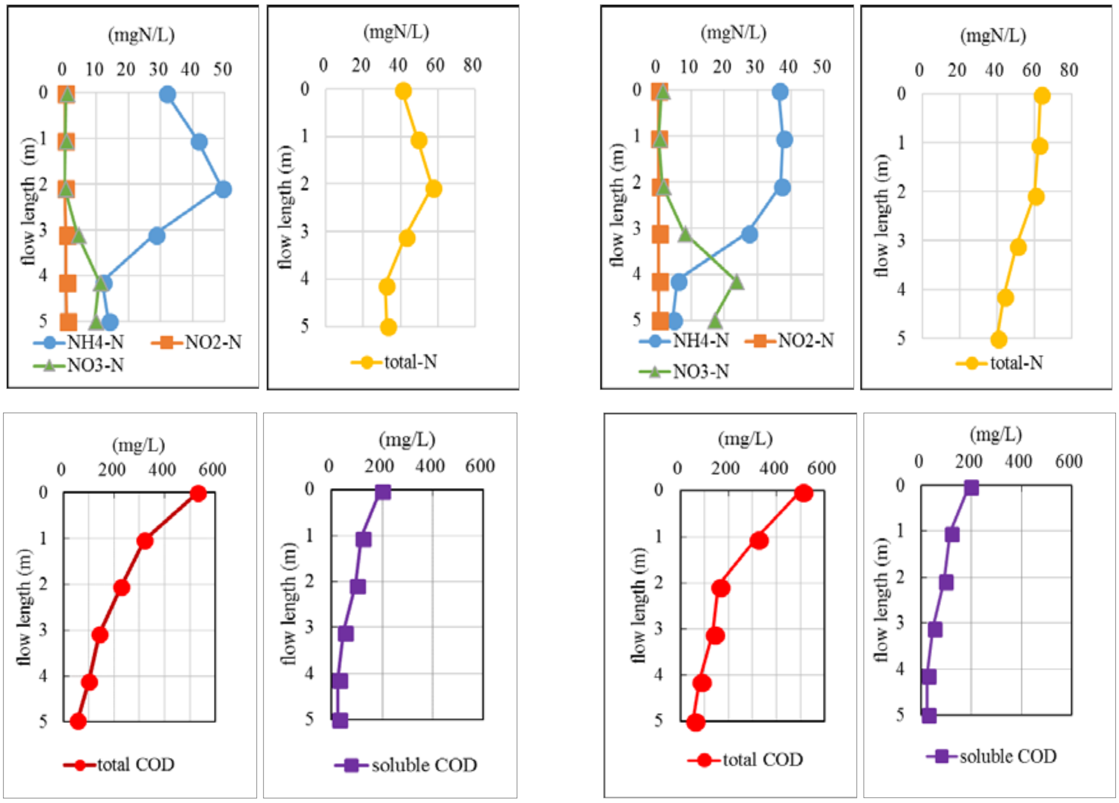
This study evaluates actual wastewater retention time (HRT) of the DHS reactor by using saturated sodium chloride (NaCl) a solution with a high electronic conductivity. The result show that, the theory HRT 4 hours but the actual retention time was 2.4 hours. It can be seen that actual HRT was less than theory because of the short cut in DHS reactor.

3.3 Water quality profile

Water quality profile along DHS reactor height was investigated on days 282 (HRT 4 hours) and 338 (HRT 5 hours) for the evaluation of characteristic of each segment in DHS reactor. On day 282, ammonia was increased in segment 1 and 2, it showed ammonia production rate from organic nitrogen was higher than ammonia degradation rate because at HRT 4 hours was too short retention time, over loading for DHS reactor. On the other hands, there was no accumulation of ammonia in segment 1 and 2 on day 338. Then ammonia was decreased in segment 3 to segment 4 while nitrate was also detected in segment 4. In conclusion, there was nitrification process was accelerated in segment 3 to segment 4. Furthermore, total nitrogen was decreased in segment 3 and segment 4. There was predomination of denitrification process inside the sponge because inside the sponge was anoxic condition as shown in Fig. 1. From the water quality profile, it was confirmed that the nitrification and denitrification was occurred at same time. The nitrification process can occur at surface of the sponge and denitrification process can occur inside of the sponge (Araki et al., 1999). In addition, most of total COD and soluble COD were removed in segment 1 then they were removed along flow length from the inlet of the DHS reactor shown in Fig. 1.

3.4 Tracer experiment

This study evaluates actual wastewater retention time (HRT) of the DHS reactor by using saturated sodium chloride (NaCl) a solution with a high electronic conductivity. The result show that, the theory HRT 4 hours but the actual retention time was remained 2.4 hours. Distribution was incomplete and it resulted short cut in DHS reactor.



(A) (B)

Fig. 2. Water qualities profile along flow length from DHS reactor on day 282 and 338 (A) Day 282 at HRT 4 hours (B) Day 338 at HRT 5 hours.

3.5 Sludge concentration

The sludge concentration has been observed in order to confirm the performance of sponge media in collect sludge. Sludge concentration was collected 3 intervals on day 286 (HRT 4 hours), day 344 (HRT 5 hours) and day 450 (flow rate fluctuation). The measurement has been shown in Fig. 3. On day 286, the sludge concentration was the highest in segment 1 and decreased along the distance of wastewater. At day 344, DHS reactor has been operated, the sludge concentration inside the sponge decreased especially in segment 1 because the sludge concentration was grazed by worm and protozoa (Fig. 2). By the way after changing condition to flow rate fluctuation in day 450. In conclusion, the sponge medium was effectively carried the sludge and no clogging in the media shown in Fig. 2. As the result, the sponge media in DHS reactor was effectively carried at maximun 32 gVSS/L-sponge which was higher than previous research (26.4 gVSS/L) (Onodera et al., 2014).

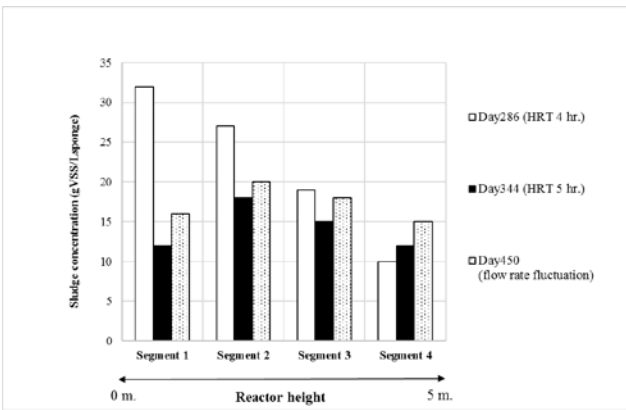


Fig. 3. Sludge concentration each segment of DHS reactor.

3.6 Specific Oxygen Uptake Rate (SOUR)

The potential of oxygen activity of Specific Oxygen Uptake Rate (SOUR) in sponge was observed on day 450, shown in table 2. Retained sludge activity was evaluated indirectly by monitoring of oxygen uptake rate. The result showed that the heterotrophic group's activity was highest in segment 1 at about 0.534 gO_2/gVSS/day then the oxygen uptake rate of nitrifying bacteria (autotrophic group's) in segment 1 was also highest at about 0.143 gO_2/gVSS/day. The results indicated that nitrification in segment 1 was suppressed because of the shortage of DO by the COD removal.

Table 2 Summary of Specific Oxygen Uptake Rete (OUR) and Sludge concentration on day 450

Segment	Sludge conc.	Control (endogenous)	Acetate (heterotrophic)	Ammonium (autotrophic)
	gVSS/Lsponge		gO_2/gVSS/day	
Segment 1	16.2	0.248	0.534	0.143
Segment 2	19.5	0.077	0.163	0.082
Segment 3	17.8	0.104	0.202	0.122
Segment 4	14.7	0.075	0.086	0.089

3.7 Denitrification activity

The evaluation of retained sludge in denitrification activity was determined by nitrate consumption rate under the anoxic condition. The accumulated sludge was squeezed completely and measured sludge concentration shown in table 3. Denitrification activity was highest in segment 3 at about 3.82 mgN/VSS/day. This information was also confirmed by total nitrogen profile data in Fig. 1.

Table 3 Summary of denitrification activity and dissolved oxygen (DO) inside sponge.

Segment	**Denitrification activity**
	mgN/VSS/day
Segment 1	2.81
Segment 2	2.76
Segment 3	3.82
Segment 4	3.26

4. Conclusions

Down-flow Hanging Sponge was an interesting technology for Bangkok. It can effectively eliminated organic matter removal at about 90% .The nitrification process can occur at surface of sponge (ammonia removal of 93%) and denitrification process can occur inside of sponge (total nitrogen removal of 58%). DHS technology is recommended for a sustainable treatment system in developing countries.

Acknowledgments

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WR-B19

Evaluate of the Biodegradability on High Carbohydrate Wastewater Treated by Fungal

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Abstract

In this paper, the evaluation of the performance and biodegradability of high carbohydrate wastewater with a fungal treatment at various HRT conditions was investigated. Synthetic wastewater was prepared using the tapioca starch factory. The experimental set-up consisted of SBR operated with 6-48 hrs hydraulic retention time (HRT), mixed by a diffused aeration system, and adjusted to the optimum pH of approximately 3.0±0.2. The fungal SBR system provided the effluent with COD, SCOD and BOD in the ranges of 164-265 mg/L, 36-55 mg/l and 21-45 mg/L, respectively, and corresponded to the removal efficiency of 83.79-90.31% for COD. The optimal condition for removing organic matter of high carbohydrate wastewater was found to be with the 24hrs HRT. The effluent can be used for agricultural irrigation or be discharged into the fishpond. After the treatment with fungus, the readily biodegradable (Ss) increased to about 13.10% of TCOD at HRT of 24 hours. Furthermore, the effluent provided the BOD/COD ratio of 0.275, which is 1.53 times higher than that of the influent, indicating that the biodegradable fraction can be increased through the fungus utilization.

Keywords: Cassava; Starch wastewater; Fungal treatment; COD fractionation; Sequencing batch reactor.

1. Introduction

The industry processes generally produce large amount of wastewater. Mostly, the wastewater from industrial agricultural sectors such as the processing tapioca starch or sugar industries consists of organic substances in the forms of proteins, carbohydrates and fats, corresponding to about 40-60%, 25-50% and 10%, respectively (Thammaporn, 2012). Cassava starch wastewater normally has high organic pollutant concentration, high suspended solid concentration, low pH value, and large load change. The suspended solids, mainly being residual starch and fiber materials, are exorbitant in the cassava starch wastewater. These substances are organic compounds, and have a poor biodegradability (Bo et al., 2011). Conventional biological wastewater treatment generates large amounts of low-value bacterial biomass. The treatment and disposal of this excess bacterial biomass accounts for about 40–60% of operational costs of the wastewater treatment plant (Rani et al., 2012). A different form of biomass with a higher value could significantly change the economics of wastewater treatment. Fungi could offer this benefit over bacteria in selected wastewater treatment processes. The biomass produced during fungal wastewater treatment has, potentially, a much higher value than that from the bacterial activated sludge process. Different fungal strains have shown their ability to degrade a wide range of environmental pollutants, i.e., dyes, pharmaceutical compounds, heavy metals, and trace organic contaminants, as well as the ability to degrade lipids, proteins, complex carbohydrates, heteropolymers, aromatic hydrocarbons and other recalcitrant anthropogenic chemicals by using as either sole carbon sources or in co-metabolism and by means of a wide array of extra- and intracellular oxidative, hydrolytic and conjugative enzymes (Maza-Marquez et al., 2016; Cortes-Lorenzo et al., 2016; Blanquez et al., 2008). In this paper, the performance and biodegradability of high carbohydrate wastewater using a fungal treatment at various HRT conditions were evaluated.

2. Experimental

2.1 Synthesis of High Carbohydrate Wastewater

Synthetic high carbohydrate wastewater was prepared by using the tapioca starch factory. Tapioca starch based synthetic wastewater was heated at 55±3°C to dissolve the particulate matters before feeding to the system. This was done to simulate high strength particulate wastewater (tapioca starch wastewater) discharge at high temperature. Tapioca starch was used as a sole carbon source. NH_4HCO_3 and KH_2PO_4 were added as nutrients. Synthetic wastewater constituents are shown in Table 1.

Table 1 Characteristics of the synthetic wastewater

Parameter	Unit	Concentration
COD	mg/l	1,693.57
SCOD	mg/l	81.78
BOD_5	mg/l	304
TKN	mg/l	10.31
NH_3	mg/l	9.83
BOD/COD	-	0.18
SBOD/SCOD	-	0.15

2.2 Experimental and Operating Condition

Enrichment of seed fungi sludge was done by following Patcharin Racho (2009). The experimental set-up consisted of Sequencing Batch Reactor (SBR) operated by varying 6-48 hrs hydraulic retention time (HRT) (Lei et al., 2014), and the pH was adjusted to an optimum level of approximately 3.0±0.2 (Takahiro et al., 2001). Each cycle went through four main steps: filling, reacting (aeration), settling and drawing. The reactors were mixed and aerated by the compressed air through stone air diffusers to maintain a suitable mixing condition and to supply sufficient dissolved oxygen for microorganism growth (DO = 2 - 4 mg/L).

2.3 Sampling and Analytical Methods

The influent and effluent samples of the SBR were analyzed following the standard methods for the examination of water and wastewater (APHA, 2005). Biochemical oxygen demand (BOD) was determined with an OxiTop®-C measuring pressure head instrument (Expotech USA Inc., Houston, TX, USA). The carbonaceous material characterizations were measured in terms of the COD parameter subdivided into a number of fractions following Wentzel et al. (1999)**.**

3. Results and discussion

3.1 Performance of organic and nitrogen removal

The high carbohydrate wastewater consisted of the quantified solid, organic and nitrogen contents. The results are presented in Table 1. With a relatively low COD value (1693 mg/L), the soluble COD to COD ratio was approximately 4%. It shows that the part is a large organic substance and highly slowly degradation. This wastewater contained a relatively low nitrogen content based on the COD: N ratio, which is likely too low for a conventional biological treatment process. The fungal SBR system provided the effluent with COD, SCOD and BOD in the ranges of 164-265 mg/L, 36-55 mg/l and 21-45 mg/L, respectively, and it produced the removal efficiency of 83.79-90.31% for COD. At HRT of 24 hours, it showed the optimal condition for organic matter removal of the high carbohydrate wastewater, corresponding to 90.31%, 38.01% and 85.16% for COD, SCOD and BOD, respectively, compared to other conditions shown in table 2 and Fig. 1.

Table 2 Water quality of high carbohydrate wastewater treated by fungal

Condition		COD (mg/l)	SCOD (mg/l)	BOD (mg/l)	TKN (mg/l)	NH_3 (mg/l)
Influent		1693.568	81.778	304.000	10.308	9.835
Effluent	HRT 6 hrs	170.480	36.871	21.100	9.433	8.383
	HRT 12 hrs	173.919	31.929	25.400	8.873	8.103
	HRT 24 hrs	164.103	50.693	45.100	9.108	7.455
	HRT 36 hrs	274.491	55.164	36.200	8.855	8.085
	HRT 48 hrs	235.314	41.813	28.500	8.775	8.330

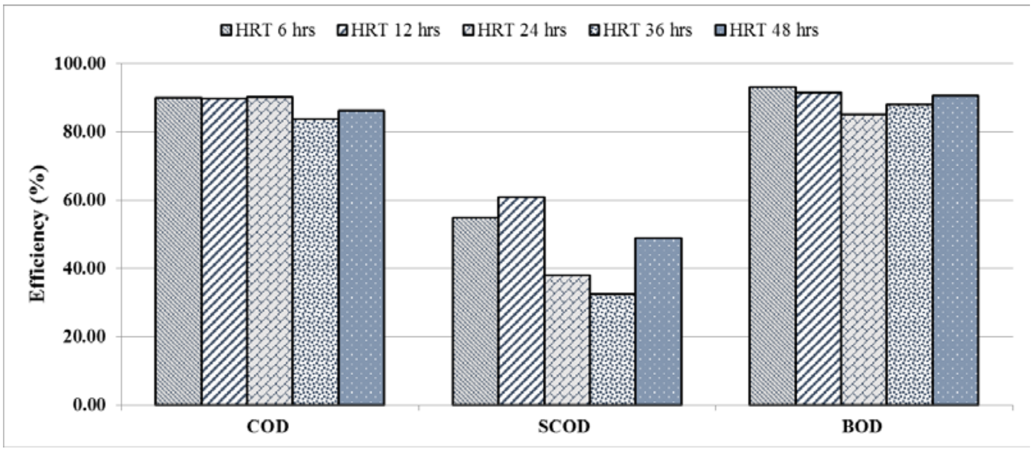

Fig. 1. Efficiency organic removal of fungal treatment at various HRT

As same as, the result of several researches such as, Takahiro et al. (2001) investigated the treatability of wastewater containing either soluble starch or cornstarch using an internal-loop airlift reactor with *Aspergillus niger* in an open system. The result for wastewater containing 25g/l cornstarch showed that the removal efficiency of TOC and the degradation efficiency of starch reached 76% and 99%, respectively. Truong et al. (2004) used *Aspergillus oryzae* for the treatment of the cassava starch processing wastewater, and observed both pellets and freely dispersed hyphal elements at pH 3.0. The treatment efficiencies obtained for TOC, COD and starch after 96 hrs were 72%, 75% and 77%, respectively.

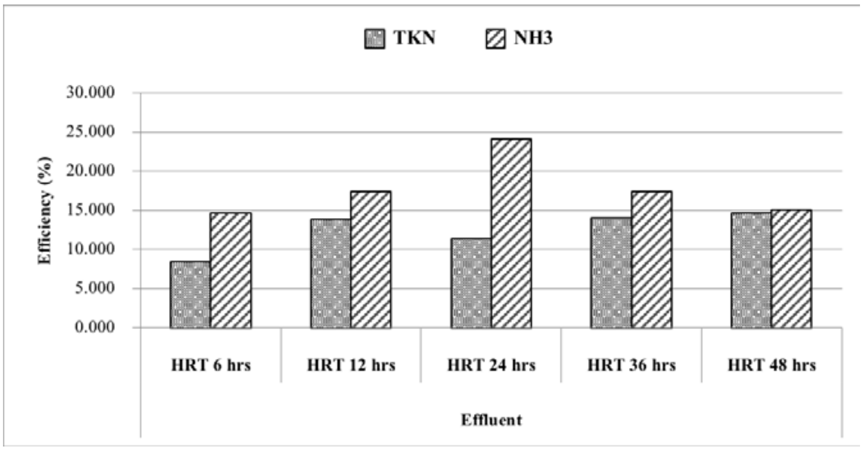

Fig. 2. Efficiency nitrogen removal of fungal treatment at various HRT

The results showed that the nitrogen removal efficiency in terms of TKN for all conditions of HRT was low. This is probably due to the presence of toxic environment for nitrifying bacteria when the pH value was adjusted to about 3.0±0.2. The pH for the optimal growth of *Nitrosomonas* and *Nitrobacter* bacteria was in the ranges of 6.0 to 9.0 and6.3 to 9.4, respectively. However, after treating by fungus, high organic contents were hydrolyzed to low organic contents. Compared to other conditions in table 2 and Fig. 1, the optimal condition for nitrogen removal was with 24 hrs HRT, and the removal efficiencies were found to be 11.4% and 24.16% for TKN and

NH_3, respectively.

The effluent from the treatment with fungus then can be used for agricultural irrigation or discharged into the fishpond. In accordance with the requirements of local environmental administration, the effluent of wastewater treatment station should reach the GB5084-92 "irrigation water quality standards", which are COD < 200mg/L, BOD_5 < 80mg/L, SS < 250mg/L, and the pH value is 5.5~8.5 (Bo et al., 2011)

3.2 Biodegradability and COD Fractionations

The biodegradability and COD fractionations were evaluated and the results are illustrated in Fig. 3. The ratio of BOD/COD is often used as an index to evaluate a biodegradability of wastewater. The BOD/COD > 0.45 indicates that the biodegradability is very good; for BOD/COD = 0.45, the biodegradability is good; for BOD/COD = 0.2–0.3, the biodegradability is poor; for BOD/COD < 0.2, the biological treatment is unsuitable. The BOD/COD ratio of high carbohydrate wastewater was found to be about 0.18 that is very low. The COD fractionation was evaluated for representing the biodegradability potential. The influent contained a particular inert (XI) fraction and readily biodegradable (Ss) of about 77.93% and 0.71% of TCOD, respectively. The high carbohydrate wastewater has a high molecular weight that is hardly biodegradable by heterotroph bacteria. After the treatment, readily biodegradable (Ss) increased to about 13.10% of TCOD at HRT of 24 hours. The XI fraction (inert particulates) exits the plant and bindsup in sludge flocs (Henzs, 2002). Although the XI fraction is inert, it can be removed by a biological treatment (Fall et al., 2012). Furthermore, the effluent provided the BOD/COD ratio of 0.275, which is 1.53 times higher than that of the influent, indicating that the biodegradable fraction can be increased through the fungus utilization.

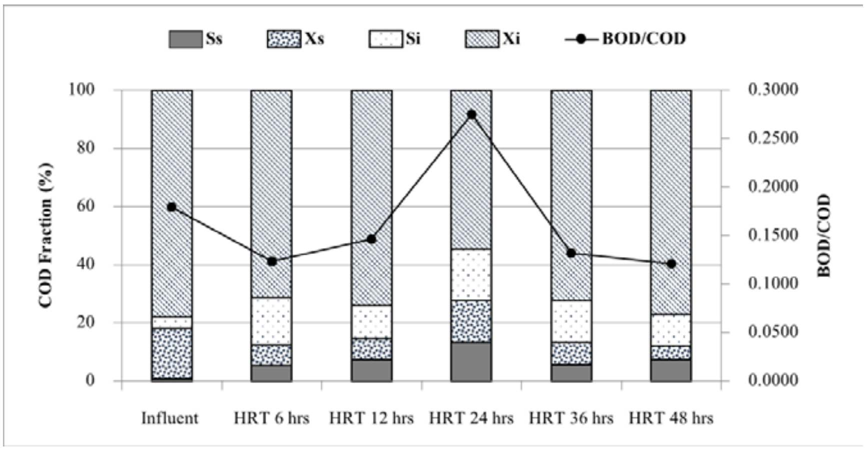

Fig. 3. The COD fractionation and biodegradability of fungal treatment at various HRT

4. Conclusions

The application of fungus for treating high carbohydrate wastewater provides the effective removal of COD in the range of 83-90%. Considering the effluent of SBR system at HRT 24 hours, the effluent provided the BOD/COD ratio of 0.275, which is 1.53 times higher than that of the influent, indicating that the improvement of the biodegradable fraction in the present of fungus. The readily biodegradable (Ss) increased to about 13.10% of TCOD. Plus, an increase of slowly biodegradable hydrolysis into readily biodegradable was observed. Furthermore, the single stage process developed in this study can reduce the operation costs because the initial cassava starch wastewater properties provide the selected fungus favourable growth conditions of initial pH (3.0-5.0). Contamination may be eliminated at the low pH. And the fungal biomass contains a high protein content and is safe for human and animal consumption, so it is marketable and can offset the operation costs. Therefore, this process is technically feasible for the treatment of any starch processing effluent with by-product recovery, contributing to sustaining the global management of the environmental resources.

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WR-B20

Characterization of dissolved effluent organic matter (EfOM) and industrial park wastewater treatment plant as a function of color

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Abstract

The aim of this research work is to establish an effective method to characterize the colored dissolved effluent organic matter (CDEfOM). The experiment was carried out on three types of treated industrial park wastewater samples (secondary effluent – biological treatment, SE followed by ozone treatment and SE followed by activated carbon treatment), collected from Yixing industrial park wastewater treatment plant (Yixing, China). Each samples were fractionated by Amberlite XRD-8 resin (non-ionic). The fractionated samples are hydrophobic acid (HPOA), hydrophobic basic (HPOB) and hydrophilic (HPI). The fractionated samples (HPOA, HPOB & HPI) were examined through UV-Vis spectrophotometer to determine the color according to two standard methods (ISO 7887:2011, method B and NCASI method color 71.01). The COD (mg/L) and DOC (mg/L) of each fractionated samples were determined. Other analytical tests like specific ultraviolet absorption at 254nm ($SUVA_{254nm}$), high performance size exclusion chromatography (HPSEC) to detect apparent molecular weight distribution (AMWD), excitation emission matrix (EEM) and X-ray photoelectron spectroscopy (XPS) were performed to characterize the physico chemical property of each fractionated samples. From the secondary effluent, it has been found that a significant portion of color is occupied by HPOA and HPI (HPOA>HPI) compared with other fractionated samples but for ozone and activated carbon treated samples HPI contains the higher color intensity than HPOA (HPI>HPOA). Ozone and activated carbon treatment is more effective to remove HPOA than HPI. From EEM, $SUVA_{254nm}$ and AMW it has been found that HPOA and HPI are humic type substance, with higher aromatic percentage, long conjugated system and provide enough facts to prove that HPOA and HPI contains a major portion of colored DOM. Furthermore, through XPS analysis four unconjugated chromophores (>C=O, -COO, C=N-O and $-CONH_2$) and two conjugated aromatic functional groups (Pyrrolic-N5 and N6 pyridinic) were found. In addition it can be said that color not only act as an aesthetic property but also brings assumption and facts about other parameters like COD, DOM, and MWD.

Keywords: Activated carbon; Colored dissolved organic matter; Fractionation; Industrial park; Ozone; wastewater

1. Introduction

Color is one of the most important aesthetic property for water. Effluent wastewater from heavy industries (textiles, paper mill, ternary etc.) produces huge amount of colored dissolved effluent organic matter (EfOM). In order to remove the color many research works had been done and is being carried out. Effluent containing comparatively low colored effluent i.e. municipal, industrial park also possess color and adequate treatment policies are being taken to remove the color. But very little number of researches are being conducted to characterize the colored dissolved effluent organic matter from different effluent wastewater treatment plants. But the characterization and identification of colored dissolved organic compounds is very much important, because light absorption by the colored fraction of dissolved organic matter (CDOM) provides useful information about biogeochemical processes (Carder et al. 1989, Matsuoka et al. 2013, Nelson et al. 2007). Through proper identification of colored dissolved organic matter (CDOM), a significant fraction can be understood about dissolved organic carbon (DOC). Because, colored dissolved organic matter (CDOM) possess an important part of DOC which plays various roles in physical and biogeochemical processes in natural waters

(Matsuoka et al. 2015). Furthermore, Dissolved effluent organic matter (EfOM) after conventional biological treatment becomes a mixture of soluble microbial products (SMP) (Barker and Stuckey 1999) and natural organic matter (NOM) transported from drinking water sources (Filloux et al. 2012), like SMP many other parameters can be explained by colored dissolved EfOM by establishing correlation between color and other parameters. But there is a scientific gap to explain the colored dissolved organic matter from different effluent wastewater treatment plants. That's why it is very much important to establish efficient identification technique for colored dissolved organic matter (CDOM). Color comes to a matter of concern for industrial wastewaters (textile, coking etc) but it is getting highlighted for industrial park wastewater reclamation as well. Effluent from industrial park sewage treatment plants contains residual contaminants that are mostly composed of non-degradable substances, which results in pollution of local aquatic systems (Zhu et al. 2015). Ozonation and activated carbon have been reported as the effective technologies for the removal of color from secondary effluent (Von Sonntag and Von Gunten 2012). However, little information is known about the contribution of different fractionated organic compounds to the color. At the same time, researchers performed different advanced techniques on industrial park wastewater as a function of effectiveness, removal efficiency etc but it had never been emphasized the effect on different fractionated organic samples as a function of color. So there is a significant gap in information from the previous research works.

Thus the main objective of this study is to establish an effective analytical method to characterize the colored dissolved effluent organic matter, to characterize the color or color bearing compounds, emphasizing the effect of different treatments (secondary effluent – biological treatment, SE followed by ozone treatment, SE followed by activated carbon treatment) on each fractionated samples of dissolved effluent organic matter (EfOM).

Fractionation through XAD macroporous resins are one of the commonly used technique for the fractionation of dissolved organic matter (Matilainen et al. 2011), is a favourable way to obtain information about changes in the hydrophobicity/hydrophilicity and acid/base behaviours of EfOM. There are different characterization techniques like excitation emission matrix (EEM) (Chen et al. 2003, Coble 1996), x-ray photo electron spectroscopy (XPS) (Arrigo et al. 2010, Nowicki et al. 2009), high performance size exclusion chromatography (HP-SEC) (Wang et al. 2010), are popular for the characterization of DOC.

2. Experimental

2.1 Wastewater treatment plant (WWTP) and water samples

The water used in this study was effluent wastewater with pH of 6~8. Water samples collected from seven different sites of industrial park wastewater treatment plant (40% industrial wastewater and 60% municipal wastewater being treated) at Yi Xing, China. All of the sites were examined for primary data collection and three major sites were chosen for intensive analysis, those are Site 3 - secondary effluent (SE) – biological treatment (pre-hypoxia, anaerobic, anoxic, aerobic, post – hypoxia, post -aerobic) treatment, Site 6 - SE followed by ozone treatment and Site 7 - SE followed by granular activated carbon treatment. The hydraulic retention time (HRT) for Site 3, Site 6 and Site 7 are 4 h, 1 h and 30 min. respectively. For site 6 the ozone dosage was 40mg/L with the gas flow (oxygen) of 160 L/h and for site 7 the wastewater treated/filtered through 80L of granular activated carbon (GAC-adsorbent) in a treatment bath of 160L. The effluent from Site 3, Site 6 and Site 7, typically have the following characteristics: COD - 50~80 mg/l, 30~50 mg/l and 30~50 mg/l, Colour (EPA method 110.2) - 30~50, <30 and <30, Total Nitrogen (TN) - <10, <7 and <7, Ammonia - <2, <1 and <1 respectively.

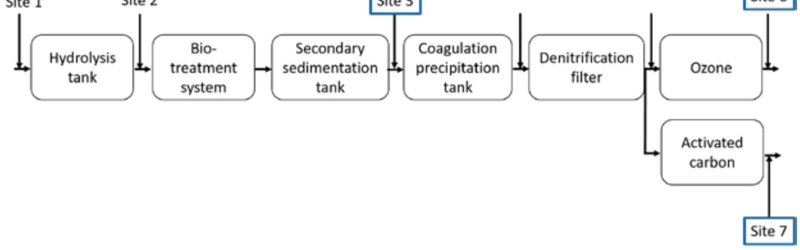


Fig. 1. Operation flow chat of industrial park wastewater treatment plant in Yi Xing, China.

All the analysis were conducted after the filtration of the wastewater samples. The water samples were filtered using a 0.45μm filter paper (GN-6 Metricel membrane, Pall Corporation) in order to remove the particles and inorganic substances prior to the analysis of dissolved effluent organic matter (EfOM). The filtered raw wastewater quality is shown in Fig. 2 along with the true color in two different standard methods.

2.2 True color measurement

Two different standard methods of (a) International standard ISO 7887:2011(E) (Water quality - Examination and determination of colour) and (b) NCASI (National Council for Air and Stream Improvement) METHOD COLOR 71.01 (Platinum-Cobalt Standard Method) were adopted to measure the true color of the wastewater samples.

2.2.1 International standard ISO 7887:2011(E) (Water quality - Examination and determination of colour)

This international standards specifies four different methods, designated A to D, for the examination of color. In order to characterize the true color of the water samples method B was followed in this experiment. In accordance with method B the color of the water is determined using a spectrophotometer with 10mm light path length (UV-6100 double beam spectrophotometer, MAPADA instruments) at three different wavelengths of (λ1) 436nm, (λ2) 525nm and (λ3) 620nm (Fig. 2 (a)).

2.2.2 NCASI (National Council for Air and Stream Improvement) METHOD COLOR 71.01 (Platinum-Cobalt Standard Method)

According to this method the color is determined by comparison of the absorbance of the sample to the absorbance of the platinum-cobalt (Pt-Co) standard solution (with a color value of 500 PCU). Single wavelength 455nm was chosen to measure the absorbency using a spectrophotometer with 10mm light path length (UV-6100 double beam spectrophotometer, MAPADA instruments). 456 nm wavelength was chosen as it proposed for the standardization of colour measurement for different wastewater samples with low color intensity (Bennett and Drikas 1993, Hongve and Åkesson 1996). The unit of color is the color produced by 1 mg platinum/litter in the form of the chloroplatinate ion, or PCU. A seven point (PCU455nm) calibration curve was plotted, secured from the absorption values from different diluted (using Milli-Q water) fractions of the Pt-Co standard solution. The linear curve fitting results the equation of: $Y = (0.00278) X + (– 0.00434)$ with the R – square value of 0.99953. Fig. 2 (b) represents the PCU (color reading) of wastewater samples from different seven sites.

2.3 Fractionation procedure

2.3.1 Resin preparation

An approximate amount of resin was cleaned by preparing a slurry of resin-NaOH (0.1N), followed by pouring out the fine resins, floating on the surface of the slurry. The remaining resins were soaked for 24h in 0.1N NaOH. In order to remove the organic contaminates, the resin was placed in a soxhlet extractor and sequentially extracted for 24hrs followed by stored in methanol (37% Con.) until used. Glass columns were packed with a H2O-resin slurry and rinsed with Milli-Q water to remove methanol. The resin was further cleaned immediately before use, with three successive 0.1M NaOH (80 ml)-H2O (80ml) – 0.1M HCl (80ml) for 10ml column of resin (XAD-8) with the flow rate of 180ml/h. Then rinsed with Milli-Q water until the DOC level goes less than 0.4 mg/L (Aiken et al. 1992, Gong et al. 2008, Leenheer 1981).

2.3.2 Wastewater sample preparation

Wastewater samples with lower DOC level (< 5 mg C/L) is not suitable for ordinary fractionation process. To do the fractionation of such kind water samples (< 5 mg C/L), modified fractionation technique is needed (Marhaba et al. 2003). Since the existing wastewater samples in this study (site-3, site-6 and site-7) have lower DOC value. So, in order to overcome this issue after filtration the wastewater samples were concentrated by a reverse osmosis (RO) membrane system. The concentration degree was 20 (Jin et al. 2016), namely each 1-L water sample was concentrated to 50 ml. The DOC level of the wastewater samples before and after are shown in Table 1.

Table 1 The DOC and degree of chroma of effluent wastewater from three different sites (before and after concentration)

Sample	Site-3: Secondary effluent (SE)		Site-6: SE followed by ozone treatment		Site-7: SE followed by granular activated carbon treatment	
	DOC (mg/L)	PCU	DOC (mg/L)	PCU	DOC (mg/L)	PCU
Before Concentration	9.33	7.32	6.97	1.92	1.88	1.92
After Concentration (20 times)	45.8	32.86	35.17	5.52	10.67	4.44

2.3.3 Fractionation process

The wastewater samples were fractionated using SupeliteTM XAD-8 resin. The DOM fractionation method used in this study was modified from elsewhere (Aiken et al. 1992, Bu et al. 2010, Gong et al. 2008, Jin et al. 2016, Labanowski and Feuillade 2009, Leenheer 1981, Marhaba et al. 2003, Yang et al. 2013). An aliquot 150ml (pH-6~8 as original) of concentrated waster sample (SE, SE-O3 and SE-GAC) was pumped through the XAD-8 with the flow rate of 150ml/h, followed by passing 25ml of Milli-Q water to take out the remaining water sample from the column inside. The first adsorbent from XAD-8, hydrophobic base (HOB), was then eluted by a sequential flow of 10ml of 0.1M HCl followed by 15ml of 0.01M HCl with the flow rate of 90ml/h. Before collecting the eluted sample first 6ml discharged as is was the remaining Milli-Q water inside the column. The effluent sample from the XAD-8 was acidified to pH 2 and recycled through the XAD-8 column at 150ml/h followed by passing 10ml of 0.01M HCl to get the nonsorbed portion of the sample. The hydrophilic fraction (HI) was the effluent and the hydrophobic acid (HOA) was adsorbed on to the resin, which was eluted by passing 10ml of 0.1M NaOH, followed by passing 15ml of Milli-Q water with a flow rate of 90ml/h. In order to collect the hydrophobic neutral (HON) the XAD-8 needed to dried at 40°C (or air dried) for 24 hours followed by Soxhlet-extracted with anhydrous methanol. Then the anhydrous methanol is evaporated using rotary evaporator and dried 40°C for 24 hours. Due to such complexity and having less contribution to color, in this experiment HON was not collected. All of the elution is this procedure were performed in a forward direction or by gravity flow. Milli –Q water was added with all the eluted samples (HOB, HOA) to make the sample volume to the original volume (150ml). Later on the pH was adjusted to original pH range (6~8).

2.4 Analytical method

2.4.1 DOC and UV absorbance measurement

DOC was measured by a Shimadzu TOC-VCPH (total organic carbon analyser) with infrared detection. The DOC analyser was calibrated with potassium hydrogen phthalate standard solutions before each run. All of the samples were filtered with a 0.45 mm filter, acidified with HCl and purged with nitrogen to remove inorganic carbon before measurement. SUVA254nm was measured by UV-VIS spectrophotometer (UV-6100 double beam spectrophotometer, MAPADA instruments) using 1-cm path length quartz cells. All analyses were performed in triplicate for all of the measurements of DOC and UV_{254}.

2.4.2 Fluorescence excitation-emission matrix (EEM) analysis

Fluorescence measurements were conducted using a Fluorescence Spectrophotometer (F-7000, Hitachi, Japan) with a 150 W xenon lamp. The analyses were performed at ambient temperature. A 1-cm quartz cuvette with four optical windows were used for the analyses. Emission scans were performed from 220 to 550 nm with 5 nm steps, while excitation wavelengths were measured from 200 to 400 nm with 5 nm intervals. The slit widths for excitation and emission were 5 nm. The detector was set to high sensitivity and the scanning speed was kept at 12000 nm/min. The fluorescence spectra for Milli-Q water was measured with the same method, and subtracted (using FL solutions 2.1 for F-7000) from all of the samples spectra to eliminate water Raman scattering and reduce other background noises throughout the experimental period. The EEM spectra were plotted as contours. The X-axis represents the emission spectra, while the Y-axis represents the excitation wavelength and the third dimension, i.e., the contour line, is given to express the fluorescence intensity.

2.4.3. High performance size exclusion chromatography (HPSEC) for apparent molecular weight distribution (AMWD) analysis

The characterization of the apparent molecular weight distribution (MWD) of the EfOM was performed using size exclusion chromatography (SEC) coupled with ultraviolet detector (UV254) detector. The high performance liquid chromatography (HPLC) system was a Breeze 1525 (Waters Co., U.S.A.) with a TSKgel® G3000SWXL SEC column (Tosoh, Japan). The column was kept at ambient temperature. The mobile phase, Milli Q water buffered with 5 mM phosphate to pH 6.8, and 0.01 M NaCl, was filtered through a 0.22 µm membrane, and then degassed (ultrasonication) for 30 min. The flow rate was 0.8 mL/min and the injection volume was 200 µL with 20 minutes run time (Wang et al. 2010).

2.4.4 X-ray photoelectron spectroscopy (XPS) analysis

X-ray photoelectron spectroscopy (XPS) was used to determine different carbon (C1s), oxygen (O1s) and nitrogen (N1s) species in the EfOM fractions. The liquid fractions were dried at 45°C for 72 hours in order to get the powder and stored in a desiccator, until it is used for XPS analyses. The XPS analyses were performed with an X-ray photoelectron spectrometer (K-Alpha, Thermo Fisher Scientific, UK). Each analysis commenced with a survey scan in the binding energy range from 100 to 1000 eV. A high energy resolution scan was applied with a step size of 0.05 eV.

3. Results and discussion

3.1 Characterization of EfOM

3.1.1 Measurement of colour intensity and standard correlation analysis between color intensity and COD

Fig. 2 shows the measurement of chroma or colour intensity of effluent wastewater from 7 different sites at Yi Xing industrial park wastewater treatment plant. The colour intensity was measured in two different standards are (a) ISO 7887, method B and (b) Platinum-cobalt standard method (NCASI method color 71.01).

ISO 7887, method B (Fig. 2 a) was followed to measure the true colour of the wastewater samples by measuring the absorption at three different wave lengths (436nm, 525nm and 620nm) The selected wavelengths situated in such a way so that it can bring information from the total range of visible spectra (380nm to 720nm). Chemical compound absorb a certain energy (ΔE=LUMO-HOMO) in the form of wavelength, to make a pie ($\pi \rightarrow \pi^*$ or $n \rightarrow \pi^*$) to pie star electron transition (to carry an electron from the ground state or highest occupied molecular orbital- HOMO to excited state or lowest unoccupied molecular orbital- LUMO). As the wavelength is inversely proportional to the energy so the energy level of these tree wavelength can be arranged in the order of 436nm > 525nm > 620nm. On the other hand, chemical compounds with higher number of conjugated double bond system or having higher aromatic rings, required less energy for electron transition due to the electron resonance. Which implies, the absorption due to longer wavelengths indicates the presence of broad chemical structures, having long conjugated double bong system, higher aromaticity or complex aromatic compounds with long aromatic conjugated system and due to the electron resonance configuration, these chemical compounds have smaller electron transition band width, in other words the gap between HOMO and LUMO energy lever is small (Aihara 1999, Owen 1996).

In Fig. 2 it can be seen that the degree of chroma decreased along with the intensive treatment process from site 1 to site 7 and in every sites the absorbency for 436nm is higher than 525nm and 525 is higher than 620nm. In case of site 6 and site 7 there is no absorption for 525nm and 620nm, which implies the advance treatment on site 6 (SE-O_3) and site 7 (SE-GAC) was effective enough to breakdown (by O_3) and adsorb (by (GAC) the complex chemical structures (higher molecular weights or long conjugated system). On the other hand the absorbency for 436nm decreased gradually up to site 3 (SE-biological treatment) but after site 3, there was no significant changes in colour intensity (abs. at 436nm) through the remaining treatments. It implies the remaining treatments were not effective enough to decompose comparatively smaller chemical structures with lower molecular weights.

620 nm is the longest wavelength (contains lowest energy among three wave lengths) among three wavelengths and absorbency for this wavelength indicates chemical compounds, having lower ΔE (LUMO-HOMO) to make $\pi \rightarrow \pi^*$ or $n \rightarrow \pi^*$, in other words, the presence of comparatively long conjugated double bond system with higher aromatic structures. These chemical compounds are more likely to be complex in chemical structure. In case of 525nm, it contains comparatively higher energy (as 525 nm < 620nm). It indicates the presence of chemical compounds having comparatively higher ΔE (LUMO-HOMO). Since the energy level is

higher than 620nm, that's why a part of the total absorbency by 525nm comes from those larger molecules (longer conjugated system) identified by 620nm. 436nm (highest energy among three) follows the same phenomena and it indicates more simple chemical structures and a certain portion of its total absorbency comes from the chemical structures absorbs 525nm and 620nm. Due to these phenomena the spectral absorbency will always maintain the sequence of 436nm >525nm >620nm.

Fig. 2 (b) shows the Platinum-cobalt standard method (NCASI method color 71.01) and according to this method a gradual decrease in colour intensity from site 1 to site 7 were observed but it does not provide much information regarding chemical compounds like ISO 7887- method B. Due to its single value of chroma, the readings from this method were used for standard correlation with other parameters. Fig. 2 (c) shows the standard correlation between COD and degree of colour (PCU $_{455nm}$) with the r-square value of 0.95, which indicates a strong relation between COD level and degree of colour in PCU_{455nm}.

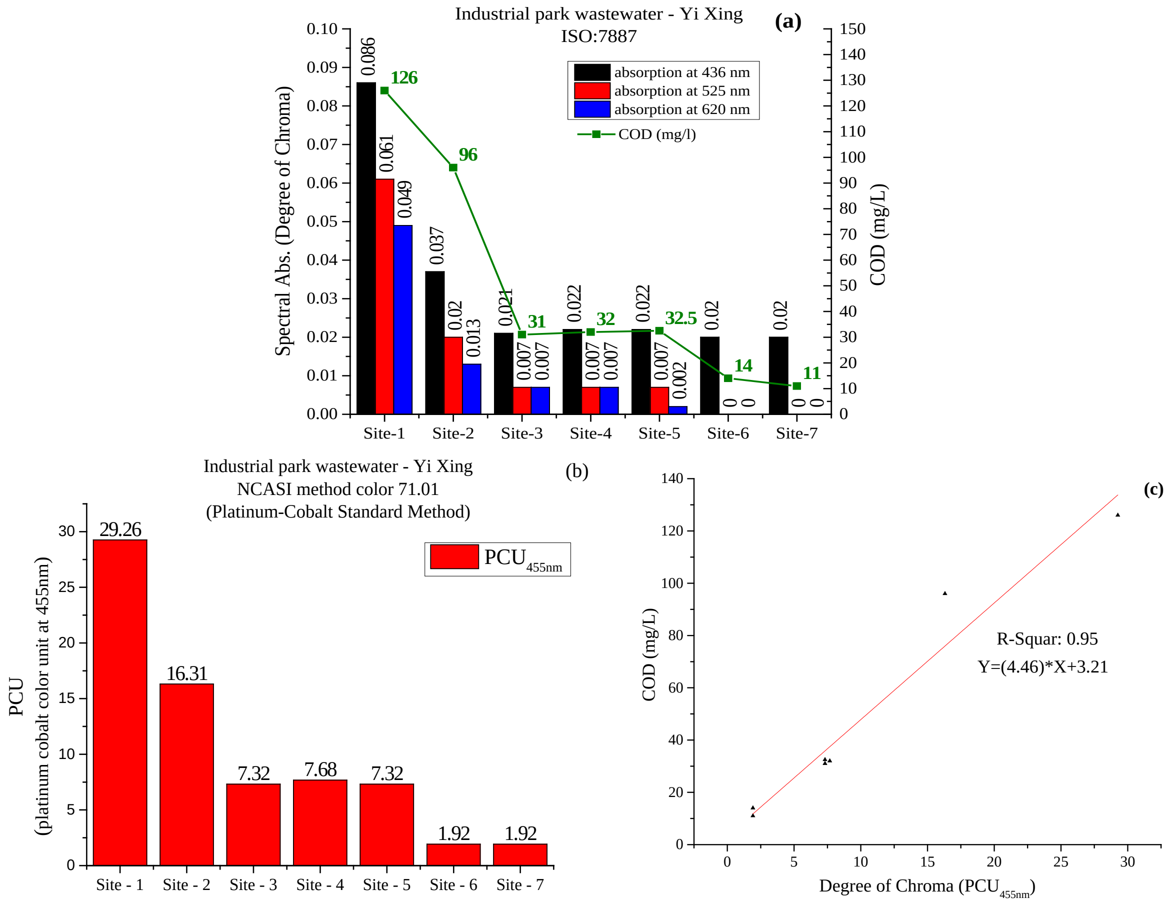


Fig. 2. Determination of true color of Yi-xing industrial park wastewater using (a) ISO 7887:2011, method B and (b) NCASI method color 71.01 (Platinum-cobalt standard method) (c) Standard correlation between chroma (PCU455nm) and COD (mg/L).

A strong (R-Square: 0.95) correlation is found from the standard correlation between colour intensity (PCU_{455nm}) and COD (mg/L). Which indicates intensity of color can be act as an indicator for COD level.

3.2 Characterization of different fractions of effluent wastewater from three different treatments (SE, SE-O_3, SE-GAC) in terms of Color, DOC and $SUVA_{254}$

3.2.1 Analysis of secondary (biologically treated) EfOM

Fig. 3 shows the degree of chroma (ISO 7887, method B and Pt-Co methods) and DOC level of three different fractions (HPOA, HPOB and HPI) of secondary effluent. Running a standard correlation between DOC and color intensity in PCU_{455nm}, it was found that the r-square (R^2) value is 0.85 and it implies there is a strong correlation exist between DOC (mg/L) and color (PCU). On the other hand, HPOA and HPI are the dominating fractions to show color and among these two HPOA is intense than HPI (HPOA = 48.32% and HPI=40.03%; Pt-

Co standard method (Fig. 3 b)) to exhibit color. The reason behind such an influence on exhibiting color for HPOA is due to its physicochemical property. HPOA are usually found to be composed of complex, aromatic and high molecular weight subunits (Swietlik and Sikorska 2006), can contains lignin components conjugated to carbohydrates (Wershaw et al. 2005), humic material, fulvic and humic acid (Croue et al. 2000), aliphatic carboxylic acids, one and two ring of aromatic carboxylic acids, one and two ring phenols and aquatic humic substances (Aiken et al. 1992). The presence of carboxylic acid or acetic acid (-COOH) (according to the literature) indicates the presence of chromophore (due to absorb longer wavelength) and in order to exhibit color along with chromophore, chromogene is needed (acceptor of electrons - chromogene is constituted of aromatic structures, normally based on rings of benzene, naphthaline or antracene, which makes bonds with chromofores that contain double conjugated links with delocated electrons) (Carmen and Daniela 2012). Carboxylic acid (-COOH) can be identified as an unconjugated chromophore (covalently unsaturated group responsible for absorption in the UV or visible) (Gürses et al. 2016). The presence of aromatic carboxylic acid indicates the presence of chromogene-chromophore structure, which is responsible for color if the emission wavelength belongs to visible spectra (Carmen and Daniela 2012). Besides, the higher absorption for HPOA at $SUVA_{254nm}$ empowered this fact of having a significant amount of aromatic compound (45.84%, Fig. 3c). Due to these physicochemical property HPOA is the dominating fractions to impart colour.

On the other hand HPI also exhibited color near to HPOA and in general HPI contains polyfunctional organic acids and aliphatic acids (Aiken et al. 1992), most likely represent complex mixtures of relatively low molecular weight carboxylic acids derived from terpenes, carbohydrates, and peptides mentioned elsewhere (Wershaw et al. 2005). Besides from the $SUVA_{254nm}$ for HPI it can be seen that it contains the higher amount of aromatic compounds (51.88%, Fig. 3 (c)), which implies it may contain long aromatic conjugated system. Since, HPI also contains unconjugated chromophore carboxylic acid (-COOH) with high mount for aromaticity (chromogene) so it may one of the chemical composition to exhibit color. HPI usually contains compounds of low molecular weight (i.e. comparatively short conjugated double bond system) which may one of the reasons for relatively low chroma than HPOA.

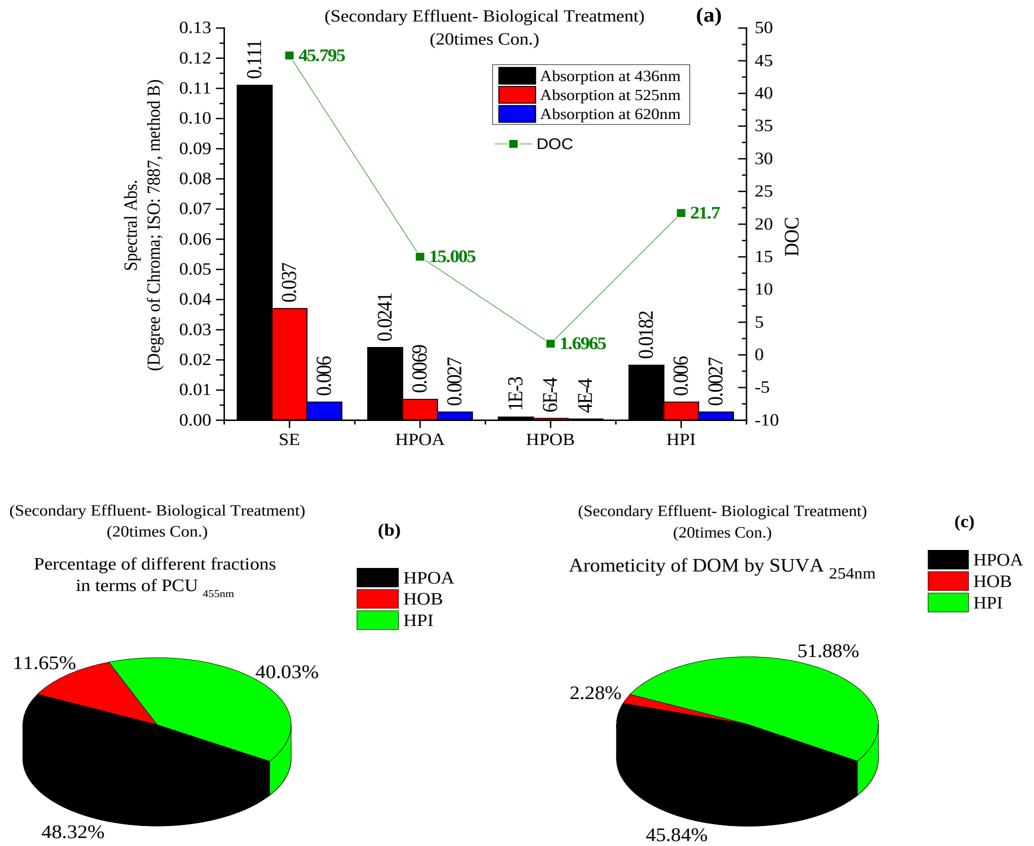


Fig. 3. Analysis of different fractions of biologically treated secondary effluent, in terms of
(a) colour intensity according to ISO 7887, method B vs. DOC
(b) percentage of colour intensity according to platinum cobalt standard method
(c) percentage of $SUVA_{254nm}$ absorbency, representing the aromaticity (in %) among different fractions.

On the other hand HPOB showed comparatively the list percentage (CPU_{455nm}11.65%, Fig. 3b) of colour as it contains the least amount of aromatic compounds ($SUVA_{254nm}$ = 2.28%) in other words having the shortest conjugated system among these three fractions.

3.2.2 Analysis of SE-O3 treated EfOM fractions

Fig. 4 shows the degree of chroma (ISO 7887, method B and Pt-Co methods) and DOC level of three different fractions (HPOA, HPOB and HPI) of SE-O_3 treated sample. In case of three fractionated samples, the chroma is very less compared to secondary effluent (SE) (ISO 7887, method B, Fig. 3a and Fig. 4a). Among three fractions HPI (PCU_{455nm} = 46.51%, Fig. 4b) showed the higher percentage of color followed by HPOA (PCU_{455nm} =29.34%, Fig. 4b) and HPOB (PCU_{455nm} =24.14%, Fig. 4b). Standard correlation between DOC and color ($PCU_{455nm)}$ gave the r-square value of 0.94, which implies a strong relation between these two parameters. In case of $SUVA_{254nm}$ for HPI ($SUVA_{254nm}$ = 70.24%, Fig. 4c) shows much higher percentage (i.e. higher aromatic compounds) it emphasize the fact that O_3 was much effective to remove HPOA ($SUVA_{254nm}$ = 26.87%, Fig. 4c) type compounds compared with HPI. Since in HPOA the aromaticity is low it indicates low molecular structure or compounds with low molecular weight and leading to the fact of having short conjugated system, which may be one of the possible reasons for having lower chroma than HPI.

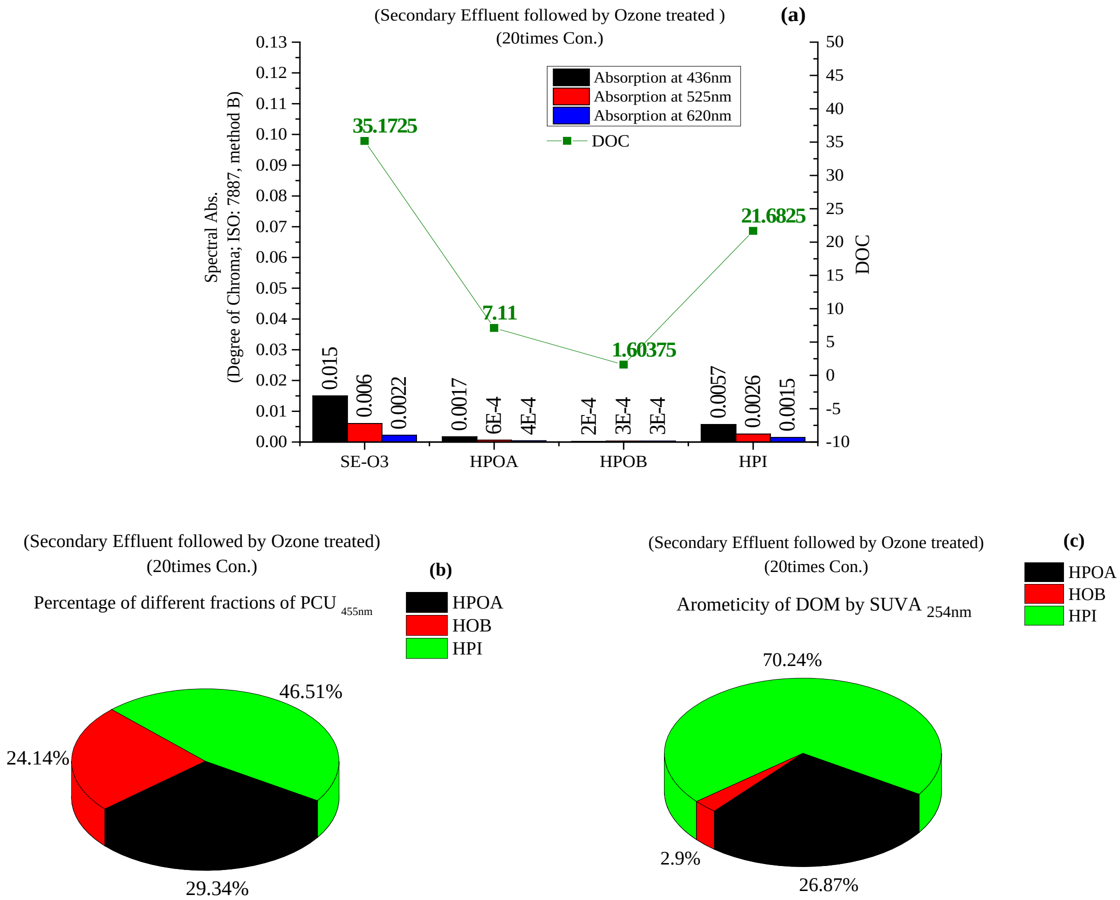


Fig. 4. Analysis of different fractions of SE-O_3 effluent, in terms of
(a) colour intensity according to ISO 7887, method B vs. DOC
(b) percentage of colour intensity at different fractions according to platinum cobalt standard method
(c) percentage of $SUVA_{254nm}$ absorbency, representing the aromaticity among different fractions.

3.2.3 Analysis of SE-GAC treated EfOM fractions

Fig. 5 shows the degree of chroma (ISO 7887, method B and Pt-Co methods) and DOC level of three different fractions (HPOA, HPOB and HPI) of SE-GAC treated sample. Like ozone treated sample the fractions of SE-

GAC treated samples contains low chroma compared with secondary effluent (ISO 7887, method B, Fig. 3a and Fig. 5a). It indicates the good efficiency of GAC on removing dissolved organic color substances. Among all the fractions HPI (PCU_{455nm} = 43.04%, Fig. 5b) showed the higher percentage of color followed by HPOA (PCU_{455nm} =29.34%, Fig. 5b) and HPOB (PCU_{455nm} =27.63%, Fig. 5b). Standard correlation between DOC and color ($PCU_{455nm)}$ gave the r-square value of 0.88 and it implies strong relation between DOC and chroma. In case of $SUVA_{254nm}$ HPI ($SUVA_{254nm}$ = 73.25%, Fig. 5c) shows much higher percentage (i.e. higher aromatic compounds) like ozone it also emphasize the fact that granular activated carbon (GAC) are effective to adsorb HPOA ($SUVA_{254nm}$ = 23.55%, Fig. 5c) compared with HPI. Since, the aromaticity is low for HPOA it indicates low molecular structure or compounds with low molecular weight and leading to the fact of having short conjugated system, which may be one of the possible reasons for having lower chroma than HPI.

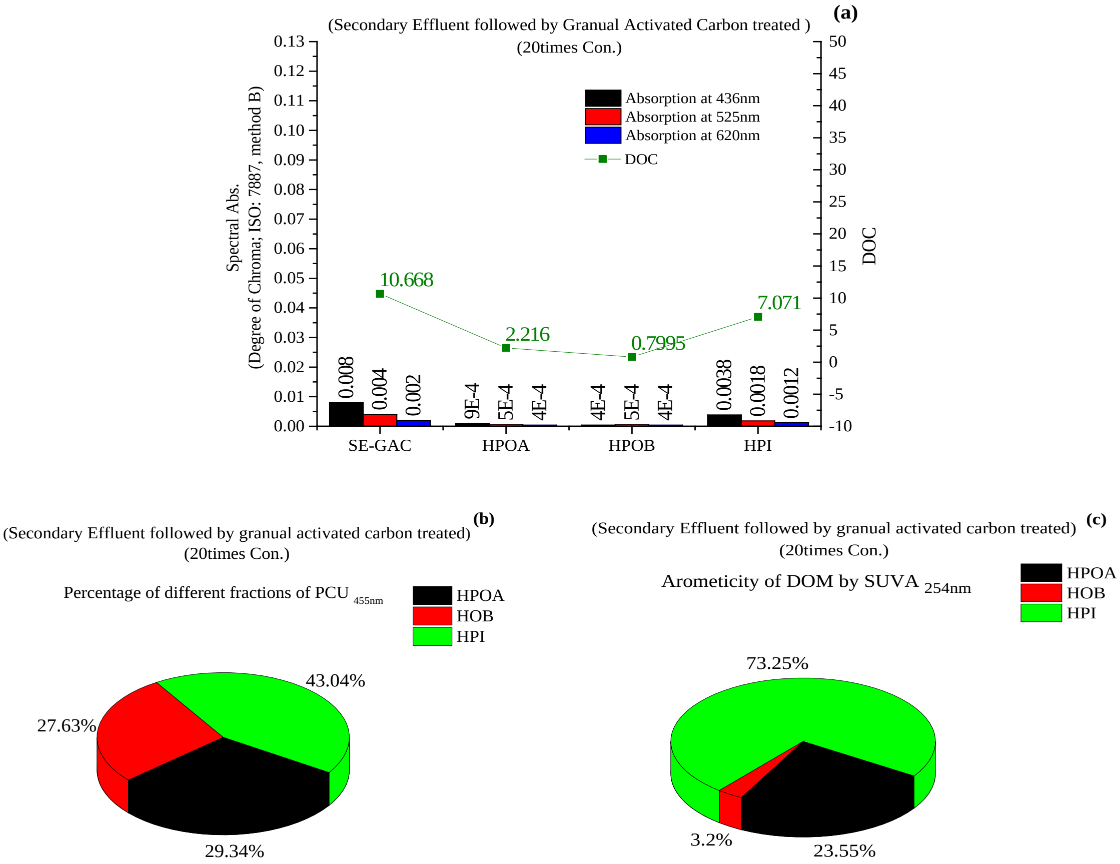
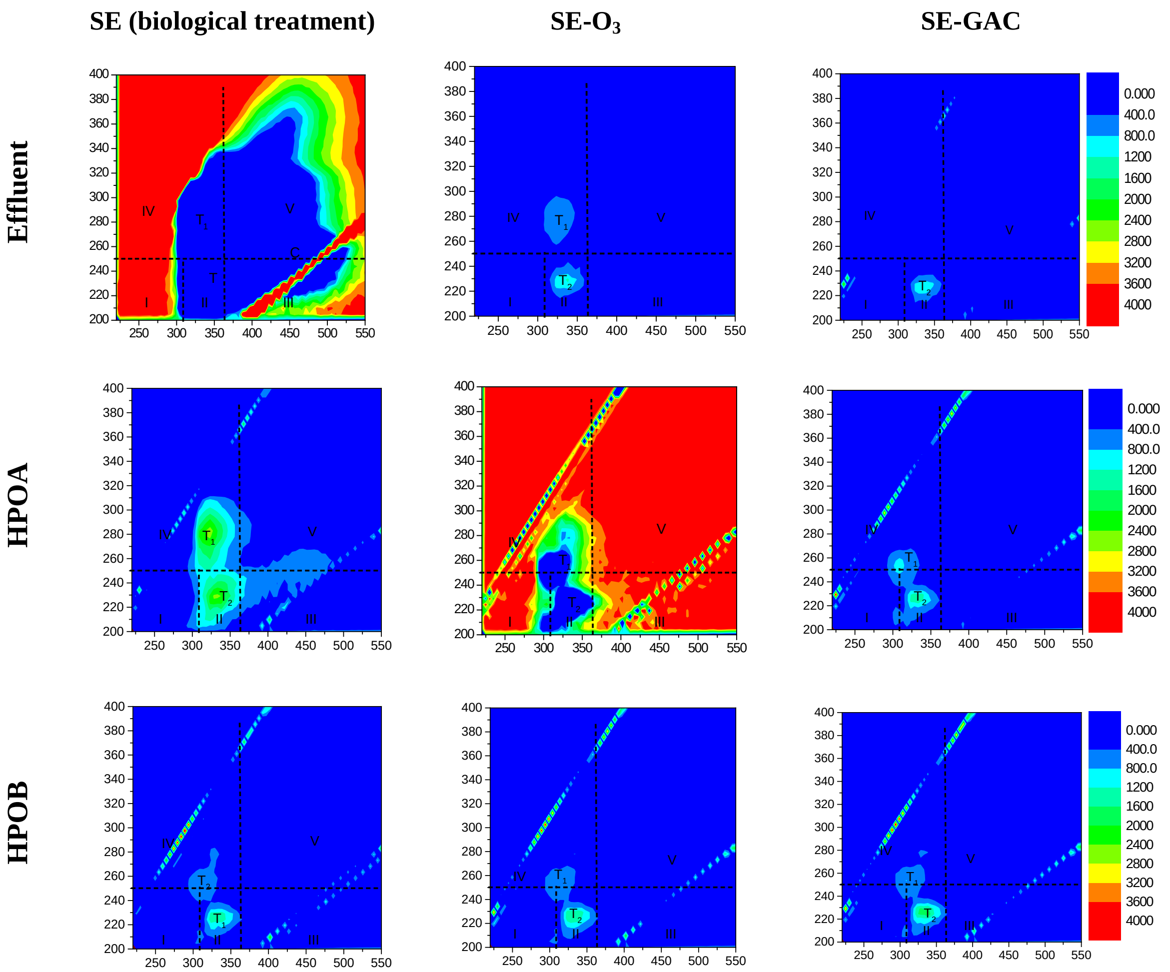


Fig. 5. Analysis of different fractions of SE-GAC effluent, in terms of
(a) colour intensity according to ISO 7887, method B vs. DOC
(b) percentage of colour intensity at different fractions according to platinum cobalt standard method
(c) percentage of SUVA 254nm absorbency, representing the aromaticity among different fractions.

3.3 Analysis of EEM fluorescence spectra for the identification colored DEfOM and removal EfOM through different advanced methods (O_3 and GAC)

EEM fluorescence spectra have been widely employed to distinguish the chemical composition of DOM because of its ability to identify certain classes of organic matter in both natural and engineered water systems. It is difficult to make use of all the information collect with EEM spectroscopy. The characterization of FDOM composition is based on contour plots, position of emission maxima, position of wavelength independent fluorescence maximum (Ex_{max}/Em_{max}), and fluorescence intensity at (Ex_{max}/Em_{max}). The EEM picks can be distinguished into five main regions, referred to as fluorescence peak I (aromatic protein I), II (aromatic protein II), III (Fulvic acid-like), IV (soluble microbial by-product-like) and V (Humic acid-like) commonly detected in wastewater samples, mentioned elsewhere (Chen et al. 2003), the picks in these regions are similarly classified as pick B, pick T_2, pick A, pick T_1 and pick C respectively (Coble 1996). The changes in EfOM (industrial park wastewater) due to different treatments (i.e., SE, SE-O3 and SE-GAC) and their influence on different fractions are presented by EEM contour plots in Fig. 6. Besides getting information on DOM, EEM fluorescence also gives information about chemical compounds exhibits colour (peak C). As depicted in Fig. 6, three fluorescence peaks, peak T_1, T_2 and C were detected. The parameters, including fluorescence peak locations (Ex $_{max}$ (nm) and Em $_{max}$ (nm)), intensity (F $_{max}$ (cps)), and different peak intensity ratios (T_1/T_2) identified from EEM fluorescence spectra, are listed in Table 2.

For characterizing the colour exhibiting compounds, among three peaks (T_1, T_2 and C) peak C is more likely to explain the existence of color and also correlate with the previous information through ISO-7887, method B (Fig. 3(a)). Peak C is also characterized as visible fluorescence peak elsewhere (Coble 1996). The logic behind saying these peak as visible fluorescence peak due to the fact that, the emission wavelength situated in the range of visible wavelength (380nm to 720nm). Peak C is found in SE (Ex $_{max}$/ Em $_{max}$ = 259/456) and two of its fractions of HPOA (Ex $_{max}$/ Em $_{max}$ = 254/447) and HPI (Ex $_{max}$/ Em $_{max}$ = 249/412) with the maximum fluorescence intensity of 2679 cps, 626 cps and 915 cps respectively (Table 2). Comparing with HPOB and any other fractions from other treatments (SE-O_3 and SE-GAC). Here, all the Em $_{max}$ for SE, HPOA and HPI are greater than 400nm with the Ex $_{max}$ around 254nm, which implies the existence of the colour bearing compounds. In addition, the chemical compounds situated in this region (humic type) have chromophore groups connected with higher numbers of conjugated double bonds in aromatic and aliphatic structural systems (red-shifted) (Swietlik and Sikorska 2006). These properties or outcomes shows much similarity with ISO: 7887-method B or PCU_{455nm} as colour was identified in HPOA and HPI (HPOA > HPI >> HPOB, (Fig. 3 a, b) and percentage of aromaticity by UV_{254nm} (HPI > HPOA>>HPOB, Fig. 3 c). Besides, the maximum fluorescence intensity (HPI>HPOA) shows proportionality to DOC (HPI >HPOA) in Fig. 3 (a), here even though HPI possess higher aromaticity and DOC value compared with HPOA, in case of color intensity HPOA>HPI. Which implies the importance of a specific functional group to exhibit color, being attached with the chromogene structures or long aromatic conjugated system (Swietlik and Sikorska 2006).



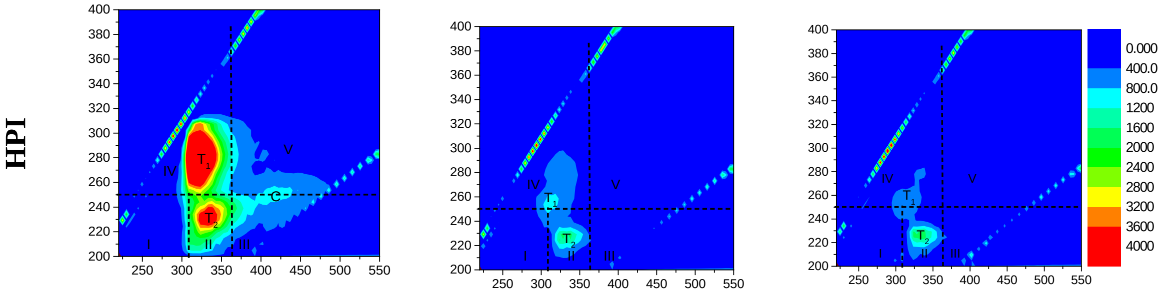


Fig. 6. EEM fluorescence spectra of SE, SE-O_3, and SE-GAC samples along with three different fractions (HPOA, HPOB and HPI)

In comparison of the effect of different treatments by EEM (Fig. 6) it can be seen that peak C is not available in SE-O3 effluent and SE-GAC effluent, which explains the removal of yellowish color from the SE effluent as explained earlier, as the abs. is very small compared with SE (Fig. 3 a, Fig. 4 a and Fig. 5 a). For SE-O3 effluent, peak T_1 and T_2 but for SE-GAC effluent only peak T_2 were found. Peak T_1 indicates the soluble microbial by product-like material and T_2 indicates the presence of aromatic proteins-like substance (Yang et al. 2013). It implies granular activated (GAC) was more effective to remove soluble microbial by product like materials by adsorption and showed better efficiency on T_2 type compounds compared with ozone treated samples, since the maximum fluorescence intensity for GAC (F_{max} (cps)=1119) is lower than O_3 (F_{max} (cps)=1307) treated sample. In case of fractionated samples pick T_1 appeared (Fig. 6), which is very much possible due to resin contamination during the long period of fractionation (approximately more than 24 hours). As the resins are contamination free if only it is stored in methanol but during long period of fractionation it is easy to get contaminated a little but it is easy to catch up that little contamination by EEM, because of it high sensitivity. Except this contamination peak T_1 different fractions of SE-O_3 and SE-GAC more or less similar intensity for peak T_2 (Table 2).

Table 2 Mean values for wavelength-independent fluorescence properties of visible humic-like fluorescence (peak C) of industrial park wastewater treatment plant: excitation maximum (Ex_{nm}), emission maxima (Em_{nm}) and maximum fluorescence intensity (F_{max})

	Different peaks	**II (peak T_2)**			**IV (peak T_1)**			**V (peak C)**		
Different treatment	**Fractions**	**Ex_{max} (nm)**	**Em_{max} (nm)**	**F_{max} (cps)**	**Ex_{max} (nm)**	**Em_{max} (nm)**	**F_{max} (cps)**	**Ex_{max} (nm)**	**Em_{max} (nm)**	**F_{max} (cps)**
SE (biological treatment)	Effluent	239	353	9936	283	323	9334	259	456	2679
	HPOA	229	333	2503	283	323	2626	254	447	626
	HPOB	224	333	1502	254	309	801	-	-	-
	HPI	234	333	4446	283	323	8193	249	412	915
SE-O_3	Effluent	229	338	1307	278	323	792	-	-	-
	HPOA	229	338	1677	248	309	941	-	-	-
	HPOB	224	333	1570	254	309	797	-	-	-
	HPI	229	338	1754	254	309	936	-	-	-
SE-GAC	Effluent	229	338	1119	-	-	-	-	-	-
	HPOA	224	333	1515	254	309	1006	-	-	-
	HPOB	224	338	2018	254	309	811	-	-	-
	HPI	224	333	1779	254	309	782	-	-	-

3.4 High performance size exclusion chromatography (HPSEC) to analyse the apparent molecular weight (AMW) distribution of EfOM fractions

Chromatographic characterization and AMWD of NOM was determined by HP-SEC with UV-detection at

254 (Fig. 10). The system was calibrated with PSS standards with MWs of 1.8, 4.2, 6.5, and 32 kDa (Sigma–Aldrich, USA), the system was calibrated with PSS standards with MWs of 1.8, 4.2, 6.5, and 32 kDa (Sigma–Aldrich, USA). Considering the existence of a series of non-ideal interactions between the column stationary phase and solute, and the fact that the standards may not represent the true size of DOM molecules during analysis, the term ‘‘AMW” is used, rather than the terms ‘‘MW” or ‘‘molecular size” (Hoque et al. 2003, Wang et al. 2010).

HPSEC chromatographs have been processed by OriginPro 9 software. The result of AMW is illustrated in Fig. 10. Three major peaks of 3614 Da (peak 1), 2426 Da (peak 2) and 1691 Da (peak 3) were identified in the effluent wastewater (i.e. SE, SE-O_3 and SE-GAC) and their fractionated samples. Peak 1 (3614 Da) and peak 2 (2426 Da) indicates the humic type substance as molecular weight (MW) ranging from 0.2 to 20 kDa represents the humic substances (HS) (Boyer et al. 2008).

Clear existence of peak 1 (3614 Da) and peak 2 (2426 Da) is very much likely to explain the existence of color, as HS incorporate high MW aromatic structures that enriched in oxygenated functional groups attached to it like carboxylic acid and phenol group. In addition HS are responsible for the brownish yellowish color detected in the water (Boyer et al. 2008). From Fig. 10 (a), it can be seen that, peak 1(3614 Da) and peak 2 (2426 Da) can be easily identified in the effluent wastewater samples (SE, SE-O_3 and SE-GAC) with different absorption (Abs. UV_{254}) intensity of SE > SE-O3 > SE-GAC. According to some feature of HS structure, it is considered the most hydrophobic fraction of the NOM (Boyer et al. 2008). Which implies the fact of SE having comparatively higher color intensity than SE-O_3 and SE-GAC. It also emphasize the point of HPOA and HPI having color substances as the intensity of peak 1 (3614 Da) and peak 2 (2426 Da) is very low in HPOB for all fractionated samples, besides very low AMW with low intensity peak 4 (281 Da) is found in HPOB fraction (Fig. 10 d). In comparison between HPOA and HPI (Fig. 10 b and Fig. 10 c) it can be seen that pick 1 and pick 2 are well identified for SE in both fractions that’s why there is not much variation between HPOA and HPI (HPOA>HPI) in SE but for SE-O3 and SE-GAC the picks in HPI are more defined compared with HPOA (HPI>HPOA), which implies and strengthen the fact of HPI having higher color intensity compared with HPOA for SE-O3 and SE-GAC (Fig. 4 b and Fig. 5 b). It also come along with the previous analysed data (ISO 7887, method B and EEM).

In case of treatment efficiency, from the AMW (Fig. 10) it is clearly visible that granular activated carbon (GAC) adsorption was more efficient than ozone (O_3) treated samples (SE-GAC > SE-O_3). For effluent wastewater peak 3 (1691 Da) is well defined in SE and lowered in SE-O3 (1523 Da) but it is completely gone in SE-GAC treated sample. Similar behaviour is observed for fractionated samples as well (Fig. 10 (b), (c) and (d)).

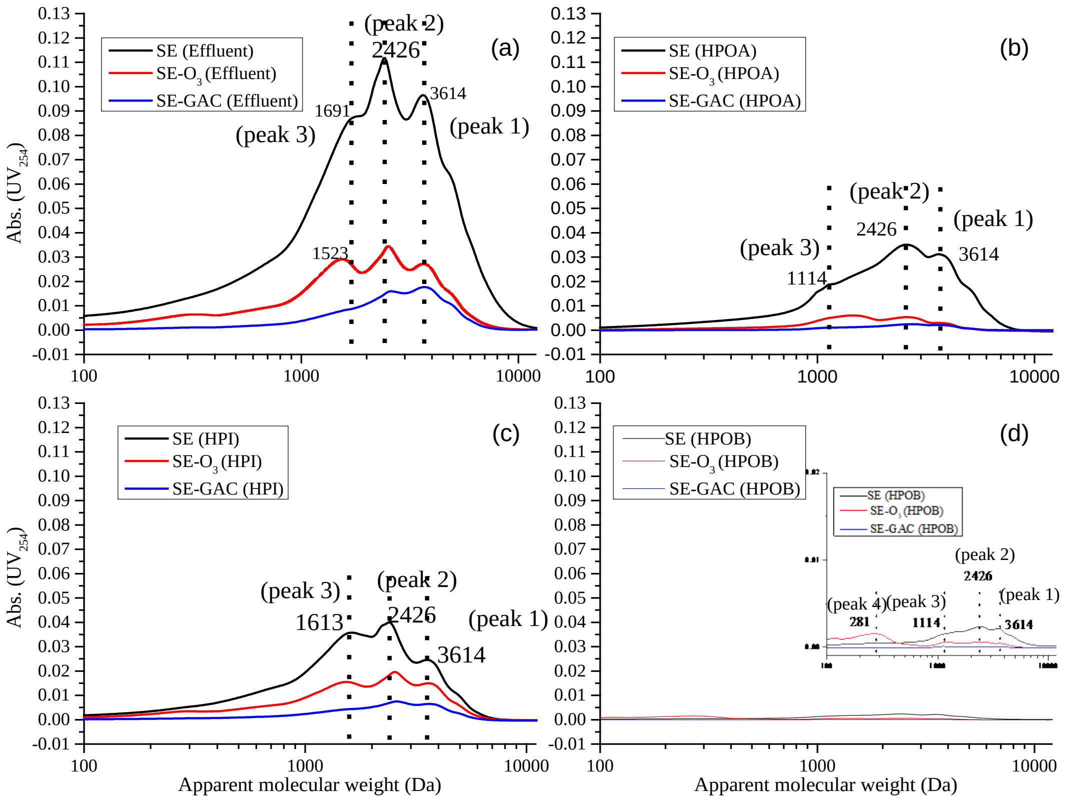


Fig. 7. AMW of different fractionated samples (a) Effluent (b) HPOA (c) HPI and (d) HPOB of three different treatments (SE, SE-O3 and SE-GAC) in terms of treatment efficiency measurement and influence on colour compounds.

3.5 Analysis through X-ray photoelectron spectroscopy (XPS) analyser

Besides knowing the type and nature of the substances for exhibiting color in dissolved EfOM, XPS spectrum spectroscopy technique is also used to identify and to qualitative measure of functional groups in different effluent wastewater and their fractionated samples.

In order to explain the color identification of chromophore is very much important to characterize the chemical compounds. Color produced by chemical compounds having into their structure aromatic rings that contain delocated electrons (conjugated double bond system) and also different functional groups. A chemical compound exhibit color due to the chromogene-chromophore structure (acceptor of electrons). The chromogene is constituted from an aromatic structure normally based on rings of benzene, naphthaline or antracene, from which are binding chromofores that contain double conjugated links with delocated electrons. The chromofore configurations are represented by the azo group (-N=N-), ethylene group (=C=C=), methine group (-CH=), carbonyl group (=C=O), carbon-nitrogen (=C=NH; -CH=N-), carbon-sulphur (=C=S; ≡CS-S-C≡), nitro (-NO2; -NO-OH), nitrozo (-N=O; =N-OH) or chinoid groups (Carmen and Daniela 2012). The existence of such functional group or such chemical property in dissolved EfOM emphasize the chroma.

3.5.1 XSP C1s, O1s and N1s spectra for SE, SE-O3 and SE-GAC

In order to gain an increased understanding of the characteristics of EfOM in terms of color, the C1s, O1s and N1s high resolution spectra for each of the three effluent (i.e. SE, SE-O3 and SE-GAC) and each of the three fractions from every effluent were obtained by XPS analysis. The results were analysed by XPS Peak Processing software with % lorentzian-Gaussian (0: G, 100: L) of 20. During the peak fitting the binding energy were kept fixed with the variation of ±0.3eV. As can be seen from XPS spectra C1s of effluent and its fractionated samples of SE, SE-O3 and SE-GAC in Fig. 6, Fig. 7 and Fig. 8 respectively. Five types of chemical binding signals appeared, at 284.5 ±0.5, 285.6 ±0.5, 286.1±0.5, 287.9±0.5 and 289.3±0.5 eV which were assigned to aromatic carbon (C=C), aliphatic carbon (C-C), C-O/C-N, ketonic carbon (>C=O) and carboxylic carbon (-COOH) (Lin et al. 2014, Nowicki et al. 2009). For O1s three types of chemical binding signals appeared at 533.59±0.2, 532.45±0.2 and 531.37±0.2 eV which were assigned to C=N-O, C-OH and C=O respectively (Nowicki et al. 2009). For N1s five types of chemical binding signals appeared at 398.1±0.2, 399.2±0.2, 400.1±0.2, 400.5±0.2 and 404±0.2 eV which were assigned to imine/amide/amine, N6 (pyridinic), N5 (Pyrrolic and pyridonic), nitrogen-hydrogen bonds and nitrogen-oxygen bonds or chemisorbed nitrogen oxides respectively (Arrigo et al. 2010, Pietrzak et al. 2007).

For secondary effluent (SE) and its fractions, all five C1s species were found in effluent, HPOA and HPI samples, shown in Fig. 6 (a), (b) and (c) respectively. For HPOB, C-O/C-N (phenolic, alcohol, and ether) had not been found. Among the identified functional groups ketonic carbon (>C=O) and carboxylic carbon (-COOH) are chromophore groups or chromophore conjugations and the presence of higher percentage of aromatic compound (C=C, 284.5 eV) represents the chromogen structures. Due to fact of having chromogene-chromophore structure (acceptor of electrons) in HPOA and HPI it shows color on the other hand HPOB doesn't show color in spite of having the all three C1s species is because, unlike HPOA and HPI, the percentage of aromatic compounds is comparatively very less in HPOB (Fig. 3 (c); SUVA $_{254nm}$ abs.).

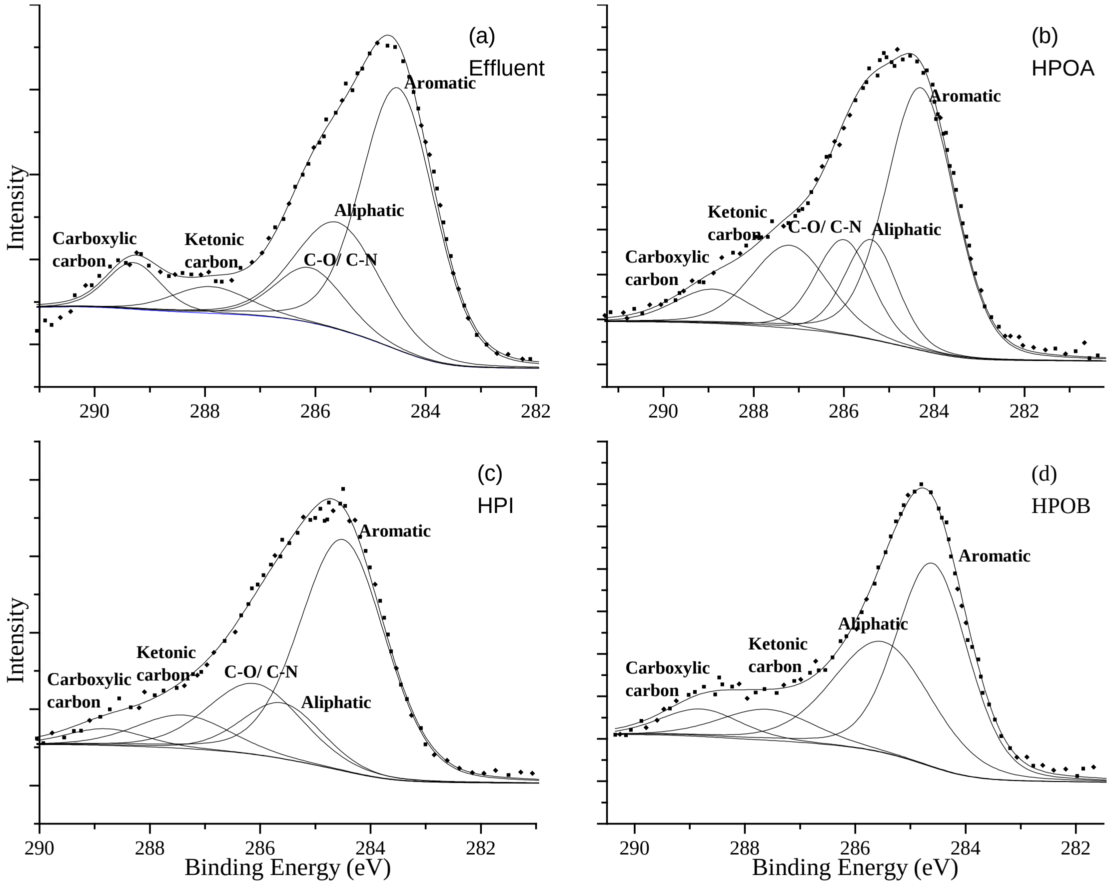


Fig. 8. XPS C 1s spectra of secondary effluent (SE) and its fractionated samples.

The identified species or functional group from O1s and N1s are very much likely to explain the chroma (Table 4). For O1s three different species (C=N-O, C-OH and C=O) were found and all are present in all the fractions and two of them (C=N-O and C=O) is identified as chromophore groups (Gürses et al. 2016). For N1s five different species were found (imine/amide/amine, N6 (pyridinic), N5 (Pyrrolic and pyridonic), nitrogen-hydrogen bonds and nitrogen-oxygen bonds or chemisorbed nitrogen oxides) among these then presence of imine, N6 (pyridinic) and N5 (Pyrrolic and pyridonic) are favourable functional groups to explain the presence of color, since these three are chromophore groups and N6 (pyridinic) and N5 (Pyrrolic and pyridonic) are large aromatic conjugated system itself. O1s and N1s high resolution spectra were shown in the supplementary data (Fig. S1-S8).

Table 3 Curve fitting results of XPS C 1s, O1s and N 1s spectra for Secondary effluent (SE).

C 1s

Species	Effluent			HPOA			HPI			HPOB			Ref.
	BE[a] (eV)	fwhm [b] (eV)	%	BE[a] (eV)	fwhm [b] (eV)	%	BE[a] (eV)	fwhm [b] (eV)	%	BE[a] (eV)	fwhm [b] (eV)	%	
Aromatic (C=C)	284.5	1.57	52.49	284.3	1.9	47.84	284.5	1.84	56.16	284.6	1.53	47.76	(Lin et al. 2014)
Aliphatic (C-C/C-H)	285.6	1.83	24.89	285.4	1.80	15.40	285.6	1.7	12.54	285.5	2	35.68	
Ketonic[a] carbon (C=O)	287.9	1.63	5.55	287.6	2	14.02	287.4	2	8.81	287.6	2	9.43	
Carboxylic [b] carbon (O-C=O)	289.3	1.14	6.79	288.9	2	5.31	288.8	1.7	3.74	288.8	1.7	7.13	(Nowicki et al. 2009)
C-O/C-N	286.1	1.47	10.28	286	1.66	17.43	286.1	2	18.76	-	-	-	

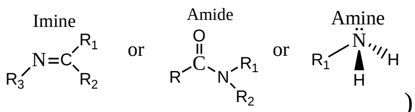
O 1s

Species	Effluent			HPOA			HPI			HPOB			Ref.
	BE[a] (eV)	fwhm [b] (eV)	%	BE[a] (eV)	fwhm [b] (eV)	%	BE[a] (eV)	fwhm [b] (eV)	%	BE[a] (eV)	fwhm [b] (eV)	%	
C=N-O [c]	533.59	2	29.48	533.59	1.18	10.5	533.39	1.46	33.88	533.59	1.18	12.82	(Nowicki et al. 2009)
C-OH	532.45	1.48	48.02	532.45	1.62	39.31	532.5	2	56.75	532.45	1.89	78.64	
C=O	531.37	1.54	22.50	531.37	2	50.18	531.55	1.72	9.37	531.47	1.42	8.54	

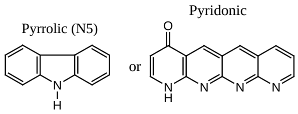
N 1s

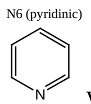
Species	Effluent			HPOA			HPI			HPOB			Ref.
	BE[a] (eV)	fwhm [b] (eV)	%	BE[a] (eV)	fwhm [b] (eV)	%	BE[a] (eV)	fwhm [b] (eV)	%	BE[a] (eV)	fwhm [b] (eV)	%	
Imine/ amide/ amine[d]	398.2	0.6	4.24	398.2	2	35.34	398.2	1.68	8.51	398.2	2	10.28	(Pietrzak et al. 2007)
N6 (pyridinic) [e]	399.2	1.33	31.24	399.2	1.03	9.78	399.2	1.66	28.31	399.2	1.7	40.12	
N5 (Pyrrolic and pyridonic)[f]	400.1	2	14.37	400.1	2	13.89	-	-	-	-	-	-	
Nitrogen – hydrogen bonds	400.5	2	4586	400.5	2	40.99	400.5	2	48.79	400.4	1.74	49.59	
Chemisorbed nitrogen oxides	404	1.03	4.29	-	-	-	404	2	14.39	-	-	-	(Arrigo et al. 2010)

[a] Ketonic carbon (C=O): is also known as Acetaldehyde/Acetone with λ_{max} = 160 -290. [b] Carboxylic carbon (O-C=O): acetic acid with λ_{max} = 204. [c] C=N-O: Acetoxime (>C=N-) with λ_{max} = 190 and [d] Imine/amide/ amine (



): Acetamide (-CONH$_2$) with λ_{max} = 178 -220 are said chromophore groups (Gürses et al. 2016) as these functional groups are able to absorb higher wavelength and being attached with other chemicals it influences the total chemical compounds to absorb long wavelength and emission of longer wavelength which lead to the emission of visible wavelength and shows color. Beside these chemical compounds few other aromatic functional groups were detected e.g. [e] N6 (pyridinic):



and [f] N5 (Pyrrolic and pyridonic): 

which are capable of absorb and emit even longer wavelengths because of the aromatic structure and also influence other chemical compounds to absorb longer wavelengths by being attached with them and lead to chroma.

In case of SE-O_3 treated effluent and its fractionated samples (Fig. 7) the identified species are all same like SE except in HPOA there is no carboxylic carbon (-COOH) (Fig. 7 (b)) and it may count as one of the reasons for HPOA to show less chroma compared with HPI (Fig. 4 (b)), which was opposite for SE fractions (Fig. 3 (b)). In addition the removal of carboxylic carbon (>C=O) from HPOA (Fig. (b)) indicates the O_3 was more likely to be effective on those compounds connected with ketonic carbon.

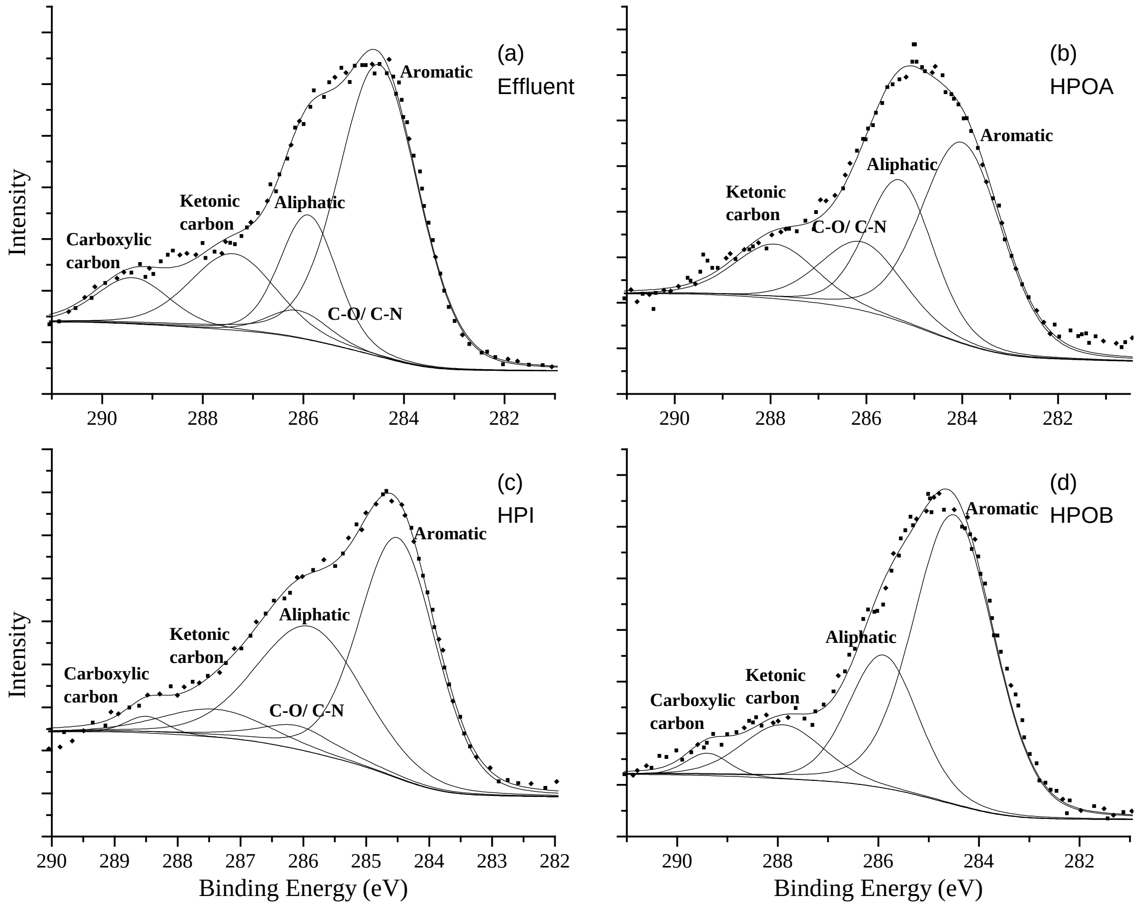


Fig. 9. XPS C 1s spectra of SE-O3 treated sample and its fractionated samples.

For O1s the XPS spectra didn't show any significant change from the fractions of SE and for N1s spectra N5 (Pyrrolic and pyridonic) could not be found, which implies the O3 treatment was effective on N5 (Pyrrolic and pyridonic) and similar types of chemical compounds (Table 5). O1s and N1s high resolution spectra were shown in the supplementary data (Fig. S9-S16).

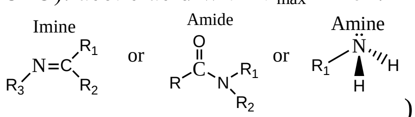
Table 4 Curve fitting results of XPS C 1s, O1s and N 1s spectra of SE-O3 treated sample.

C 1s													
Species	**Effluent**			**HPOA**			**HPI**			**HPOB**			**Ref.**
	BE[a] (eV)	**fwhm [b] (eV)**	**%**	**BE[a] (eV)**	**fwhm [b] (eV)**	**%**	**BE[a] (eV)**	**fwhm [b] (eV)**	**%**	**BE[a] (eV)**	**fwhm [b] (eV)**	**%**	
Aromatic (C=C)	284.5	1.85	55.30	284	2	45.70	284.5	1.44	48.85	284.5	1.9	64.49	(Lin et al. 2014)
Aliphatic (C-C/C-H)	285.9	1.33	16.99	285.3	1.64	26.35	285.9	2	35.37	285.9	1.62	24	
Ketonic[a] carbon (C=O)	287.4	2	15.62	287.9	2	12.39	287.4	2	7.86	287.9	1.9	10.01	
Carboxylic [b] carbon (O-C=O)	289.4	1.71	8.10	-	-	-	288.5	0.74	1.74	289.4	1.0	1.5	(Nowicki et al. 2009)
C-O/C-N	286.1	1.42	3.98	286.1	2	15.57	286.1	1.48	6.19	-	-	-	

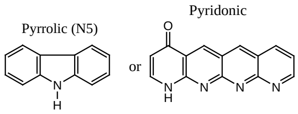
O 1s													
Species	**Effluent**			**HPOA**			**HPI**			**HPOB**			**Ref.**
	BE[a] (eV)	**fwhm [b] (eV)**	**%**	**BE[a] (eV)**	**fwhm [b] (eV)**	**%**	**BE[a] (eV)**	**fwhm [b] (eV)**	**%**	**BE[a] (eV)**	**fwhm [b] (eV)**	**%**	
C=N-O [c]	533.7	1.26	14.75	533.5	1.03	7.97	533.3	1.82	82.38	533.41	1.6	44.07	(Nowicki et al. 2009)
C-OH	532.67	1.81	55.69	532.45	1.23	23.74	532.45	1.21	8.36	532.52	1.36	32.89	
C=O	531.5	2	29.56	531.25	2	68.29	531.5	1.13	9.25	531.5	1.55	23.04	

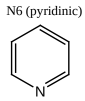
N 1s													
Species	**Effluent**			**HPOA**			**HPI**			**HPOB**			**Ref.**
	BE[a] (eV)	**fwhm [b] (eV)**	**%**	**BE[a] (eV)**	**fwhm [b] (eV)**	**%**	**BE[a] (eV)**	**fwhm [b] (eV)**	**%**	**BE[a] (eV)**	**fwhm [b] (eV)**	**%**	
Imine/ amide/ amine[d]	398.2	1.85	16.68	398.2	2	36.29	398.2	2	12.50	398.2	2	11.45	(Pietrzak et al. 2007)
N6 (pyridinic) [e]	399.2	1.39	39.21	399.2	1.48	14.19	399.2	1.01	15.16	399.2	2	34.66	
N5 (Pyrrolic and pyridonic)[f]	-	-	-	-	-	-	-	-	-	-	-	-	
Nitrogen – hydrogen bonds	400.5	2	39.80	400.5	2	32.38	400.5	2	55.84	400.5	2	53.89	
Chemisorbed nitrogen oxides	404	2	4.31	404	2	17.14	404	2	16.51	-	-		(Arrigo et al. 2010)

[a] Ketonic carbon (C=O): is also known as Acetaldehyde/Acetone with λ_{max} = 160 -290. [b] Carboxylic carbon (O-C=O): acetic acid with λ_{max} = 204. [c] C=N-O: Acetoxime (>C=N-) with λ_{max} = 190 and [d] Imine/amide/ amine (



): Acetamide ($-CONH_2$) with λ_{max} = 178 -220 are said chromophore groups (Gürses et al. 2016) as these functional groups are able to absorb higher wavelength and being attached with other chemicals it influences the total chemical compounds to absorb long wavelength and emission of longer wavelength which lead to the emission of visible wavelength and shows color. Beside these chemical compounds few other aromatic functional groups were detected e.g. [e] N6 (pyridinic):



and f N5 (Pyrrolic and pyridonic): 

which are capable of absorb and emit even longer wavelengths because of the aromatic structure and also influence other chemical compounds to absorb longer wavelengths by being attached with them and lead to chroma.

From the C1s XPS results from granular activated carbon treated samples (SE-GAC) and its fractions it can be seen that Fig. 8, HPOA contains all the five functional groups but in HPI and HPOB there is no carboxylic carbon (-COOH) group. Inspire of having the chromophore groups the chroma is very low in SE-GAC treated sample.

In order to explain the chroma it can be said that only chromophore groups itself cannot exhibit color, to impart color chromophore groups must attached with the chromogene groups, along with long aromatic or aliphatic conjugated system. In addition the effectiveness of GAC on specific compounds (i.e. C1s species) is difficult to explain from this spectral identification (Fig. 8).

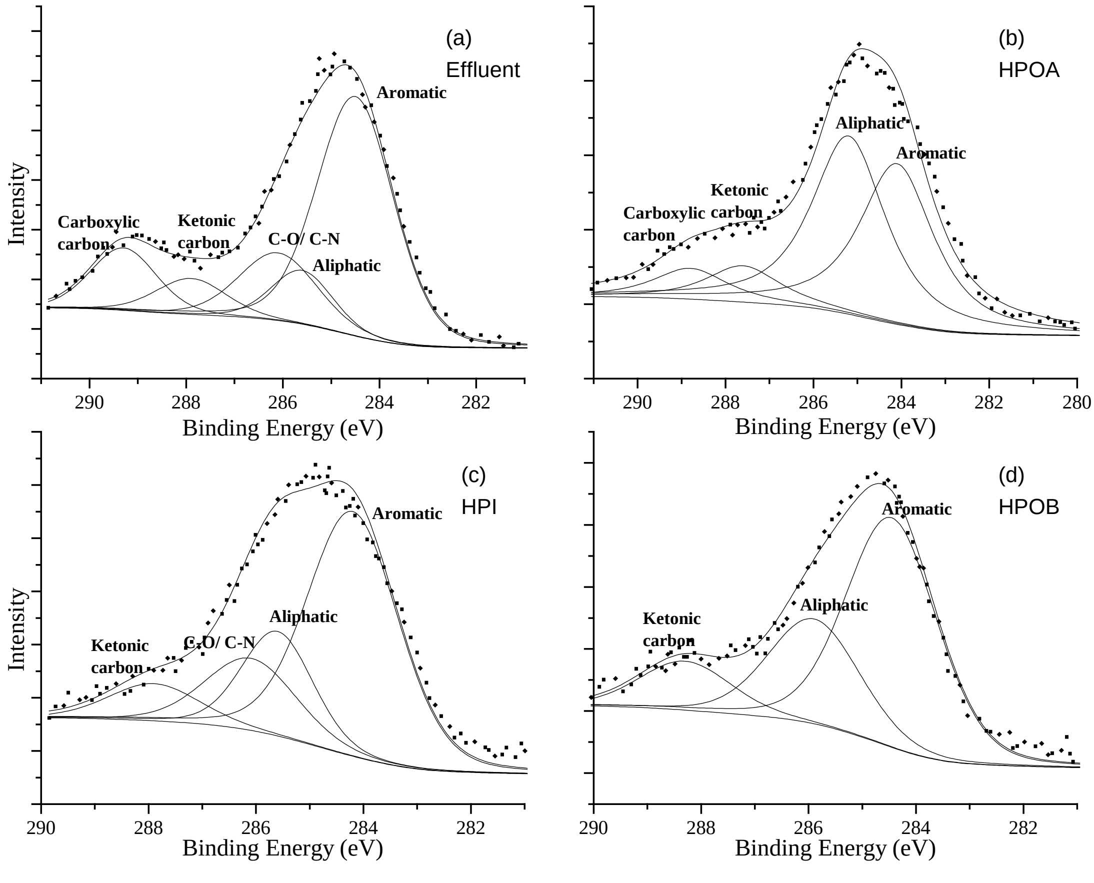


Fig. 10. XPS C 1s spectra of SE-GAC treated sample and its fractionated samples

In case of XPS O1s spectral analysis (Table 6) it can be seen that, all the species were able to identified except for HPOA the binding energy for C=N-O is not available. It again explains the fact of HPO having lower chroma than HPI (HPI>HPOA) which is opposite from SE fractionated (HPOA>HPI). The XPS N1s spectra doesn't provide significant information to explain (supplementary file S17-S24).

Table 5 Curve fitting results of XPS C 1s, O1s and N 1s spectra of SE-GAC treated sample.

C 1s

Species	Effluent			HPOA			HPI			HPOB			Ref.
	BE[a] (eV)	fwhm [b] (eV)	%	BE[a] (eV)	fwhm [b] (eV)	%	BE[a] (eV)	fwhm [b] (eV)	%	BE[a] (eV)	fwhm [b] (eV)	%	
Aromatic (C=C)	284.5	1.87	54.69	284.1	2	46.41	284.2	2	56.20	284.45	2	59.54	(Lin et al. 2014)
Aliphatic (C-C/C-H)	285.6	1.5	9.87	285.2	2	51.48	285.6	1.56	18.73	285.9	2	27.92	
Ketonic[a] carbon (C=O)	287.9	1.72	7.53	287.6	2	1.05	287.9	2	8.53	288.3	2	12.53	
Carboxylic [b] carbon (O-C=O)	289.3	1.6	12.24	288.8	2	1.06	-	-	-	-	-	-	(Nowicki et al. 2009)
C-O/C-N	286.1	1.9	15.67	-	-	-	286.1	2	16.54	-	-	-	

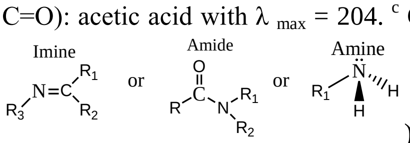
O 1s

Species	Effluent			HPOA			HPI			HPOB			Ref.
	BE[a] (eV)	fwhm [b] (eV)	%	BE[a] (eV)	fwhm [b] (eV)	%	BE[a] (eV)	fwhm [b] (eV)	%	BE[a] (eV)	fwhm [b] (eV)	%	
C=N-O [c]	533.59	1.12	9.98	-	-	-	533.59	1	7.36	533.59	1.27	14.71	(Nowicki et al. 2009)
C-OH	532.55	1.44	39.81	532.6	1.52	26.59	532.6	1.51	51.51	532.6	1.6	47.58	
C=O	531.5	2	50.21	531.3	2	73.41	531.5	2	41.14	531.5	1.76	37.7	

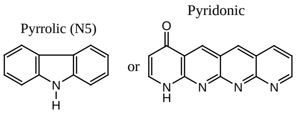
N 1s

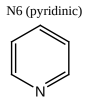
Species	Effluent			HPOA			HPI			HPOB			Ref.
	BE[a] (eV)	fwhm [b] (eV)	%	BE[a] (eV)	fwhm [b] (eV)	%	BE[a] (eV)	fwhm [b] (eV)	%	BE[a] (eV)	fwhm [b] (eV)	%	
Imine/ amide/ amine[d]	398.2	2	30.22	398.2	2	48.47	398.2	2	39.26	398.2	2	14.64	(Pietrzak et al. 2007)
N6 (pyridinic)[e]	399.2	1.45	11.72	399.2	1.5	18.01	-	-	-	399.2	1.54	20.02	
N5 (Pyrrolic and pyridonic)[f]	400.1	2	20.25	400.1	2	28.96	400.1	2	25.00	-	-	-	
Nitrogen – hydrogen bonds	400.5	2	24.27	-	-	-	400.5	2	19.31	400.5	2	47.92	
Chemisorbed nitrogen oxides	404	2	13.54	404	1	4.55	404	2	16.43	404	2	17.42	(Arrigo et al. 2010)

[a] Ketonic carbon (C=O): is also known as Acetaldehyde/Acetone with λ_{max} = 160 -290. [b] Carboxylic carbon (O-C=O): acetic acid with λ_{max} = 204. [c] C=N-O: Acetoxime (>C=N-) with λ_{max} = 190 and [d] Imine/amide/ amine (



): Acetamide (-CONH$_2$) with λ_{max} = 178 -220 are said chromophore groups (Gürses et al. 2016) as these functional groups are able to absorb higher wavelength and being attached with other chemicals it influences the total chemical compounds to absorb long wavelength and emission of longer wavelength which lead to the emission of visible wavelength and shows color. Beside these chemical compounds few other aromatic functional groups were detected e.g. [e] N6 (pyridinic):



and [f] N5 (Pyrrolic and pyridonic): 

which are capable of absorb and emit even longer wavelengths because of the aromatic structure and also influence other chemical compounds to absorb longer wavelengths by being attached with them and lead to chroma.

4. Conclusions

This experiment successfully established a multi analytical methodology to characterize the dissolved organic color substances present in industrial park wastewater. An effective fractionation method is established through XAD-8 resin fractionation to analyse different fractions of hydrophobic acid (HPOA), hydrophobic basic (HPOB) and hydrophilic (HPI) substances. ISO 7887, method B and NCASI method color 71.01 were incorporated to measure the color intensity or chroma and it has been found that among all the fractionated HPOA and HPI are the dominating fractions to impart color. From further analysis through SUVA $_{254nm}$, EEM and HPSEC it has been found that HPOA and HPI contains humic type substances, enriched with aromatic compounds and possess longer conjugated system, and these are the basic physico chemical property for any colouring substances. Furthermore, through EEM fluorescence spectra it has been found that for SE the color bearing compounds in HPOA (Ex $_{max}$/ Em $_{max}$=254/447) and HPI (Ex $_{max}$/ Em $_{max}$=249/412) were present in pick C (Ex: 250nm-400nm, Em: 380nm-550nm). In addition, for each Ex $_{max}$ (SE-259nm, HPOA-254nm and HPI-249nm) the Ex $_{max}$ (SE-456nm, HPOA-477nm and HPI-412nm) should be the corresponding wave length for ΔE (difference between HOMO & LUMO energy or required energy for $\pi \rightarrow \pi^*$ transition) for one specific compound. This phenomena leads to the next step to identify the unknown chemical substance responsible for color. It is only applicable for SE as EEM couldn't find any visible emission wavelength in SE-O_3 and SE-GAC samples. Through the XPS C1s, O1s and N1s analysis several chromophore groups has been found, those are Ketonic carbon (>C=O, λ_{max} =160-290), Carboxylic carbon (O-C=O, λ_{max} = 204), Acetoxime (>C=N-, λ_{max} = 190) and Acetamide (-$CONH_2$, λ_{max} =178-220).on the other hand, few aromatic conjugated functional groups has also been detected, those are N6 (pyridinic), N5 (Pyrrolic and pyridonic).

From the secondary effluent, it has been found that a significant portion of color is occupied by HPOA and HPI (HPOA>HPI) compared with other fractionated samples but for ozone and activated carbon treated samples HPI contains the higher color intensity than HPOA (HPI>HPOA). Which comes to a point that, Ozone and activated carbon treatment functions more likely to those compounds which are HPOA in nature, in other words HPI is not sensitive to ozone or activated carbon treatment as HPOA. In comparison between O_3 treatment and GAC treatment, it has been found that GAC treated samples have low AMW compare to O3 treated samples (HPSEC analysis). On the other hand, XPS analysis emphasized that O_3 is more effective on Pyrrolic (N5) and pyridonic attached compounds or polycyclic compounds compare to A.C.

Acknowledgement

Financial support for this study was obtained from the Major Science and Technology Program for Water Pollution Control and Treatment (2017ZX07106005). We thank Mr. Pengfeng Li for his help in sample collection. The study was also supported by CAS-TWAS fellowship for international PhD students.

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Supplementary information WR-B20

Characterization of dissolved effluent organic matter (EfOM) and industrial park wastewater treatment plant as a function of color

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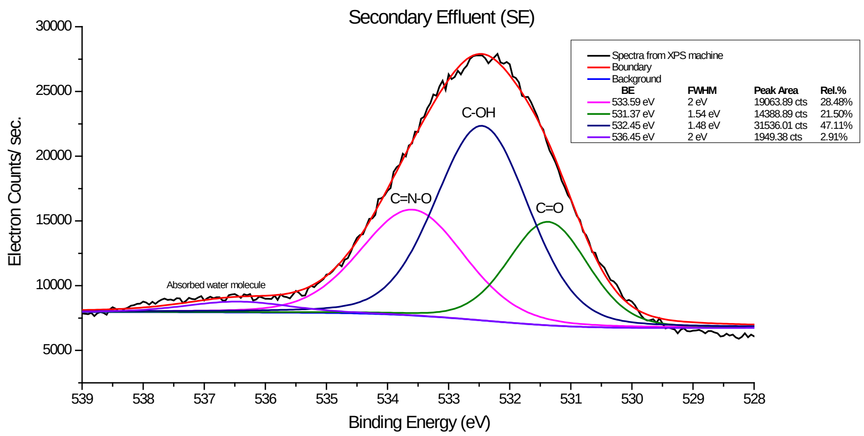
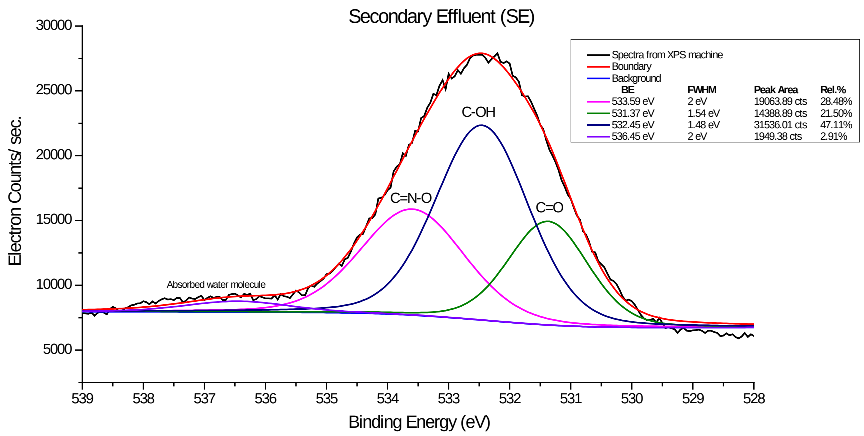


Fig. *S*1. XPS O1s of secondary effluent.



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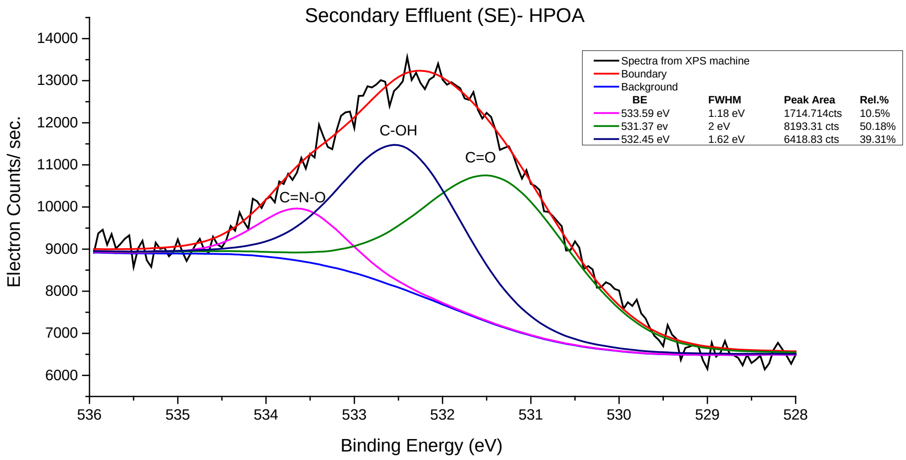


Fig. S2. XPS O1s of HPOA (SE)

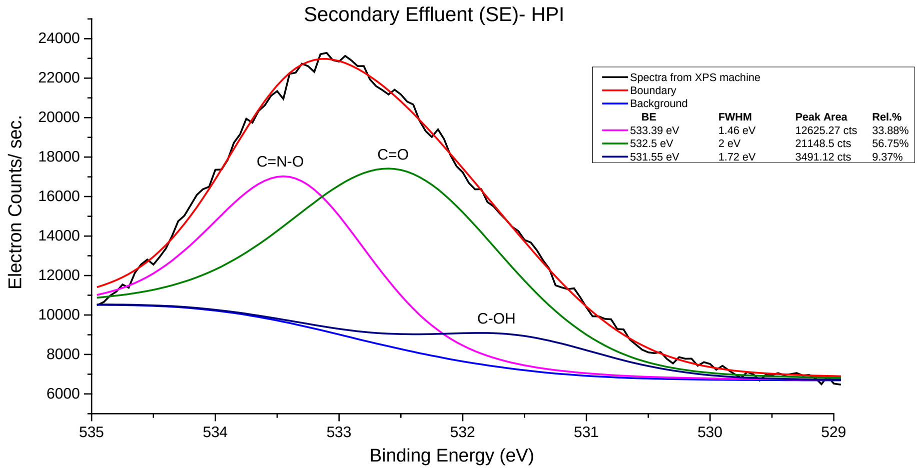


Fig. S3. XPS O1s of HPI (SE)

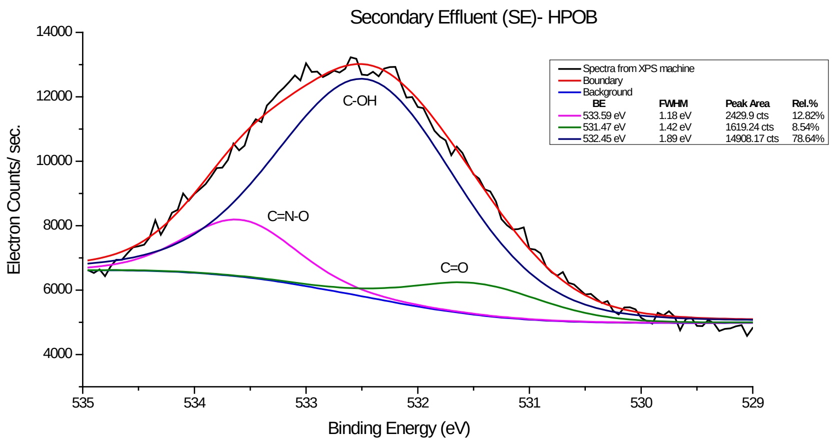


Fig. S4. XPS O1s of HPOB (SE)

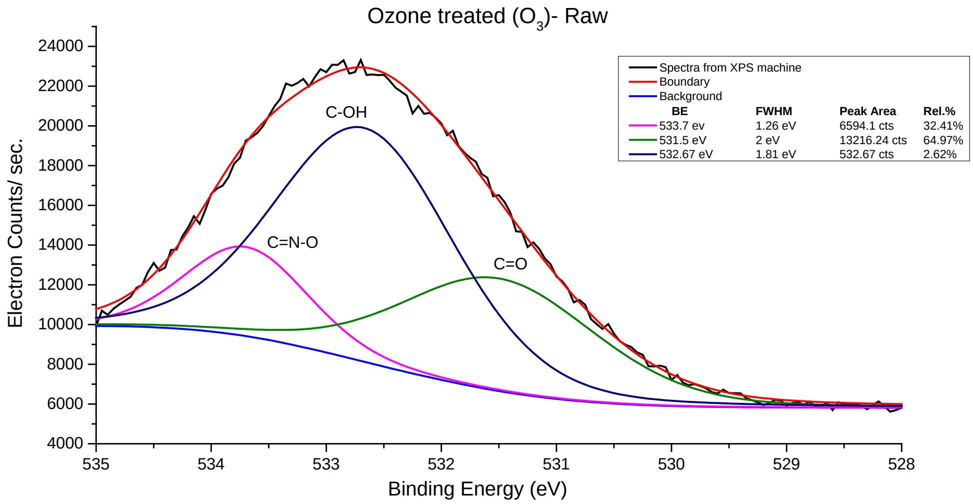
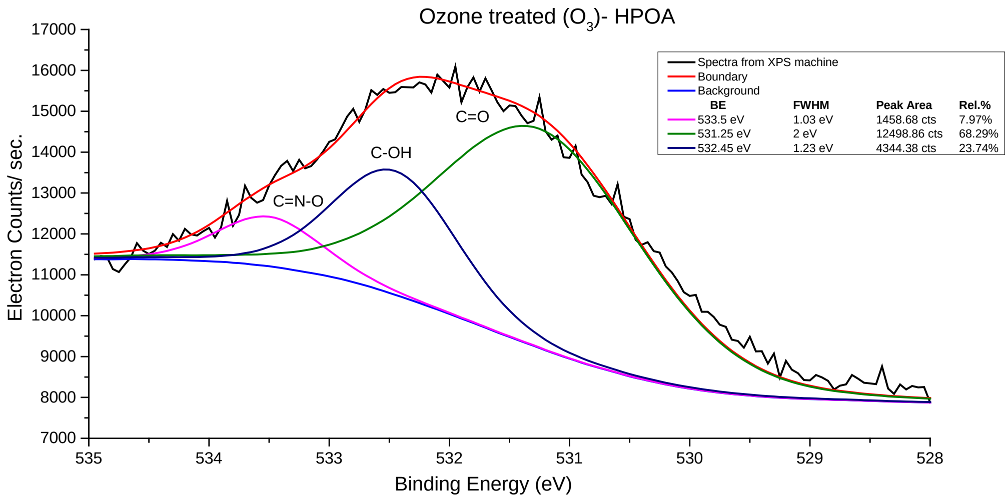


Fig. S5. XPS O1s of effluent (SE-O3).



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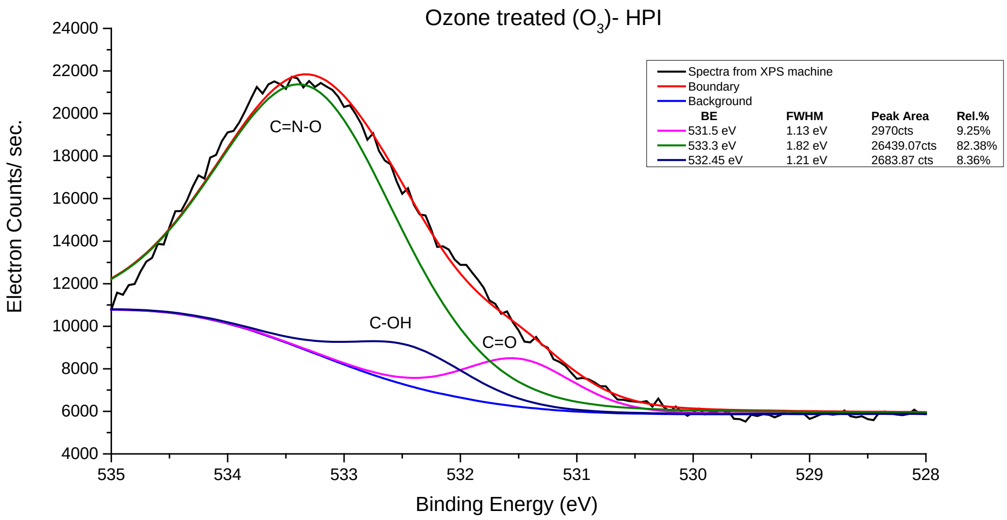


Fig. S7. XPS O1s of HPI (SE-O3)

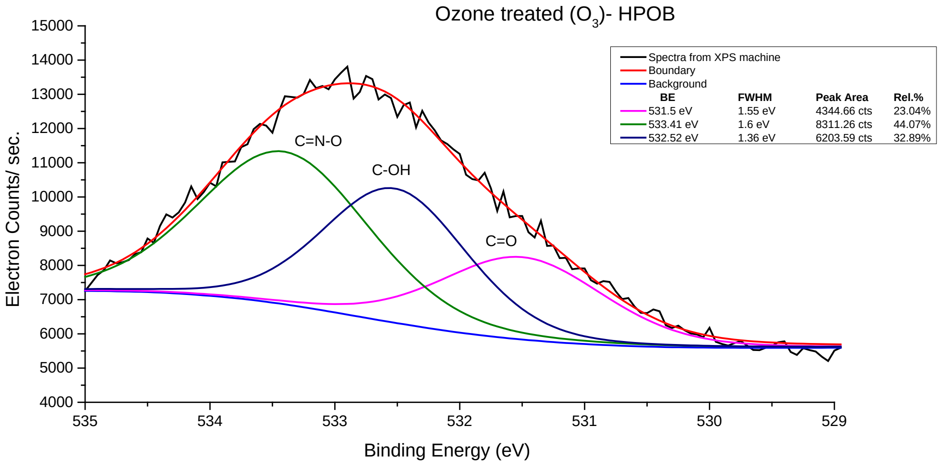


Fig. S8. XPS O1s of HPOB (SE-O3)

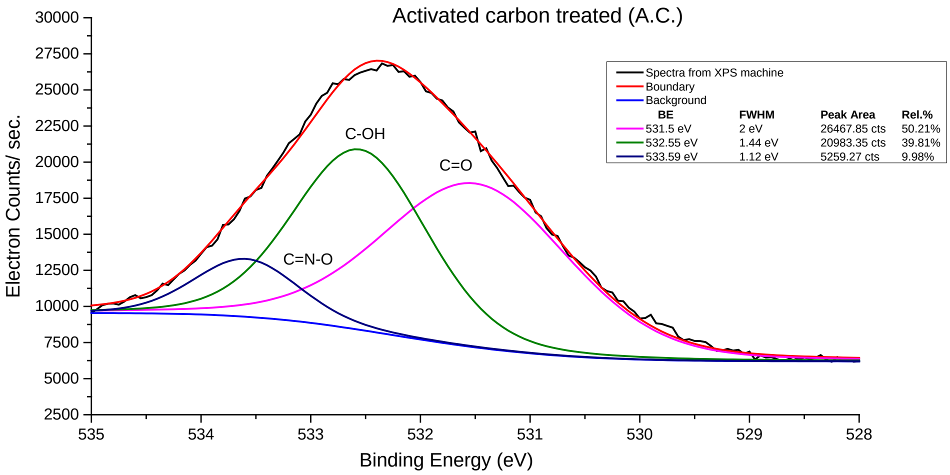


Fig. S9. XPS O1s of effluent (SE-GAC)

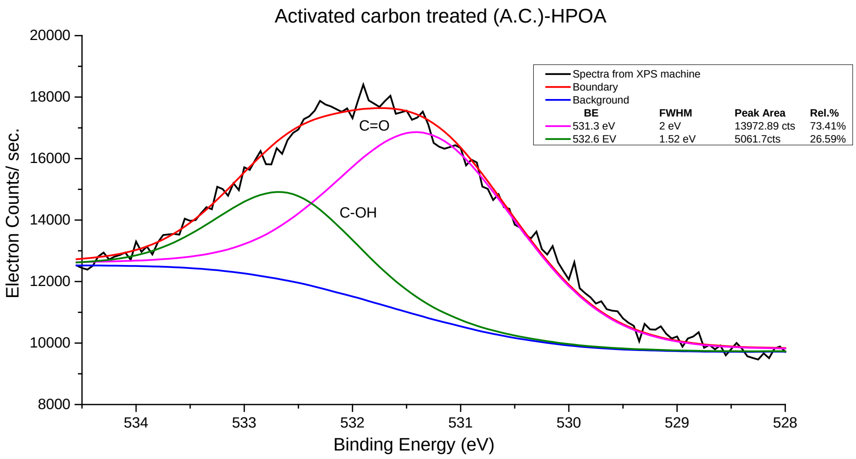


Fig. S10. XPS O1s of HPOA (SE-GAC)

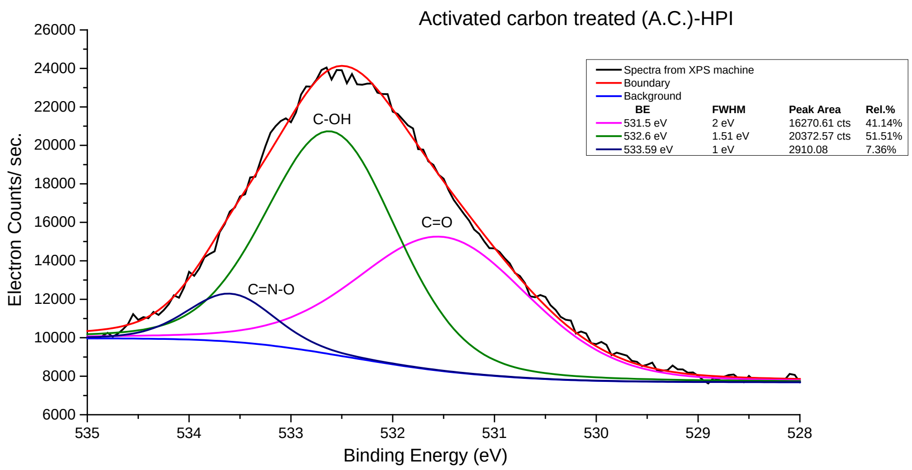


Fig. S11. XPS O1s of HPI (SE-GAC)

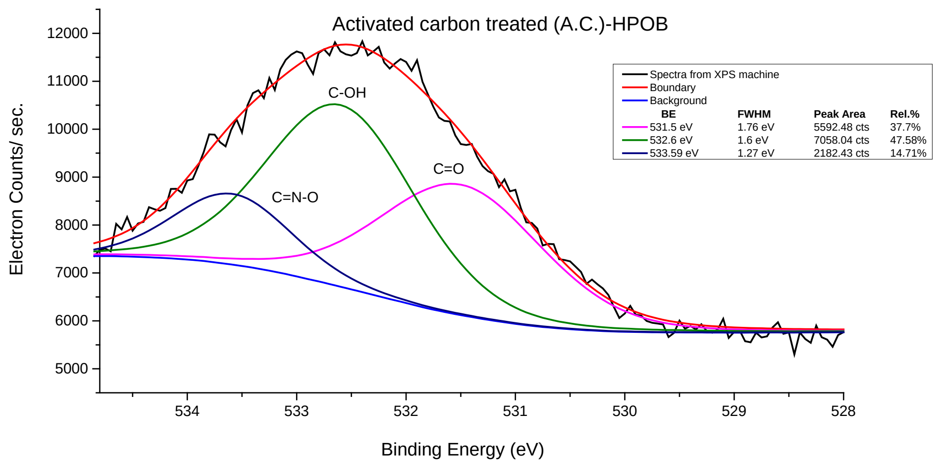
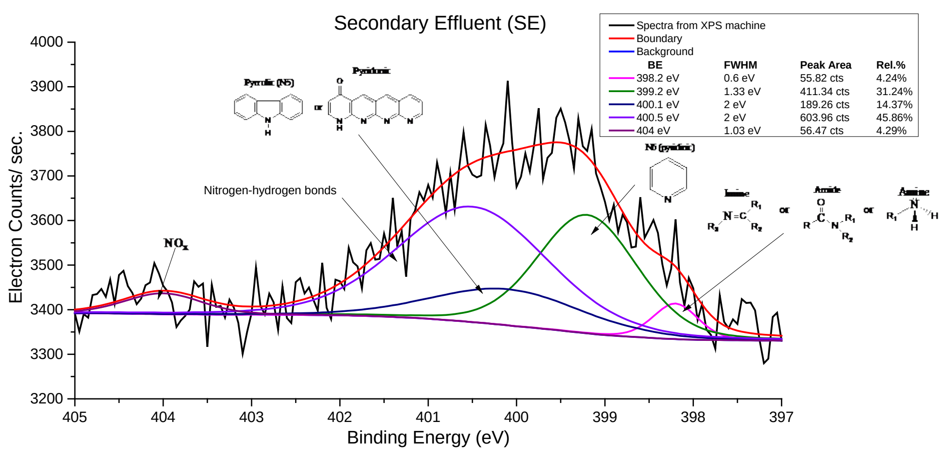


Fig. S12. XPS O1s of HPOB (SE-GAC)



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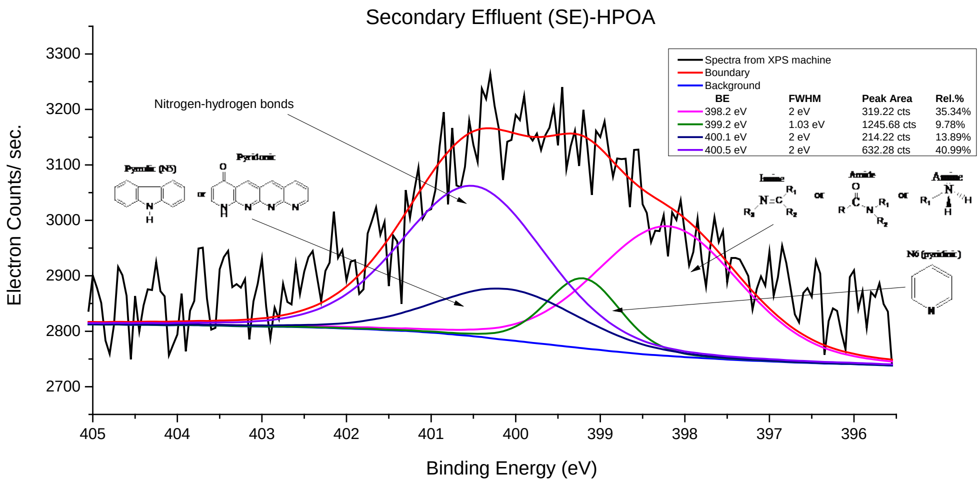

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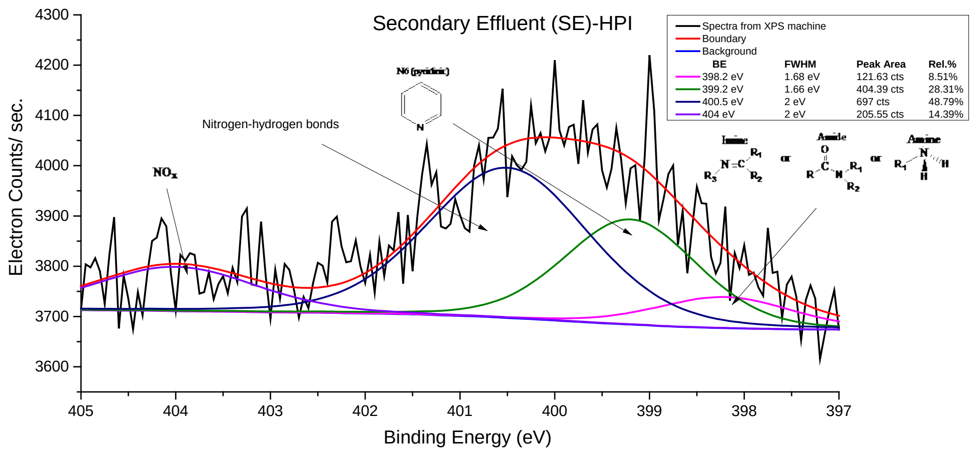

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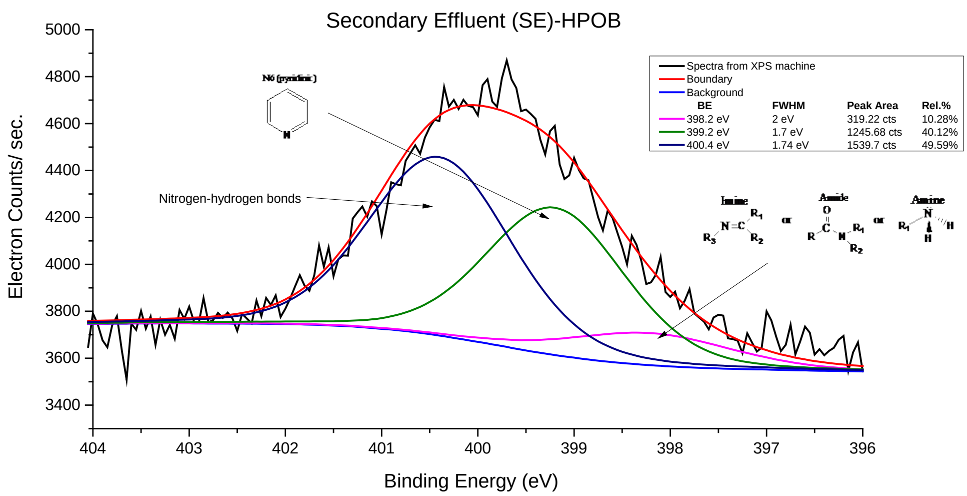

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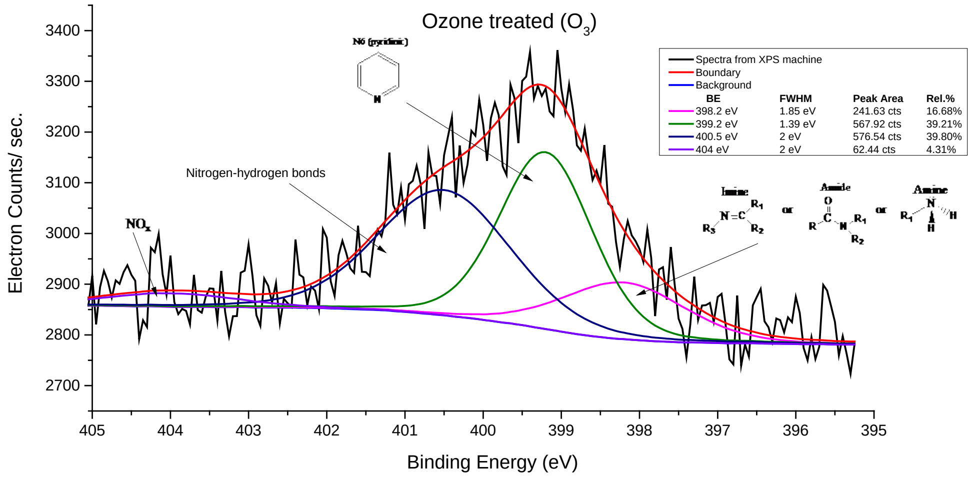

Fig. S17. XPS N1s of effluent (SE-O3)

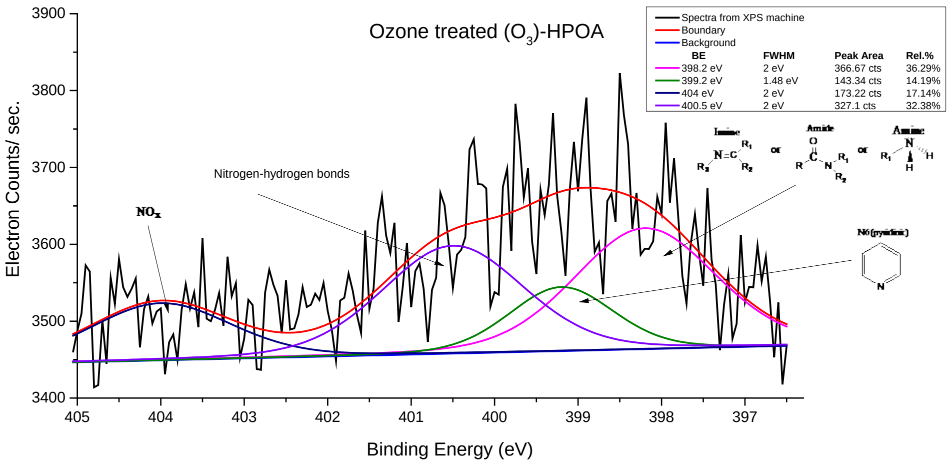

Fig. S18. XPS N1s of HPOA (SE-O3)

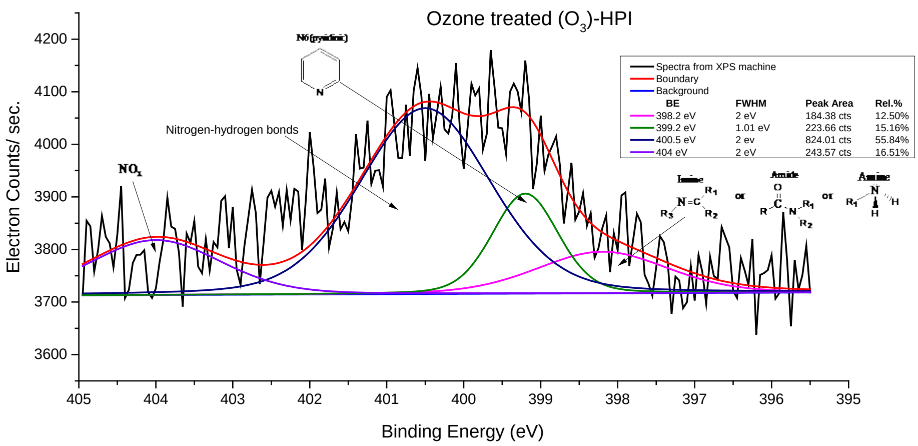

Fig. S19. XPS N1s of HPI (SE-O3)

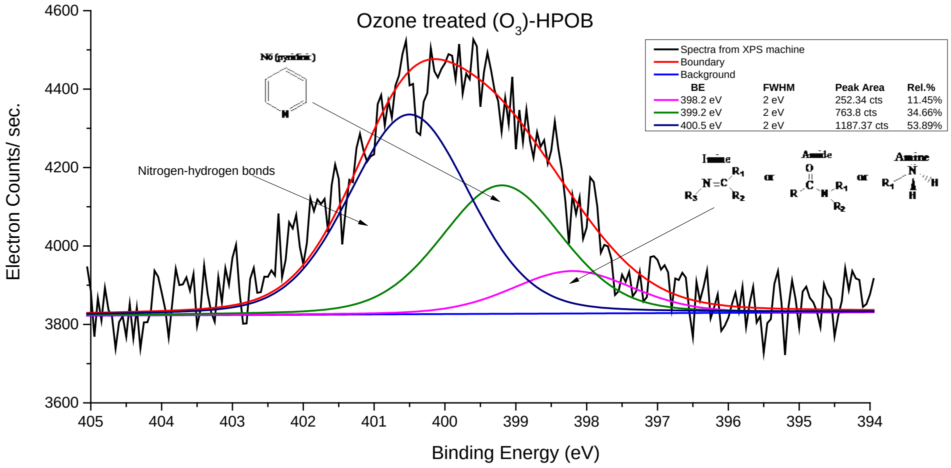

Fig. S20. XPS N1s of HPOB (SE-O3)

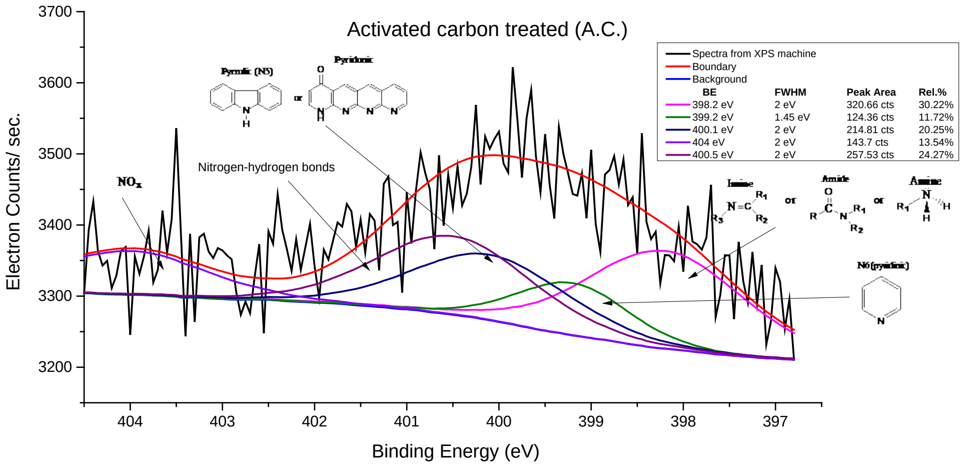

Fig. S21. XPS N1s of effluent (SE-GAC)

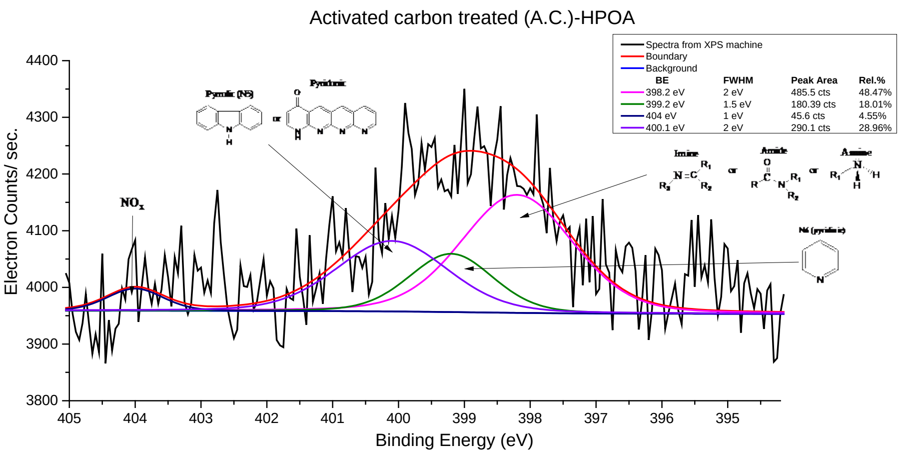

Fig. S22. XPS N1s of HPOA (SE-GAC)

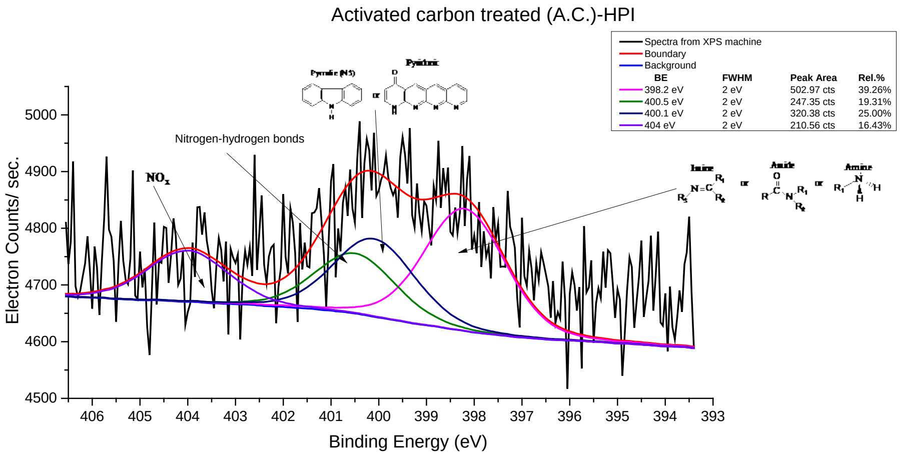

Fig. S23. XPS N1s of HPI (SE-GAC)

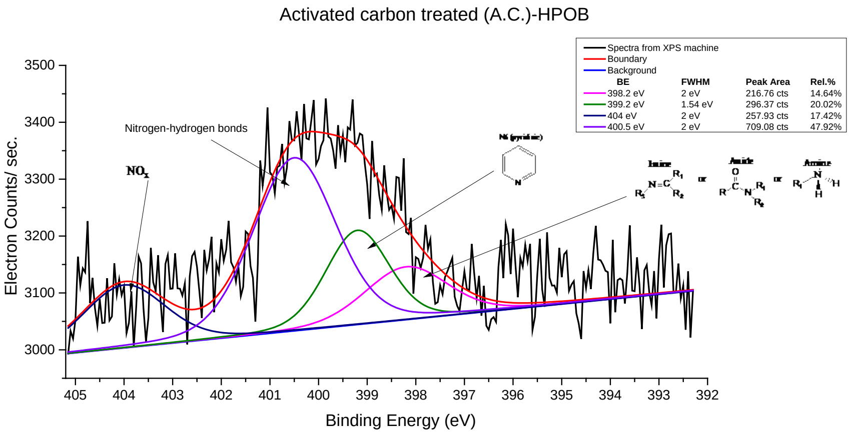

Fig. S24. XPS N1s of HPOB (SE-GAC)

WR-P02

Fabrication of Ultrafiltration PLA Hollow Fiber Membrane for Surface Water Treatment Applications

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Abstract

Novel ultrafiltration Poly(lactic acid) (PLA) hollow fiber membranes were successfully fabricated via nonsolvent induced phase separation (NIPS) by dry-wet spinning method. The preparation procedure of the hollow fibers is quite complicated especially when the new material was used. The solution used for spinning contains 20 % PLA, 2 % glycerin, 0.5 % Polyethylene glycol (PEG1500) and *N*-methyl-pyrrolidone (NMP). The spinning mixture was heated above 60 pressurized using nitrogen gas with various spinneret parameters. The spinning parameters such as feed pressure, air gap and take-up speed significantly affected the structure, morphology and filtration performance of the membranes. The asymmetric structure of the hollow fiber membrane was examined by field-emission scanning electron microscope (FE-SEM). The FE-SEM image showed that the PLA hollow fiber membranes have double finger-like structure (macrovoid), which was the normal structure formed in NIPS method. The PLA hollow fiber membrane exhibited excellent ultrafiltration performance of 99 % in bovine serum albumin (BSA) rejection. Moreover, the PLA hollow fiber membranes can completely remove *E. coli* and total coliform from surface water. These results indicated that the PLA hollow fiber membranes can be a promising candidate for fabricating hollow fiber membranes made of nonpetroleum based polymer in surface water treatment application.

Keywords: Polylactic acid (PLA); Hollow fiber; Membrane

1. Introduction

Conventional petroleum-based plastics are commonly used due to their high stability, strength, durability, and ease of processing procedure. However, the decomposition is difficult due to inherent hydrophobicity, high molecular weight and additives, such as antioxidants and stabilizers of petroleum-based plastics make decomposition difficult. Plastic waste now accounts for some 150 million tons per year, but landfills and incineration treatments present serious pollution issues, such as desertification, toxic substances, greenhouse gases, etc. As the awareness of these hazards as well as the necessity of environment protection has increased. Polymer materials, which naturally decompose, such as polylactic acid (PLA), polyhydroxyalkanoates (PHA) and polybutylene succinate (PBS), have been investigated [1-4]. Of these green materials, PLA has been shown to have superior properties, such as a high melting point (~170^{o}C), low glass transition temperature (~60^{o}C) and high mechanical strength. As a thermoplastic, PLA usually undergoes preheating before the forming process. Due to its semi-crystalline nature, PLA recrystallizes during heating and results in distinct physical properties [5-7]. Therefore, PLA is renowned for conventional plastic replacement.

Membranes play a central role in our daily life [8] and have become an important part in chemical technology because they can be used in board range of applications [9]. Most of the polymer membranes were made from petroleum-based polymer. When these polymer membranes were discarded into the environments, their wastes will be degraded over hundred years causing the serious global problems in the management of the increasing amount of these solid wastes. Therefore, membranes from biodegradable polymers are used instead.

The fabrication of hollow fiber is known to be a complicated procedure process especially when the new material was used. Nonsovent induced phase separation (NIPS) has been widely used for fabrication of hollow fiber membrane in commercial scale [10-11] due to the simplicity and convenience of NIPS method for preparing porous membranes. Therefore, it is likely to be possible to prepare PLA membrane with flat sheet and hollow fiber microstructures [10-13]. Moriya et al. [10] have studied the effect of solvent, nonsolvent and PEG on membrane morphologies and filtration performance of PLA hollow fiber membranes prepared via nonsovent induced phase separation (NIPS). In their study, the factors involved in the hollow fiber membrane formation include (a) polymer dope formation such as polymer concentration and additive (b) spinning parameters such as air gap, take-up speed, coagulation and bore fluid temperature [14-16]. In this paper, PLA hollow fiber with good ultrafiltration performance was fabricated via NIPS using only one formulation of dope solution containing 20% PLA, 2% glycerin, 0.5% Polyethylene glycol (PEG (1500)) and *N*-methyl-2-pyrollidone (NMP) solvent. The effects of spinning parameters on the structure, morphologies and filtration performance of hollow fiber membrane have been studied.

2. Experimental

2.1 Materials

Poly (lactic acid) (Ingeo 2003D) was purchased from NatureWorks LLC and dried under conventional oven at 50 ^oC for 24 hours before use. NMP was purchased from POSH. S.A. (Labscan). Glycerin was purchased from Iltalmar company. Bovine serum albumin (BSA) was purchased from S.M. Chemical Supplied Co., Ltd. All materials were used as received without further purification.

2.2 Frabrication of PLA Hollow Fiber Membranes

PLA resin (20 wt. %), glycerine (2 wt. %), PEG (1500) were dissolved in NMP at 80^oC for 6 hours to form homogeneous dope solution. Then, the dope solution was transferred into the polymer dope tank and kept at 70^oC overnight for eliminating the air bubbles formed during stirring and pouring. The degassed dope solution was used to fabricate PLA hollow fiber membranes using the dry-wet spinning process shown schematically in Fig. 1. Water was used as bore fluid and coagulant at room temperature. The dope solution and bore fluid (water) was pressurized by nitrogen gas through spinneret, with an outer tube diameter of 1.06 mm and inner tube diameter of 0.66 mm, to a coagulation bath of water. The preparation parameters such as feed pressure, take-up speed have been varied, while the dope solution temperature and bore fluid rate were fixed at 70^oC and 10 mL/min, respectively. After phase separation and solidication of membrane, the membrane was collected by roller. All the spinning conditions were summarized in Table 1. The obtained membranes were immersed in water over 3 days to completely remove the NMP used in membranes fabrication. Next, the membranes were immersed in glycerin for 10 min to preserve the pore structure during the stage of dry. The membranes were dried in the ambient air prior to further tests.

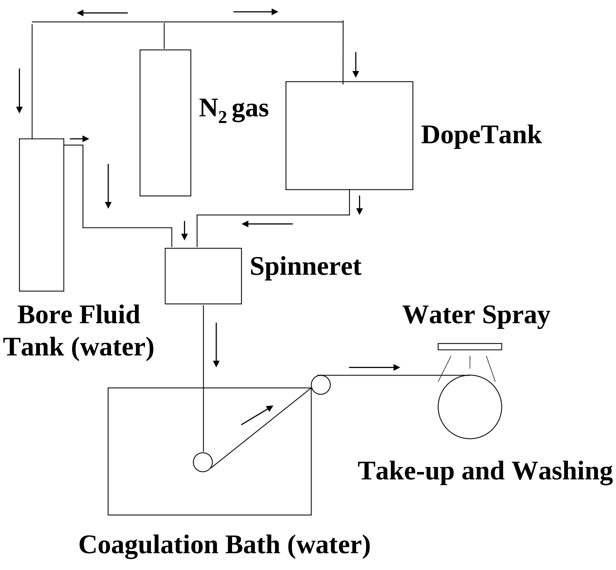

Fig. 1. Schematic diagram of spinning process

Table 1 Spinning parameters and structure parameters of hollow fiber membranes.

Code	Feed pressure (MPa)	Air Gap (cm)	Take-up speed (m/min)	i.d. (μm)	o.d. (μm)	Wall thickness (μm)
HF-PLA1	0.045	25	220	916	1237	161
HF-PLA2	0.045	5	220	955	1206	125
HF-PLA3	0.045	5	270	808	1017	105
HF-PLA4	0.065	5	220	938	1223	142
HF-PLA5	0.1	5	220	909	1207	149
HF-PLA6	0.1	5	270	746	991	123

2.3 Characterization of the PLA hollow fiber membranes

2.3.1 Characterization of the structure and morphologies of PLA hollow fiber by FE-SEM

A Field Scanning Electron Microscope (FE-SEM) was used to characterize the cross-section, outer and inner surface morphologies of asymmetric PLA hollow fiber membranes. Specimens to study the cross-section of hollow fiber membranes in FE-SEM were prepared by fracturing the dried membrane sample in liquid nitrogen. The specimens were covered with a thin layer of gold using sputter coater before the FE-SEM analysis. The diameter of hollow fiber membranes was measured from FE-SEM image using Image J 1.44 P program.

2.3.2 Measurement of hollow fiber pure water flux

The hollow fiber membranes were prepared for measurement of pure water flux using a lab-scale permeation system. Prior to the test, the hollow fiber membranes were immersed in pure water to remove glycerin for overnight. Pure water was circulated through the inside of membrane under pressure (1-3 bar) and then, the pure water permeating from the membrane was collected. The pure water flux of the membrane (J) was calculated by the following Eq. (1):

$$J = \frac{Q}{A \times t} = \frac{Q}{n\pi dlt} \tag{1}$$

Where *Q*, *A*, *t*, *n*, *d* and *l* denote the total filtrate volume (m^3), the membrane area (m^2), the operation time (h), the number of fibers in one testing, the diameter of the testing fibers (m) and the effective length of the fiber (m), respectively.

2.3.3 BSA rejection

The BSA (MW = 67,000) solution of 1000 ppm was used as the feed solution. The BSA concentration of feed and permeate were evaluated by UV-Visible Spectroscopy using the absorption wavelength of 280 nm. The % BSA rejection can be calculated using the following Eq. (2):

$$R(\%) = \left(1 - \frac{C_p}{C_f}\right) \times 100 \tag{2}$$

Where C_p and C_f are the BSA concentration (ppm) in the permeate and feed, respectively.

2.3.4 Mechanical Properties

Tensile strength and elongation at break of each samples were determined using a Tensometer (Monsanto model T10) at room temperature with a crosshead rate of 50 mm/min and a 25 mm gauge length. At least 5 replicates were tested, and average values were reported.

3. Results and discussion

The fabrication of hollow fiber is still a complex process especially when the new material was used. The spinning parameters play an important role in formation of membrane hollow fiber via NIPS. In this study, a number of hollow fiber membrane were prepared by dry-wet solution spinning via NIPS. The spinning parameters such as feed pressure, air gap and take-up speed were varied while the formulation of polymer dope solution was fixed.

3.1 The effect of spinning parameters on the hollow fiber membrane structure and morphologies

The PLA hollow fiber spinning parameters and structure were summarized in Table 1. The results showed that the diameter and wall thickness of membrane decreased with the increase in take-up speed of membrane. The wall thickness of membrane also increased with the feed pressure. The air gap between spinneret and coagulant bath also affected the structure of hollow fiber membrane. The asymmetric structure of the hollow fiber membranes were examined by FE-SEM. The FE-SEM images of cross-section membranes are displayed in Fig. 2. It revealed that the PLA hollow fiber membranes have got double finger-like structure (macrovoid), which is the normal structure formed in NIP method. This results indicates that phase separation was induced by nonsolvent (water) penetrated from both inner and outer surfaces of hollow fiber membranes [7]. There is sponge-like layer between 2 macrovoids in the middle of membranes. FE-SEM image in Fig. 2 clearly showed the 3 layers of membrane (finger-like structure near the inner side of membrane, sponge-like in the middle of membrane and the finger-like near the outer side of membrane). The finger-like structure layers near inner side of membrane are thicker than the layer near outer side of membrane may be due to the velocity of bore fluid. The porous structure was formed at the inner surface and outer surface of hollow fiber membrane. This may be due to the diffusion of solvent out slowly or nonsolvent diffused into the dope solution rapidly. The inner surface showed larger pores compared with the outer surface due to the velocity of bore fluid. The larger of finger like structure was found when the air gap was increased from 5 cm to 25 cm.

3.2 Pure water flux and BSA rejection

The pure water flux and BSA rejection of PLA hollow fiber membranes are shown in Fig. 3. The PLA hollow fiber membranes HF-PLA-2, HF-PLA3 and HF-PLA6 showed high pure water flux because the wall thickness of these membranes were thinner compared to the other membranes. The PLA hollow fiber membranes exhibited 71–99 % in BSA rejection. The BSA rejection of HF-PLA1, HF-PLA3 and HF-PLA4 were higher than 90%. These results indicated that these membranes exhibited excellent ultrafiltration performance.

3.3 Tensile Strength

The results related to the tensile strength and the elongation at break of PLA hollow fiber membranes are summarized in Fig 4. The hollow fiber membranes exhibited 1.9-2.5 MPa in tensile strength and 4-6 % in elongation. HF-PLA3 showed the highest tensile strength, while HF-PLA1 showed the highest elongation

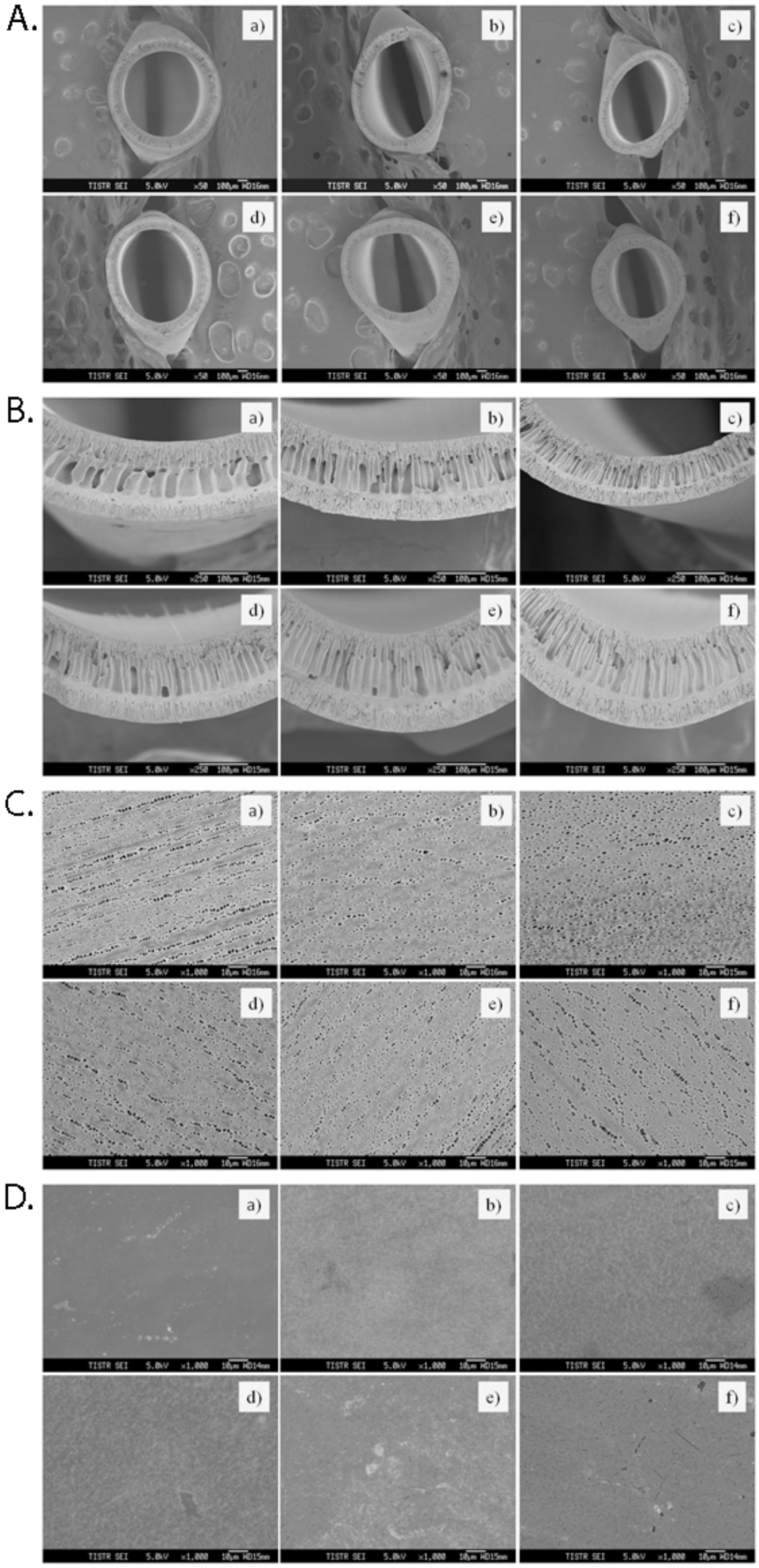

Fig. 2. FE-SEM images showing (A) and (B) cross sections at low and high magnifications, (C) inner surfaces and (D) outer surfaces for (a) HF-PLA1, (b) HF-PLA2, (c) HF-PLA3, (d) HF-PLA4, (e) HF-PLA-5 and (f) HF-PLA-6

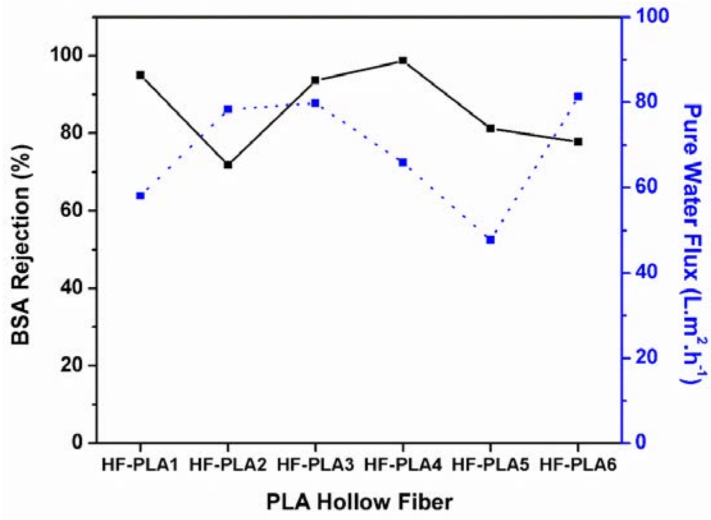

Fig. 3. BSA rejection together with pure water flux of PLA hollow fiber membranes

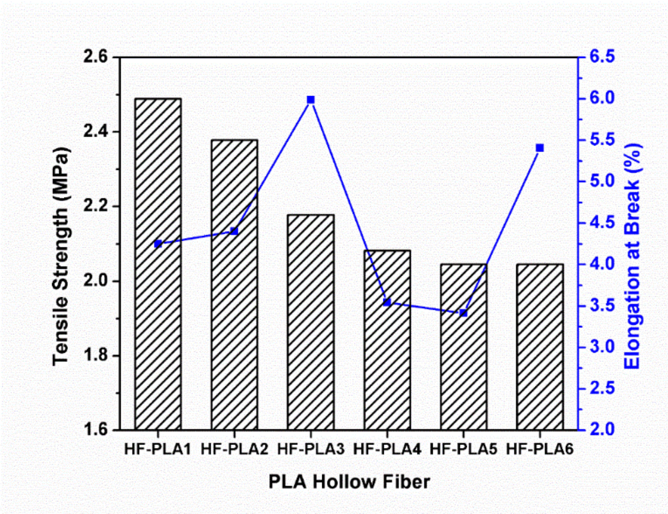

Fig. 4. Tensile strength and Elongation of PLA hollow fiber membranes

3.4 Removal of E. coli and total coliform

The prepared membrane was selected to study the microbe removal from the feed water. Characteristic, amount of *E. coli*, together with the total coliform of the feed and permeate waters are tabulated in Table 2. It was observed that the color changed from turbid yellow to colorless when the feed water was passed through the PLA hollow fiber. The colorings was likely to be trapped by the polymeric hollow fiber. The number of *E. coli* was decreased from 23 MPN/100 mL to no detection. Furthermore, the total coliform was also lowered from 13 MPN/100 mL to none due to the pore size and ultrafiltration performance of membrane.

Table 2 Amount of *E.*Coli and total coliform in feed and permeate of surface water using PLA hollow fiber membrane.

Sample	Physical Appearance	*E. Coli* (MPN/100 mL)	Total Coliform (MPN/100 mL)
Feed water	Turbid Yellow	23	13
Permeate water	Clear	Not Detected	Not Detected

4. Conclusions

PLA hollow fiber membranes were successfully fabricated via nonsolvent induced phase separation by solution spinning method. The dope solution contained 20 % PLA, 2 % glycerin, 0.5 % PEG (1500) and NMP solvent at 70 ºC using water at RT as a bore fluid and coagulant. The spinning parameters affected the structure, morphologies and the filtration performance of membrane. PLA hollow fiber membrane obtained from this work exhibited excellent ultrafiltration performance with 94 % in BSA rejection. These results indicated that PLA hollow fiber membrane can be a good candidate for hollow fiber membrane made of petroleum-based polymer.

Acknowledgement

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WR-P03

Quantification of Ammonium Oxidizing Bacteria (AOB) from Full Scale of BNR WWTPs for Possible Water Reclamation in Bangkok and Phuket Province

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Abstract

In this work, influents and effluents were analyzed with respect to flow rate, biochemical oxygen demand (BOD), ammonium (NH_4^+), nitrate (NO_3^-), total nitrogen, and total phosphorus concentrations. Wastewaters in the study were from the following two full scale wastewater treatment plants (WWTPs) in Bangkok and Phuket province. Low efficiency of nitrogen removal at centralized WWTP in Bangkok was found in the summer period. Influent ratios of COD:N at centralized WWTP in Bangkok and Phuket WWTPs are less than 3 and higher than 5, respectively. The overall of total of nitrogen removal efficiency in Bangkok WWTP is low but NH_4^+ removal efficiency is high. On other hand, at Phuket WWTP, the overall of total nitrogen is high and NH_4^+ removal is also high. Quantitative real-time PCR (qPCR) was used to quantify and specific ammonium oxidizing bacteria (AOB) were most prevalent in the aeration tank at the Phuket WWTP rather than in the aeration tank at Bangkok WWTP. In this case, effluent from Phuket WWTP could be considered as reclaimed water because of low nitrogen concentration.

Keywords: AOB; Bangkok and Phuket Wastewater Treatment Plants

1. Introduction

Ammonium- nitrogen (NH_4^+-N) or ammonia-nitrogen (NH_3-N) in domestic wastewater is a pollutant which have deleterious effects on human health, aquatic life, and the environment. Also, other forms of nitrogen such as nitrite (NO_2^-) and nitrate (NO_3^-) are a significant potential public health hazard in drinking water, enhancing eutrophication of freshwater, lakes, estuaries, and oceans and presents the risk of methemoglobinemia (blue baby syndrome) in infants. Domestic sewage, agriculture, and industries are all sources of N, but domestic sewage is the major source in Thailand [4, 5]. For these reasons, nitrogen should be removed before it is discharged into the environment. The conventional approach for nitrogen removal from wastewater involves a biological nitrification process converting ammonium, (NH_4^+) to nitrite (NO_2^-) on to nitrate (NO_3^-) followed by denitrification of NO_3^- to NO_2^- to nitric oxide (NO) to nitrous oxide (N_2O) and then to the nitrogen gas (N_2) end product. The nitrification/denitrification process is well known and is widely used for the treatment of municipal wastewater. The goals of this research were focused on nitrogen removal efficiencies and to quantity on ammonium oxidizing bacteria (AOB) from Bangkok and Phuket WWTPs by using quantitative real-time PCR (qPCR).

2. Experimental

Samples from the Bangkok and Phuket WWTPs were analyzed to identify ammonium oxidizing bacteria (AOB) by using Quantitative real-time PCR (qPCR). Genomic DNA was extracted from 2.0 mL of sludge samples using the method of Zhou et al, 1996 [3] with some modifications and cleaned up with Gel/PCR DNA Fragments Extraction Kit (Geneaid, Taiwan). The amount of DNA was determined by NanoDrop® Spectrophotometer ND-1000 (Wilmington, USA). Quantitative real-time PCR (qPCR) was performed using a CFX96 Real-Time PCR machine (Bio-Rad, Japan), triplicates for each sample. Total bacteria were quantified by the primers EUB 338F (5'-ACTCCTACGGGAGGCAGC-3') and 518R (5'-ATTACCGCGGCTGCTGG-3') Fierer et al. 2005. Bacterial AOB amoA genes were quantified in each sample using primers amoA 1F (5'-

GGGGTTTCTACTGGTGGT-3') and amoA 2R (5'CCCCTCKGSAAAGCCTTCTTC-3') Rotthauwe et al. 1997). The qPCR was run in a total volume of 20 µL, containing 10 µL of the qPCR master mix Luna® Universal qPCR Master Mix, 0.4 µL of each primer (10 pM), 8.2 µL of milliQwater and 1 µL of DNA template adjusted to 6-10 ng-DNA per µL. The real time PCR protocol for amoA quantification was as follows: 3 min at 95°C, followed by 39 cycles of 10 s at 95°C, 10 s at 55°C, and 10 s at 72°C.

3. Results and discussion

3.1 Design and operational parameters for the WWTPs

Key average design and operational parameters of Phuket and Bangkok WWTPs are shown in Table 1.

Table 1 Key average design and operational parameters for the WWTPs in Phuket and Bangkok

Parameter	BNR WWTPs in Thailand	
	Phuket WWTP	**Bangkok WWTP**
Flow Rate (m^3/d)	28,735	135,945
HRT (hours)		
Anaerobic	NO	-
Anoxic	24	1.29
Aerobic	24	1.6-2.5
SRT (days)	25-30	40-60
DO (mg/L)		
Anoxic	0.1±0.05	0.1-0.4
Aerobic	1.2±0.4	1.5±0.5

Phuket and Bangkok WWTPs were selected as study sites in this work because each WWTP was designed as BNR process (nitrification and denitrification process) and similar operation for municipal treatment system. However, a notable difference between Phuket and Bangkok WWTPs would be influent of BOD concentrations. BOD at Phuket WWTP is significantly higher than BOD at Bangkok WWTP. This is because Phuket is tourist place and there are many hotels and condominiums. Average physical and chemical characteristics of influent and effluent of WWTPs are shown in Table 2.

Table 2 The average influent and effluent characteristics of the WWTPs in Phuket and Bangkok

Parameter	Phuket WWTP		Bangkok WWTP	
	Influent	**Effluent**	**Influent**	**Effluent**
pH	7.2	7.2	7.47	6.9
Temp (°C) in summer	27	26.9	27	27
Temp (°C) in winter	27	27	25	25
TSS (mg/L)	*No data*	*No data*	36.3	3.1
BOD (mg/L)	174	3.7	34.1	1.7
COD (mg/L)	*No data*	*No data*	70.8	17.4
Organic-N (mg N/L)	*No data*	*No data*	16	1.15
NH_4^+ (mg N/L)	15.9	8.7	5.6	1.3
NO_3^- (mg N/L)	*No data*	3.2	0.4	1.8
TKN (mg/L)	No data	No data	21.5	2.4
TN (mg N/L)	25.3	8.9	22.1	4.3
TP (mg P/L)	7.1	0.9	3.1	0.9

Ammonium oxidizing bacteria (AOB) at Phuket and Bangkok WWTPs are shown in Table 3. The quantification of AOB in the Phuket WWTP were higher than the quantification of AOB in the Bangkok WWTP. This indicates that ammonium oxidation was conducted by AOB in both WWTPs.

After using quantitative real-time PCR (qPCR) to quantify on ammonium oxidizing bacteria (AOB) both Bangkok and Phuket WWTPs, the results were shown that *Nitrosomonas* sp. and *Nitrospira* sp. were dominate in Phuket WWTP. This result could be confirm that NH_4^+ removal efficiency at Phuket WWTP is higher that NH_4^+ removal efficiency at Bangkok WWTP.

Table 3 Abundances from bacteria AOB in two BNR from full-scale of Phuket and Bangkok WWTPs.

Sample	AOB Gene copy number [copy/ng-DNA]	
	Phuket WWTP	**Bangkok WWTP**
Aerobic		
1	$1.47\times10^2\pm1.23\times10^1$	$5.57\times10^1 \pm 4.50\times10^1$
2	$1.76\times10^2\pm1.56\times10^1$	$1.81\times10^2 \pm 1.42\times10^2$
3	$6.35\times10^1\pm2.3$	$8.11\times10^1 \pm 5.97\times10^1$
4	No data	$1.78\times10^2 \pm 1.35\times10^2$
5	No data	$2.90\times10^2 \pm 2.52\times10^2$
6	No data	$2.05\times10^2 \pm 1.59\times10^2$
7	$1.04\times10^2\pm7.89$	$3.52\times10^3 \pm 2.75\times10^2$

4. Conclusions

The conditions at the Phuket WWTP promoted the dominance of AOB than Bangkok WWTP. BOD at the Phuket WWTP is significantly higher than Bangkok WWTP. Nitrogen removal efficiency at Phuket WWTP is significantly high than Bangkok WWTP. The treated of effluent from Phuket WWTP could be consideration as reclaimed water. The molecular technic on quantitative real-time PCR (qPCR) could be used as technic to quality ammonium oxidizing bacteria (AOB) from Bangkok and Phuket WWTPs). In addition, analysis of operational data in conjunction with AOB community structure from the both WWTP.

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WR-P04

IoT Based Real Time Monitoring of Water Levels in Tanks Using Machine Learning and Android Application

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Abstract

In this paper, the concept of water level monitoring and controlling is introduced. Wastage of water in the current scenario, merely due to overflowing tanks is not affordable. Conventional water tanks in households can neither monitor nor control the water level in tank, leading to large amount of wastage. The need of removal of these shortcomings and providing an efficient and economical solution has been the main focus of this project. The project includes the following technical aspects: IoT usage for collection of water consumption data of a household, calculation of average requirement of water in a tank by a household (Daily/ weekly/ monthly/ yearly), per person, per household or in a society and an Android Application for giving control to the user to use water judiciously in a cost efficient way and to adapt to changing needs of the household. For each household in a particular society, and for each society as a whole, average daily/monthly/yearly consumption is also calculated. These values will be helpful in classification of the household in the society based on the usage. The analysis and classification part has been done and an adaptive learning algorithm for the same has been revised and proposed.

Keywords: IoT, Machine Learning and Real Time Monitoring of water consumption.

1. Introduction

Sustaining water resource is one of the major issues surfacing recently due to uncontrolled wastage of available fresh water. Majority of the water wastage takes place because of overflowing water tanks. In most of the cases, water tanks are manually controlled by an operator. In absence of the person, water keeps on overflowing until the motor is switched off. In some other projects, which are automated, dip sensors are implemented. As a result of being in contact with water, there is a high probability of rusting of material used in the sensor. These projects can only control the water level locally, i.e. an operator is required to keep an eye on proper functioning. Smart water tank implements IoT, with which, the user can directly monitor and control the working of tank through the Smartphone and from any place in this world. This project can be installed in existing water tanks with no requirement of new tank for this purpose. This paper is organized in the following ways. Chapter two concentrates on the basic concepts used in designing the entire project. Chapter 3 concentrates on system design and its implementation with all sub units. Chapter 4 is related to the data flow from sensors and app around database.

2. Experiment

2.1 Basic concepts

2.1.1 WiFi Module

Wi-Fi module can connect to internet via hotspot by using its SSID and Password. It is be programmed to implement logic statements as per requirements of the project. The ultrasonic sensor reads the distance of water surface and returns it to the module. The module, when connected to internet, uploads this value to the database. Also it retrieves some values from the database which are set by user in the android application. Accordingly, the functioning of motor depends upon the current water level and the maximum and minimum values.

2.1.2 Ultrasonic Sensor

Ultrasonic sensor is used to generate ultrasonic sound waves which are bombarded on the surface of water. This sensor consists of a speaker which emits an ultrasonic sound wave and a microphone which detects that particular sound wave. As we have implemented the ultrasonic sensor, there is no contact of water with sensor which ensures long life of the sensor. The average life of an ultrasonic sensor under normal conditions is three years. Using ultrasonic sensor is cost effective also, as the component comes for around ₹100-150.

Here, the values from the android application and WiFi module are stored. The values are then accessed by the module and app by using some functions. The current dataset upon which the work has been performed and all the analysis has been done has been acquired from "https://www.kaggle.com/lbronchal/venezia/data" which is a website that provides dataset for data scientists.

2.1.3 Android Studio– Android application

This is a scratch programming platform to help the programmers for developing and testing android applications. The application has been created using this software. In this app, the user has to set the maximum and minimum values of water level required according to his varying requirements. These values are used to compare the current water-level (which the user can check), according to which the flow of water is controlled and provided to the user accordingly. Another module of app is of water cost which shows the cost charges applied on water. It also provides notification to user of increase or decrease in water consumptions according to which the cost is increased or decreased respectively. In this way, the app makes the users conscious of the water usage and thus minimizes the water wastage.

2.2 System design and implementation

2.2.1 Data Collection using IOT:

For this project, a WiFi module has been used as microcontroller. An ultrasonic sensor connected with ardiono as in Fig. 2 will be deployed at the top of the tank, to monitor the water levels every 10 minutes The sensor sends the ultrasonic waves to water level which is reflected by the water surface and comes back to the ultrasonic sensor. Sensor uses this time of wave propagation to calculate the distance between the sensor and the water level.

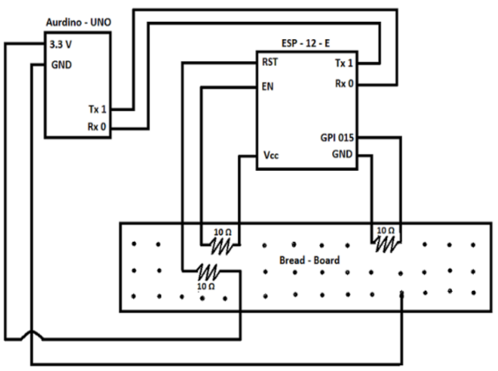

Fig. 1. Pin Diagram of ESP with Arduino.

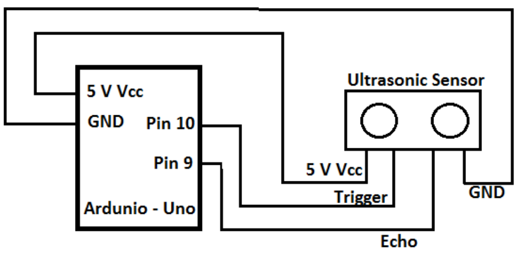

Fig. 2. Pin Diagram of Sensor with Arduino

Time taken by the pulse is actually for to and from travel of the ultrasonic signals, while only half of this is needed. Therefore, the time is time /2.

Distance Calculation: Distance= speed*time/2

Speed of sound at sea level = 343m/s or 34300 cm/s

Thus the distance measured = 17150* time (unit cm)

The water level to be monitored for each tank is collected by the ultrasonic sensor and simultaneously the data collected is shifted to the server via ESP12-e by making connections as in fig 1. The values of maximum and minimum levels are obtained by ESP from the database. These values are set from the android app. The current level of water is obtained from the ultrasonic sensor. Depending upon these values, the motor is turned ON / OFF through. The height of the water tank varies with the household and is stored by the household's respective ESP. This height shall be used to determine the percentage of water.

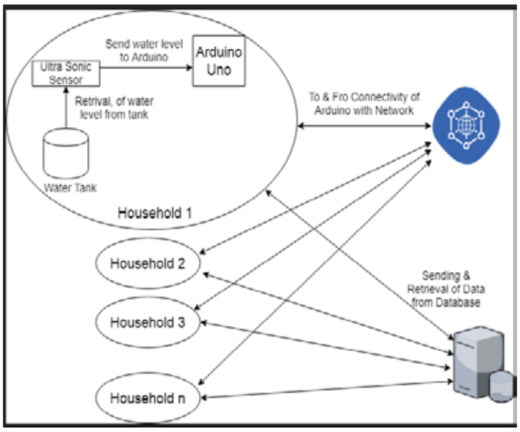

Fig. 3. System Architecture

The height of the water tank as well as the requirement of the household plays an important role in determining the working of the whole process of starting and stopping the motor. Calculations of the current water level will be done using the given height of the water tank.

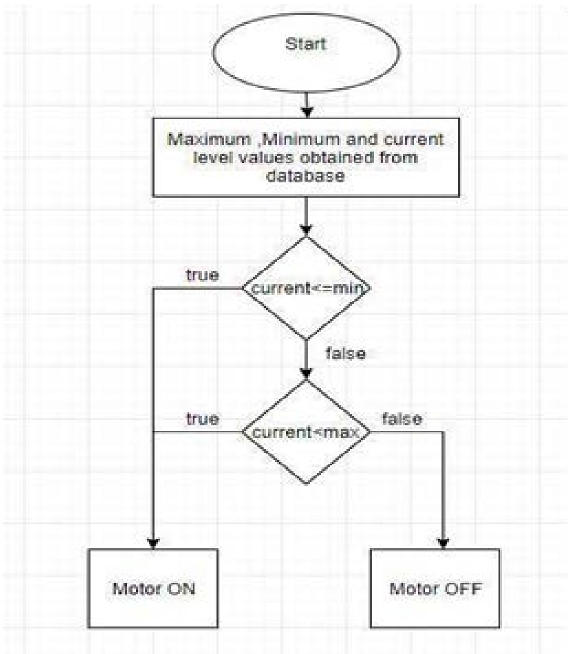

Fig. 4. Implementation in ESP

Implementation in ESP: ESP8266 is used as a microcontroller with the program flashed on it. The current level of water is obtained from the ultrasonic sensor. Maximum and minimum values are set by user. ESP8266 accesses the hotspot with its SSID and password. Once it gets access to internet, these values are stored in ESP. When the current values equals or goes below the minimum level, the motor automatically starts and when water level reaches the maximum level, the motor turns off automatically. As a result, there is no overflowing of water.

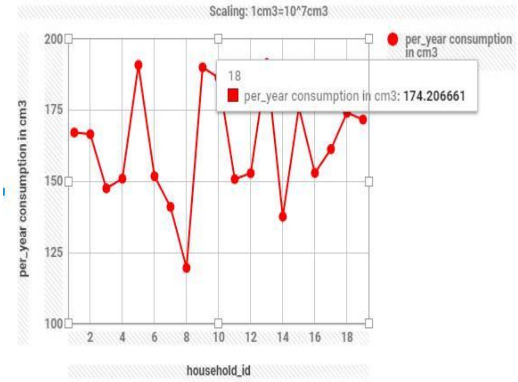

Fig. 5. Water Consumption per year

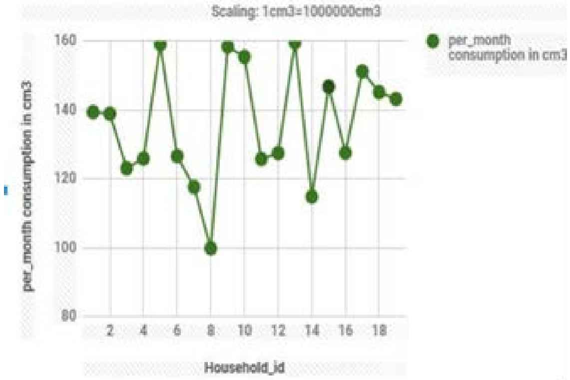

Fig. 6. Water Consumption per month

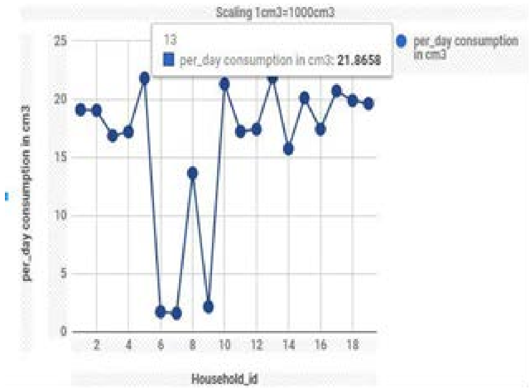

Fig. 7. Water Consumption per day

2.3. Data Analysis

2.3.1 Data Normalization

The current dataset upon which the work has been performed and all the analysis has been done has been acquired from "https://www.kaggle.com/lbronchal/venezia/data" which is a website that provides dataset for data scientists. The dataset includes data for 19 households in a society of Venice city. For each household, 8561 entries were there, (total 8561*19=162,659), each entry having two fields, time and corresponding water level. To normalize the data for further calculations and analysis, the missing values and the noise data was removed using excel function(Paste Special) and manual proofreading, only the useful data was kept and sorted likewise.

2.3.2 Statistical Computation

For each household in a particular society, the following things are calculated:
A. Per year consumption.
B. Per month average consumption.
C. Peak time consumption (maximum consumption).
D. Per day average consumption.

For each society as a whole the following things are to be calculated:
A. Average monthly consumption
B. Average yearly consumption.
C. Average daily consumption.

These values will be helpful in classification of the household in the society based on the usage.

Fig. 5. tells about the yearly water consumption by the households in the society. The monthly water consumption of each household and the daily average consumption of households is depicted in Fig. 6 and Fig. 7 respectively.

Depending on the water levels, as described above, the status of motor will be automatically controlled. If water level is in between both the levels, then the user can exercise control by toggling the status of motor from the android application. Buttons – Start and Stop will be provided for the same.

The application is designed in such a way that it will show the instantaneous value of current status of water in percentage.

2.3.3 Data Classification:

The classification of the households has to be done on the basis of the water consumption. This analysis and classification part is done using Python and among all the options, SVM seems the best for the classification of this type of supervised problem.

NN gives hundred percent accuracy, but we choose SVM over NN due to following Reasons:
-> SVM is high speed.
-> NN has many hidden layers which makes its processing slow.
->NN cannot be applied to the current dataset as the attributes are less.

i. Revised proposed algorithm

The following algorithm is designed to make the system adaptive, i.e, it can be scaled as per the user requirements. The solution model takes three inputs i.e. time, water level and number of members along with its corresponding initial weights. The steps to the algorithm are as cited:

a. The system takes the input from households denoted as h(n) which is formed as

$$h(n)=[h1(n),h2(n),\ldots\ldots\ldots\ldots,hn(n)]T\ldots\ldots\ldots\ldots\ldots\ldots(i)$$

b. For all given inputs, a weight is added to get the optimized result. The weights are given as:

$$w(n)=[w1(n),w2(n),w3(n)]T\ldots\ldots\ldots\ldots\ldots\ldots\ldots......(ii)$$

c. After applying the weight on input, the output is given as:

$$y(n)=wT(n).x(n)\ldots\ldots\ldots\ldots\ldots\ldots.............................(iii)$$

d. There is some error in calculation which should be minimized. To minimize and remove it, we calculate error as:

$$e(n)=d(n)-y(n)\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..\ldots\ldots..(iv)$$

where d(n) is original data. Since the process is repeated continuously, to make the system adaptive to state, the weights are to be changed again and again. Initially the weights maybe taken as (1,1,1) so that the attributes have equal weightage. The new weight depends on the previous weight and other things given as:

$$w(n)=w(n-1) + €(n)[d(n) – wT(n).x(n)]\ldots\ldots\ldots..\ldots.(v)$$

Here €(n) is the gain coefficient. This function is used to update the weight, resulting in increment or decrement of weight with respect to the previous weight. Seeing the equation (iv) and (v) , we can reduce the update weight function as:

$$w(n)= w(n-1) + €(n).e(n)\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(vi)$$

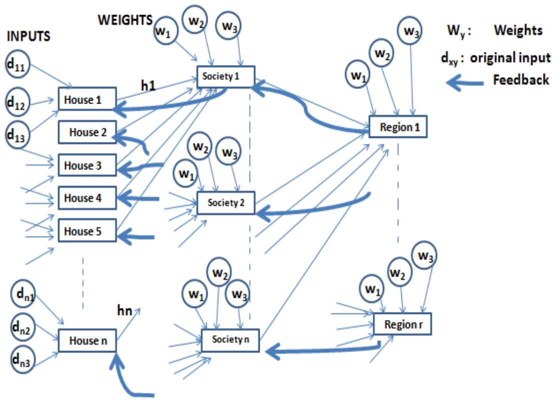

Fig. 8. Working of revised adaptive algorithm

In the Fig. 8 the node "house 1" takes three inputs along with the weights and it optimizes the water level of tank by the above mentioned formula and minimize the error giving the result as input to another node society 1. Society 1 similar to house 1 takes number of houses as input. The back arrow represents the feedback system from society 1 back to households.

Similarly, Society 1 along with updated weights gives result as input to node "region 1".This node similar to society 1 node gives feedback back to the various societies and optimizes the water tank level. The whole model gives end result of optimized water tank level at each stage i.e. household, society and region.

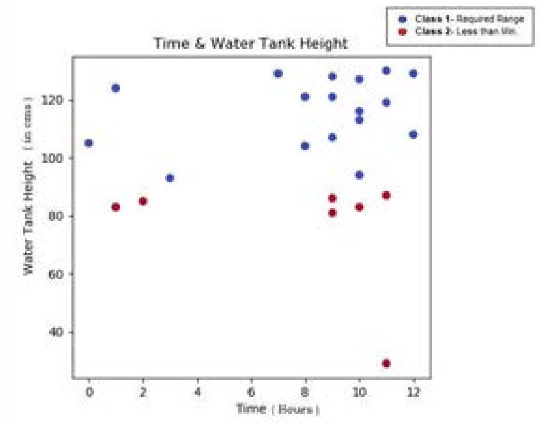

Fig. 9. Visualization of data of a house

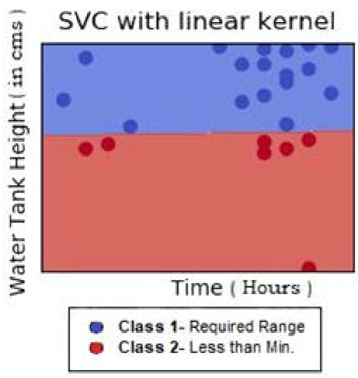

Fig. 10. Classification of the house

ii. Experiments performed

For this proposal, the following three different supervised algorithms in the field of Machine Learning has been chosen to classify the house's daily consumption into two category, first, showing consumption in a day that is in the required range; second, showing water consumption less than the minimum limits. –

a. K Nearest Neighbor

b. Neural Networks

c. Support Vector Machine

The following graphs show the binary classification of the houses in the defined two categories using the following different algorithms -

a. Support Vector Machine

Firstly, SVM is used for the classification. Fig 9 represents the data visualization of data describing the daily consumption of water in a household. The blue dots represent the water consumption which are under the required range whereas the red dots represents the water consumption that are less than the minimum limit i.e 225008 cm^3 of a house in a day. In Fig. 9, “Time” attribute is plotted on X axis and “Water Tank Height” attribute in centimeters on Y axis. The graph represents the data classification of data describing the daily consumption of water in a household into two categories. The blue dots and area represents the water consumption which are under the required range whereas the red dots and area represents the water consumption that are less than the minimum limit i.e. 225008 cm3 of a house in a day. In Fig. 10, two classes have been taken to classify the households into two classes on the basis of the water consumption. Class 1 (Blue class) represents the households having the water consumption greater than or equal to 225008 cm^3. Class 2 (Red Class) represents the households having water usage below 225008 cm^3. For classification the boundary value is taken as 225008 cm^3 because it represents the minimum water consumption value for an individual. The data is taken from Venice City and the SVM algorithm uses inbuilt functions of Python library and classifies the given dataset into two categories with an accuracy of 100%. This means if a new data point comes into consideration it will be predicted and classified into one of the two categories with an accuracy of 100%.

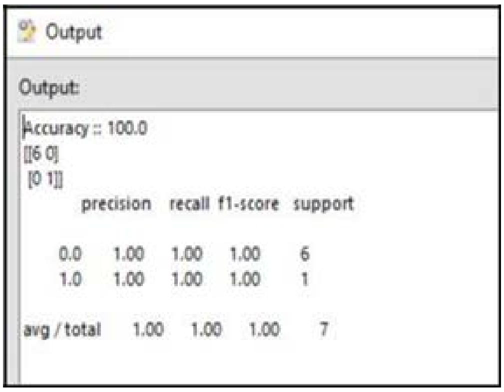

Fig. 11. Confusion Matrix for SVM

Fig. 11 shows the confusion matrix stating the different performance metrics values like precision, recall and F1 score for SVM.

b. K-Nearest Neighbour

The data is taken from Venice City and the KNN algorithm uses inbuilt functions of Python library and classifies the given dataset into two categories with an accuracy of 97.49%. This means if a new data point comes into consideration it will be predicted and classified into one of the two categories with an accuracy of 97.49%. Here, the value K signifies the number of nearest neighbors labels used to account for the decision to assign a label to the current point.

c. Neural Network

For hidden layer size lower than 10, the Neural Networks model isn’t able to predict the positive class for a data set, thus giving accuracy for classification of 68% whereas for other hidden layer sizes the accuracy of the model for classification and prediction is 100% . Thus, we summarize that the average accuracy for neural network model to predict a class for a given water consumption level data is 84%.

3. Results and discussion

Table1 gives the accuracy of classifying data of water consumption of a house in a day into two categories; first, consumption which are less than the minimum limit i.e. 225008 cm^3; second, the water consumption that are under the required range(according to our dataset).

Table 1 Comparison between classification algorithms according to experiments performed.

S. No	Algorithm	% Accuracy
1	Support Vector Machine	100%
2	K-Nearest Neighbor	97.49%

Thus, Support Vector machine classifies the given data into two classes. First class represent the water consumption which is under the required range whereas the second class represents the water consumption which is less than the minimum limit that is 2225008 cm^3 of a house in a day with maximum accuracy of 100%. According to this classification, the information of the daily water consumption of a house is determined which further determines the lower and maximum limits of water tank height for a particular house. After the limits are determined, the minimum water availability level for a house can be set so that a house will never face shortage of water. The availability of the maximum water level of a house will help make sure that the water doesn't overflow and is not wasted.

4. Conclusions

This paper proposes a system which works in a cost effective manner and help to minimize the wastage of water which is the huge problem in cities these days. This paper proposes the IOT based water management system for collection of data and statistical and dynamic computation for the calculation of average requirement of water in a society, household or per person as well as to classify the household into classes to predict the average consumption of new household on the basis of previous patterns and to check for the varying requirements. An adaptive algorithm has been also revised and proposed to make the system robust and flexible in accordance with different problem areas.

Acknowledgement

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WR-P06

Quantification of Nitrite Oxidizing Bacteria (NOB) from Full Scales of BNR WWTPs for Possible Water Reclamation in Bangkok and Samut Prakan Province

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Abstract

Quantitative real-time PCR (qPCR) was used to quantify specific nitrite oxidizing bacteria (NOB): *Nitrobacter* sp. and *Nitrospira* sp. on two biological nitrogen removal (BNR) wastewater treatment plans (WWTPs). Frist WWTP is located in Bangkok as centralized WWTP, flow rate is higher than 200,000 m^3/day). Second WWTP is located in Samut Prakan Province also as centralized WWTP but the flow rate is lower than the first one (flow rate only 8,000 m^3/day). The result is shown that in both BNR WWTPs, *Nitrospira* sp. are dominated. Also low efficiencies of total nitrogen removal at centralized WWTP in Bangkok and Samut Prakan were found. Both at Samut Prakan and Bangkok WWTPs, COD:N is lower than 3. Based on this ratio of COD:N could be postulated that there was not enough carbon source for denitrifying bacteria. The effluent from at Samut Prakan and Bangkok WWTP might be not possible to use as water reuse. However, the effluent from both plants might be reconsider as reclaimed water during the summer time.

Keywords: NOB; Bangkok and Samut Prakan Wastewater Treatment Plants

1. Introduction

Nitrogen from domestic wastewater is a significantly pollutant source of water pollution and should be removed before it is discharged into the environment. Many nitrogen forms (e.g. ammonia (NH_4^+), nitrite (NO_2^-), and nitrate (NO_3^-)) can have deleterious effects on environment. For example, NO_3^-could cause on methemoglobinemia or blue-baby syndrome. More effective technologies of nitrogen removal are needed and developed. Domestic sewage, agriculture, and industries are all sources of N, but domestic sewage is the major source in Thailand [4, 5]. For these reasons, nitrogen should be removed before it is discharged into the environment. The conventional biological nitrogen removal process is well known and involves nitrification (NH_4^+ to NO_2^- to NO_3^-) followed by denitrification (NO_3^- to NO_2^- to N_2). The goals of this research are focused on nitrogen removal efficiencies and to quantity on nitrite oxidizing bacteria (NOB) from Bangkok and Samut Prakan WWTPs.

2. Experimental

2.1 Quality of influent and effluent of wastewater quality

Influent and effluent wastewater qualities were determined according to Standard Methods for the Examination of Water and Wastewater [1]. All samples were collected one time a week for 6 months from the midyear of 2017 through the end of 2017. All samples were kept at 4°C until analysis. Wastewater qualities were determined by measuring biochemical oxygen demand (BOD), organic nitrogen, ammonium (NH_4^+), nitrate (NO_3^-) and total nitrogen (TN) and phosphorus (TP). Temperature and pH were immediately measured in the field. The wastewater influent and effluent data from the WWTPs were used to determine the efficiencies of nitrogen removal.

2.2 Quantitative PCR

Samples from the Samut Prakan and Bangkok WWTPs were analyzed to identify nitrite oxidizing bacteria

(NOB) by using Quantitative PCR (qPCR). Genomic DNA was extracted from 2.0 ml of sludge samples using the method of [3] with some modifications and cleaned up with Gel/PCR DNA Fragments Extraction Kit (Geneaid, Taiwan). The amount of DNA was determined by NanoDrop® Spectrophotometer ND-1000 (Wilmington, USA). Quantitative real-time PCR (qPCR) was performed using a CFX96 Real-Time PCR machine (Bio-Rad, Japan), triplicates for each sample. Total bacteria were quantified by the primers EUB 338F (5'-ACT CCT ACG GGA GGC AGC-3') and 518R (5-ATT ACC GCG GCT GCT GG-3'). *Nitrospira* genes were quantified using the primers NSR 1113F (5'-CCT GCT TTC AGT TGC TAC CG-3') and NSR 1264R (5'-GTT TGC AGC GCT TTG TAC CG-3'). The primer set Nitro 1198F (5' ACC CCT AGC AAA TCT CAA AAA ACC G-3') and Nitro 1423R (5'CTT CAC CCC AGT CGC TGA CC-3') was used to amplify bacterial *Nitrobacter* gene (Bhargavi et al. 2017. The qPCR was run in a total volume of 20 µL, containing 10 µL of the qPCR master mix Luna® Universal qPCR Master Mix, 0.4 µL of each primer (10 pM), 8.2 µL of milliQwater and 1 µL of DNA template adjusted to 6-10 ng-DNA per µL. The real time PCR protocol for *Nitrobactor* sp. and *Nitrospira* sp. quantification were as follows: 3 min at 95°C, followed by 39 cycles of 10 s at 95°C, 10 s at 55°C, and 10 s at 72°C.

3. Results and discussion

3.1 Design and operational parameters for the WWTPs

Key average design and operational parameters of Samut Prakan and Bangkok WWTPs are shown in Table 1.

Table 1 Key average design and operational parameters for the WWTPs in Samut Prakan and Bangkok

Parameter	BNR WWTPs in Thailand	
	Samut Prakan WWTP	**Bangkok WWTP**
Flow Rate (m^3/d)	7,673	200,000
HRT (hours)		
Anaerobic	1.25	1.16
Anoxic	3.13	2.33
Aerobic	8-12	8.15
SRT (days)	18-20	40-62
DO (mg/L)		
Anoxic	0.1-0.3	0.1-0.2
Aerobic	0.9±0.5	1.0±0.5

Samut Prakan and Bangkok WWTPs were selected as study sites because each WWTP has BNR (nitrification and denitrification process) and had been designed and similar operation for municipal treatment system. However, a notable difference between Samut Prakan and Bangkok WWTPs would be influent of BOD concentrations. Average physical and chemical characteristics of influent and effluent of WWTPs are shown in Table 2.

Table 2 The average influent and effluent characteristics of the WWTPs in Samut Prakan and Bangkok

Parameter	Samut Prakan WWTP		Bangkok WWTP	
	Influent	**Effluent**	**Influent**	**Effluent**
pH	7.2	7.2	6.7	6.9
Temp (°C) in summer	27	26.9	27	27
Temp (°C) in winter	27	27	25	25
TSS (mg/L)	178.5	4.68	62.1	11.9
BOD (mg/L)	197.9	3.08	38.4	3.8
COD (mg/L)	511.6	40.5	85.4	19.4
Organic-N (mg N/L)	No data	No data	4.5	1.7
NH_4^+ (mg N/L)	55.4	4.8	10.7	0.25
NO_3^- (mg N/L)	No data	No data	0.2	6.4
TKN (mg/L)	60.8	6.1	15.2	1.9
TN (mg N/L)	61.2	8.9	15.4	8.4
TP (mg P/L)	7.1	0.3	1.6	1.2

The qPCR results (Table 3) show the relative abundance of nitrite oxidizing bacteria (NOB) at the two BNR WWTPs. The quantification of NOB in the Samut Prakan WWTP were higher than the quantification of NOB in the Bangkok WWTP. This indicates that nitrite oxidation was conducted by NOB in both WWTPs.

Table 3 Abundances from bacteria (NOB in two BNR from full-scale of Samut Prakan and Bangkok WWTPs.

Sample	Gene copy number of EUB and NOB, [Copies/ml]					
	Samut Prakan WWTP			Bangkok WWTP		
	EUB	*Nitrospira*	*Nitrobactor*	EUB	*Nitrospira*	*Nitrobactor*
Aerobic						
1	$5.11\times10^7\pm 7.24\times10^6$	$6.60\times10^5\pm 9.94\times10^4$	$2.17\times10^4\pm 7.42\times10^2$	$5.67\times10^8\pm 8.58\times10^7$	$1.34\times10^4\pm 4.92\times10^3$	$9.20\times10^5\pm 5.43\times10^4$
2	No data	No data	No data	$8.65\times10^8\pm 9.06\times10^7$	$3.05\times10^4\pm 5.06\times10^3$	$9.77\times10^5\pm 1.24\times10^4$
3	No data	No data	No data	$4.54\times10^8\pm 6.30\times10^7$	$1.39\times10^4\pm 1.32\times10^3$	$7.25\times10^5\pm 5.78\times10^4$
4	No data	No data	No data	$1.02\times10^9\pm 3.12\times10^7$	$3.35\times10^4\pm 2.16\times10^3$	$7.39\times10^5\pm 1.44\times10^4$
5	No data	No data	No data	$1.34\times10^9\pm 6.90\times10^7$	$3.50\times10^4\pm 2.23\times10^3$	$7.98\times10^5\pm 3.08\times10^4$
6	No data	No data	No data	$8.42\times10^8\pm 1.14\times10^8$	$2.57\times10^4\pm 2.29\times10^3$	$8.01\times10^5\pm 1.14\times10^4$
7	$4.55\times10^7\pm 4.50\times10^6$	$5.29\times10^5\pm 5.15\times10^4$	$2.26\times10^4\pm 8.62\times10^1$	$1.64\times10^9\pm 2.50\times10^8$	$5.59\times10^4\pm 3.54\times10^3$	$1.54\times10^5\pm 8.92\times10^4$

After using qPCB to identify and quantify on nitrite oxidizing bacteria (NOB) from both Bangkok and Samut Prakan WWTPs, *Nitrobacter* were dominate in Samut Prakan WWTP and Nitrospira were dominate in Bangkok WWTP. Dissolved oxygen (DO) in the aeration's tank of both sites (Bangkok's and Samut Prakan's WWTPs was maintained at 0.9 mg/L. This level of DO value at aeration tank was quite low for nitrifying bacteria to remove NH_4^+ to NO_2^- and NO_2^- to NO_3^- and the main reason for maintaining this DO level is because both plant operators want to save cost of operation. *Nitrospira* were found on both plants, this type of bacteria could be as indicator to identify that there was a low DO at aeration tank. Based on this reason confirmed Daims et al. (2001) experiment that NOB (*Nitrospira*) were able to grow in aerated bioreactor with lower nitrite and oxygen concentrations and nitrify-nitrite bacteria can grow by using nitrite as an electron donor and oxygen as an electron acceptor. Nitrogen removal efficiencies of Samut Prakan WWTP is significantly higher than the Bangkok WWTP because at Samut Prakan WWTP, there is high enough carbon source. For this reason denitrifying bacteria can use carbon source as electron donor and using nitrite (NO_2^-) and/or nitrate (NO_3^-) as electron acceptor.

4. Conclusions

The conditions at the Samut Prakan WWTP promoted the dominance of *Nitrobactor* than Bangkok WWTP. BOD:N ratios at the both sites (Samut Prakan and Bangkok WWTP) are significantly low. The molecular technic on quantitative real-time PCR (qPCR) could be used as technic to quality nitrite oxidizing bacteria (NOB) from both sites. Nitrogen removal efficiencies at Samut Prakan WWTP is slightly higher than Bangkok WWTP. However, the treated of effluent from Samut Prakan and Bangkok WWTPs could be consideration as reclaimed water but not for water reuse purpose.

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WR-P08

Comparison of Natural Dyes Removal by Coagulation Process with Different Coagulants

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Abstract

The natural dyes is interesting alternative dye because it can be derived from almost anything plants, minerals, and even some insects. The advantage of natural dyes is eco-friendly, do not create any environmental problems at the stage of production and do not affect the health. Thus, the household textile industry in Thailand, especially Thai silk enterprises, has used natural dyes. However the wastewater should be removed completely before they are discharged into received water. The aim of this study was using the Poly aluminium chloride (PAC) and Ferric chloride ($FeCl_3$) as coagulants to removal natural dyes from textile wastewater of Bandu enterprises. The wastewater samples which used lac (*Laccifer Lacca Kerr.*) khe (*Maclura cochinchinensis Corner*) and golden shower pods (*Cassia fistula*) as natural dyes. The optimum conditions for each coagulation studies were set to measure the COD and color removal efficiencies. The color removal efficiency for PAC and $FeCl_3$ were 94.65 and 62.76 % for lac, 75.50 and 79.30 % for khe , 30.41 and 4.20 % for golden shower pods respectively. And the COD removal efficiency for PAC and $FeCl_3$ were 33.33 and 23.64 % for lac, 60.00 and 73.33 % for khe, 22.47 and 0.00 % for golden shower pods respectively. It can be concluded that coagulation-flocculation had effective in removal natural dyes both lac and khe but less effective for golden shower pods. The outcome of this study could be applied to treat wastewater from textile household industry.

Keywords: Natural dye; Coagulation process; Textile household industry; Lac; Khe; Golden shower pods

1. Introduction

Textile wastewater is a considerable source of environmental contamination due to its strong color, high pH and chemical oxygen demand (COD). The discharge of textile wastewater not only has diverse aesthetic effects, but such discharge can be carcinogenic, mutagenic and generally detrimental to our environment [2, 8]. The textile industry is moving towards the directions of the eco-friendly technologies [5]. Among those technologies, the applications of natural extracts including dyes have received much attention [10]. The natural dyes is interesting alternative dye because it can be derived from almost anything plants, minerals, and even some insects. The advantage of natural dyes is eco-friendly, do not create any environmental problems at the stage of production and do not affect the health [7]. Thus, the household textile industry in Thailand, especially Thai silk enterprises, has used natural dyes. However, it should be removed completely from wastewater before they are discharged into received water because it is contaminated with strong color and high COD. Although it does not affect to human health, but it will affect the scenery of the received water. Conventional treatment methods such as biological, anaerobic microbial degradation, adsorption, chemical oxidation, membrane separation process, electro-chemical are generally unsuccessful for the removal of wastewater containing dyes [8] and unsuitable for use in textile household industry because their treatment methods requires a lot of space to build a system, high cost and difficult to operate. Coagulation is widely used processes due to their relatively simple operation and low cost [11] thus it is interesting alternative wastewater system for the textile household industry. The wastewater from the textile household industry production process is not stable and has different characteristics because in dyeing process uses natural dyes, which are extract from the animal or plants to get the desired color. Therefore, it is important to use several types of coagulants to treat natural dye from wastewater. The aim of this study was using the Poly aluminium chloride (PAC) and Ferric chloride ($FeCl_3$) as coagulants to removal natural dyes from textile wastewater of household industry for support eco-friendly technologies and the development of clean products to cost-effective value added textile products [10]. The optimum conditions for each type of coagulant were finding and compare the performance of COD and color removal efficiencies. The outcome of this study could be applied to treat wastewater from textile household industry.

2. Experimental

The scope of this study was carried out to investigate wastewater treatment of textile household industry on the sub-district namely Pak Thong Chai, Pak Thong Chai district, this district is in the southern part of Nakhon Ratchasima Province, northeastern Thailand as shown in Fig.1. And it is a famous place to produce textile products especially Thai silk. There are many groups of household industry. The sampling sites had used natural dyes in process namely, Bandu enterprises. Wastewater samples which contain of natural dye were collected. The natural dyes which were used in this study, were extracted from lac *(Laccifer Lacca Kerr.)*, khe *(Maclura cochinchinensis Corner)* and Golden shower pods *(Cassia fistula)*.

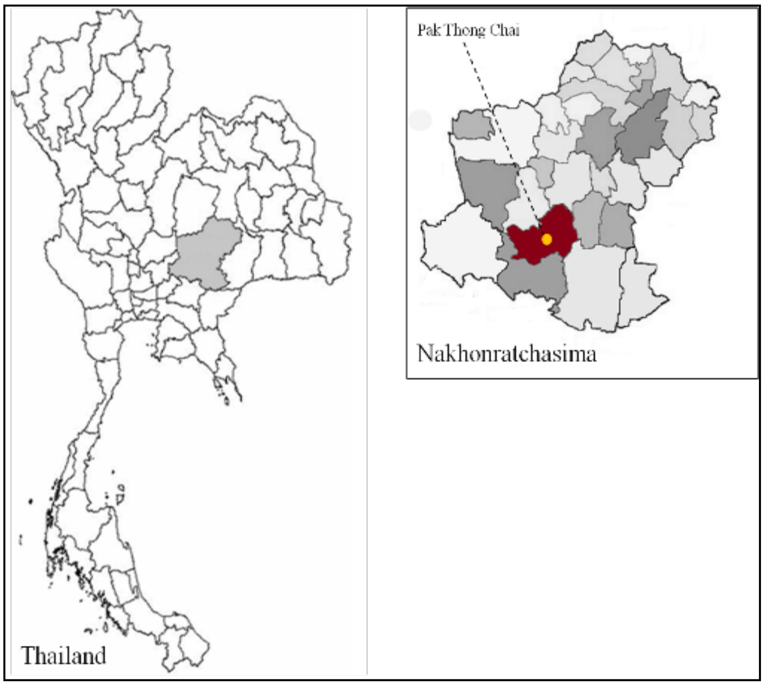


Fig. 1. The scope of this study namely Pak Thong Chai in the southern part of Nakhon Ratchasima Province.

2.1 The Characteristics of Wastewater and Analytical Methods

The study was carried out to collect wastewater which contained different natural dyes; lac, khe and golden shower pods from Bandu enterprises, the textile household industry. Wastewater samples were analyzed for various parameters and analytical methods as shown in Table 1.

2.2 The Coagulation-Flocculation Studies

The procedure of coagulation-flocculation studies are presented in Fig. 2.

2.2.1 The chemicals of coagulation-flocculation

The coagulation-flocculation studies were carried out using the jar test method to determine the optimum pH range, suitable concentration of Poly aluminium chloride($Al_2(OH)_3Cl_3$) or PAC (dosages 50 g/L) and Ferric chloride ($FeCl_3$) (dosages 20 g/L)as coagulants, suitable concentration of polymer (dosages 1 g/L) as coagulation aid for each sampling wastewater. The selected varied coagulant dosages were added to 1,000 ml of solution and it was stirred for a period of 1 min at 200 rpm after rapid mixing. It was followed by a further slow mixing of 15 min at 40 rpm, Color and COD of supernatant were measured after settling for 30 min.

Table 1 Parameter and analytical methods for wastewater

Parameter	**Unit**	**Analytical methods** (APHA et al.,2012)
Physical and Chemical quality		
pH	-	pH Meter
Color	Pt-Co	2120 C. Spectrophotometric Method
COD	mg/L	5220 C. Closed Reflux
TS	mg/L	2540 B. Total Solid Dried at 103-105ºC
TDS	mg/L	2540 C. Total Dissolve Solid Dried at 180ºC
TSS	mg/L	2540 D. Total Suspended Solids Dried at 180ºC
TVS	mg/L	2540 E. Fixed and Volatile Solid Dried at 550ºC
VSS	mg/L	2540 E. Fixed and Volatile Solid Dried at 550ºC
VDS	mg/L	2540 E. Fixed and Volatile Solid Dried at 550ºC

2.2.2 The performance of coagulation-flocculation process

The coagulation studies were carried out by using the optimum conditions which were found from the study of chemical of coagulation-flocculation. The COD and color removal efficiencies were calculated by using Eq. (1).

$$\% \ Removal\ Efficiency = \frac{C_o - C_e}{C_o} \times 100 \quad (1)$$

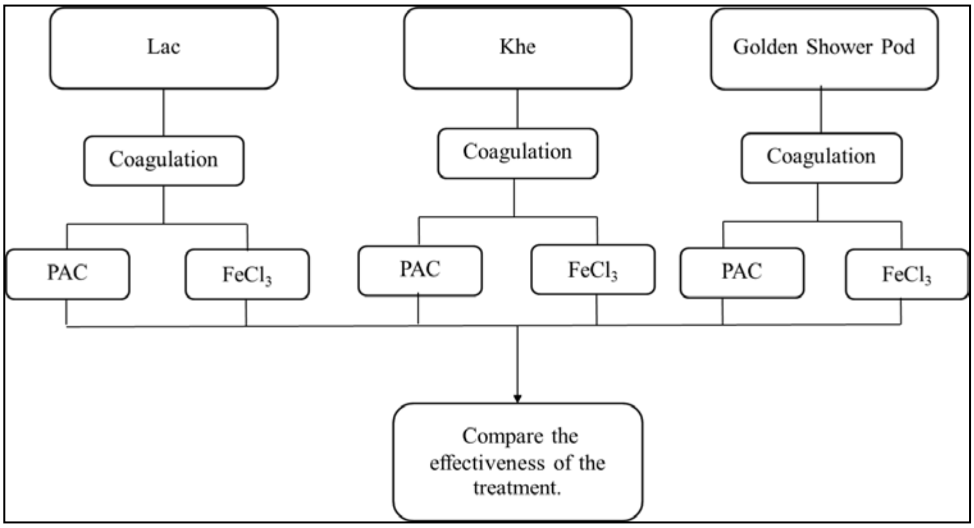


Fig. 2. The procedure of study.

3. Results and discussion

3.1 Characteristics of Textile Wastewater

As shown in Table 2, the results of raw wastewater characteristics were in the wide range of pH from 4.7-7.28, COD from 3,712-24,576 mg/l and color from 3,487.78-9,056.67 Pt-Co. These results indicated that the textile wastewater contained high of organic matter and color. These finding is the same as found in previous research of [4] and [2] The ratio of TDS/TS of all wastewater samples were in range of 0.72-0.96. These results indicated that textile wastewater contained dissolved solid more than 70% and the ratio of TVS/TS were in range of 0.73-0.80. These finding showed more than 70% of solid were organic matter. And as shown in Fig. 3 the characteristic of wastewater had ratio of VDS/TS were in range of 0.51-0.71. However, the ratio of FDS/TS were in range of 0.17-0.24. These indicated that the wastewater of natural dye contains mainly organic substances which were in soluble form. This might be because of the natural dyes which present in plants and animals are pigmentary molecules, that impart colour to the materials, they are organic matter [3].

Table 2 The characteristics of textile wastewater of Bandu enterprises.

Parameter	Unit	Natural dyes				
		Lac	Khe	Golden Shower Pods	Mean	± S.D.
pH	-	4.7	7.28	5.42	5.80	1.09
COD	mg/l	4,664.00	3,712.00	24,576.00	10,984.00	9,618.85
Color	Pt-Co	3,487.78	8,801.11	9,056.67	7,115.19	2,567.08
TS	mg/l	2,427.33	1,626.00	24,710.00	9,587.78	10,698.03
TSS	mg/l	686	74	5,630.00	2,130.00	2,487.45
TDS	mg/l	1,741.33	1,552.00	19,080.00	7,457.78	8,218.52
TVS	mg/l	1,930.00	1198	19,710.00	7,612.67	8,559.32
VSS	mg/l	686	44	4,930.00	1,886.67	2,167.86
VDS	mg/l	1,244.00	1,154.00	14,780.00	5,726.00	6,402.25
TDS/TS	-	0.7174	0.9545	0.7722	0.81	0.10
TVS/TS	-	0.7951	0.7368	0.7977	0.78	0.03
TSS/TS	-	0.2826	0.0455	0.2278	0.19	0.10
VDS/TS	-	0.5125	0.7097	0.5981	0.61	0.08
FDS/TS	-	0.2049	0.2448	0.174	0.21	0.03

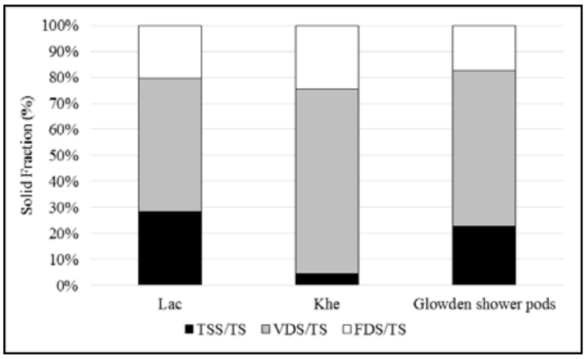
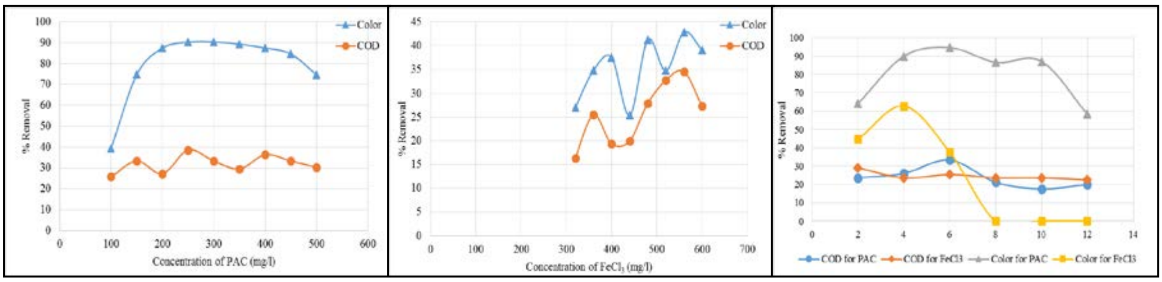


Fig. 3. The solid fraction of raw textile wastewater.

3.2 The Coagulation-flocculation Studies

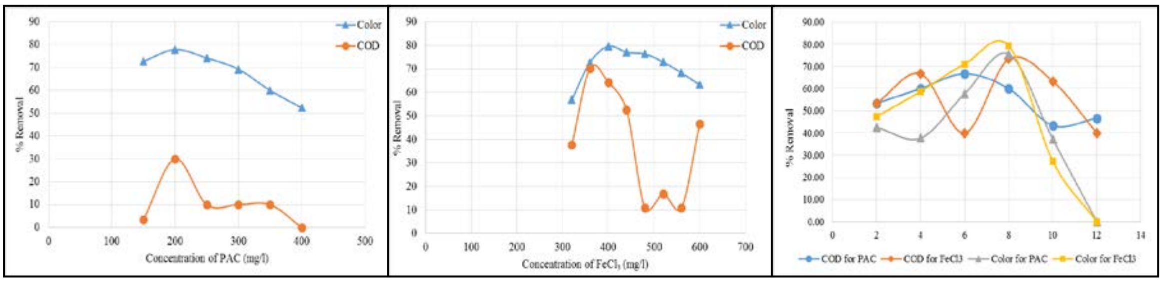
3.2.1 The chemicals of coagulation-flocculation

The jar test was used to determine the optimal conditions for Coagulation process including coagulant types of PAC and $FeCl_3$, amount of coagulant and polymer and pH. The results of chemical coagulation-flocculation for lac, khe and golden shower pods are shown in Fig.4, 5 and 6 respectively. And the result of optimum conditions for coagulation-flocculation were concluded in Table 3. The results of optimum pH for lac had found in the same range of previous research of [4]. The results showed $FeCl_3$ had optimum pH in range of 5-8. These finding was supported that ferric species usually are in range of the pH between 4-8 and completely are insoluble form. The hydrolysis of $FeCl_3$ generates ferric hydroxide particles. These particles agglomerate forming macroscopic flocs and are apparently readily adsorbed onto colloids [12].



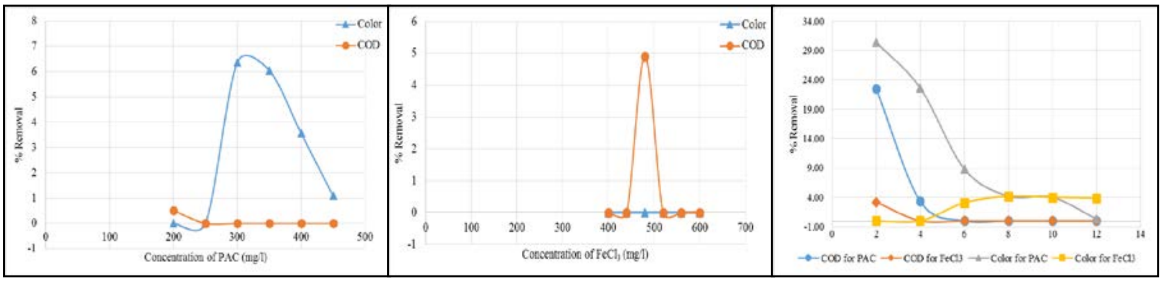
(a) (b) (c)

Fig. 4. The Results of coagulation studies to determine the optimum concentration of PAC (a) and $FeCl_3$ (b) and pH (c) for lac



(a) (b) (c)

Fig. 5. The Results of coagulation studies to determine the optimum concentration of PAC (a) and $FeCl_3$ (b) and pH (c) for khe



(a) (b) (c)

Fig. 6 The Results of coagulation studies to determine the optimum concentration of PAC (a) and $FeCl_3$ (b) and pH (c) for golden shower pods

Table 3 The conclusion of optimum conditions for coagulation process with PAC and $FeCl_3$ as coagulants.

Natural dyes	PAC			$FeCl_3$		
	Coagulant (mg/l)	Polymer (mg/l)	pH	Coagulant (mg/l)	Polymer (mg/l)	pH
Lac	250	0.7	6	560	0.6	5
Khe	200	0.6	8	400	1	8
Golden shower pods	300	0.7	2	480	0.8	8

3.3 The performance of coagulation process

The results of optimum conditions for coagulation process as summarized in Table 3 were carried out to treated raw wastewater from Bandu enterprises for measuring the performance of coagulation process. The wastewater samples before and after treated by coagulation process for using PAC and $FeCl_3$ as coagulant were analyzed COD and color. The removal efficiencies were calculated by using Eq. (1). The results of COD and color removal efficiencies were presented in Table 4 and Fig. 7. They showed the color removal efficiency for PAC and $FeCl_3$ were 94.65 and 62.76 % for lac, 75.50 and 79.30 % for khe, 30.41 and 4.20 % for Golden shower pods respectively. And the COD removal efficiency for PAC and $FeCl_3$ were 33.33 and 23.64 % for lac, 60.00 and 73.33 % for khe, 22.47 and 0.00 % for Golden shower pods respectively. In the studies using PAC and $FeCl_3$ as coagulant, it was found that all wastewater samples had color removal efficiency higher than COD. These finding are supported with the previous researches [6, 12].

Table 4 The results of COD and color removal efficiencies of coagulation process

Natural dyes	Using PAC as Coagulant		Using $FeCl_3$ as Coagulant		% Removal for PAC		% Removal for $FeCl_3$	
	COD (mg/l)	Color (Pt-Co)	COD (mg/l)	Color (Pt-Co)	COD	Color	COD	Color
Lac	3,109.33	186.67	3,561.60	1,298.89	33.33	94.65	23.64	62.76
Khe	1,484.80	2,156.67	989.87	1,822.22	60.00	75.50	73.33	79.30
Golden shower pods	19,054.93	6,302.22	24,746.67	8,676.67	22.47	30.41	0.00	4.20

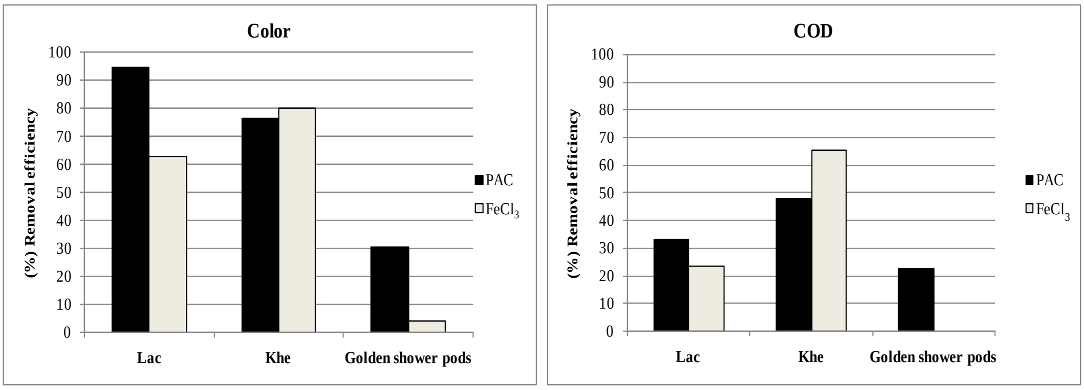


Fig. 7 The results of COD and color removal efficiencies for coagulation process of PAC and $FeCl_3$ as coagulants.

4. Conclusions

In conclusion, the results showed using ferric chloride as coagulant is suitable for treat natural dyes from khe better than PAC with the removal efficiency of COD and color removal are 77.33 and 79.30 %. Whereas using PAC as coagulant is suitable to treat natural dyes of lac and golden shower pods better than ferric chloride with removal efficiency of COD and color are 33.33 and 94.65% for lac and removal efficiency of COD and color are 22.47 and 30.41% for golden shower pods. The result of this study indicate that coagulation process can be used as a pre or post-treatment process to conventional treatment methods such as biological, anaerobic microbial degradation and adsorption for improvement of removal efficiency for textile household industry. The outcome of this study could be applied to treat wastewater from textile household industry.

Acknowledgement

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WR-P14

Experimental study for greywater treatment using green wall concept

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Abstract

Water is considered as an important natural resource as only 3% of world's total water is freshwater that is available for use. Wastewater that is generated in household or office buildings without any fecal contamination is known as greywater e.g. wastewater from showers, sinks, baths, washing machine or dishwashers etc. In domestic households the total contribution of greywater is about 65% of the total wastewater generated. This 65% of the greywater which is otherwise being wasted could be utilized for other non drinking purposes such as landscape, garden irrigation, flushing etc, thereby reducing the demand of potable water for non-potable purposes. Initially in this study a growing media of coirlite was tested for checking its efficiency in treating the greywater collected from domestic kitchen sink. The outlet and inlet sample collected were tested for pH, COD and BOD. The results showed about 50-55% reduction in the COD and BOD values also the pH value was reduced to normal range. This study also focused on testing the suitability of green wall plants for greywater irrigation. The plant species Rhoeo, Chlorophytum, Sprengeri, Red Ivy, Evergold Sedge and Fern were tested. The plant species Evergold Sedge and Fern performed better and sustained the greywater dosing. The combination of selected plants and growing media will help in the treatment of the greywater using Green wall concept.

Keywords: Blackwater; Greywater; Green wall; Growing media

1. Introduction

The water resources across the globe are deteriorating [9]. A report from United Nations stated that by 2025 around 2.7 billion people across the globe will face the problem of water shortage [9]. Large amount of water is being used for various domestic purposes and the percentage utilization in various countries is represented in Table 1. As per literature about 41%-91% of domestic water turns out to be greywater which is a huge quantity [2]. If this water could be treated and reused for gardening, irrigation and flushing etc, about 46% of water can be saved, as these activities doesn't require potable water quality [2].

In developed countries recycling and reusing greywater is a mostly preferred practice [11]. It is very much important to adopt a sustainable method of water recycling, because fresh water availability is a rising concern across the globe especially in countries like India which are rapidly developing. Wastewater which is generated in household or office buildings without any fecal contamination is called greywater [10]. Greywater can be classified into two main types i.e. highly polluted greywater and less polluted grey water. Highly polluted greywater mainly constitutes water from kitchen and laundry, while less polluted greywater excludes these two [12]. Less polluted greywater constitutes about 44-62% of the overall total greywater produced. Kitchen greywater consists of highly biodegradable organics and nutrients while laundry greywater has a high proportion of phosphates and heavy metals [1]. Kitchen waste due to its biodegradability necessitates the treatments such as grease traps as primary treatment and disinfection as a further treatment. Many researchers have combined both the grey waters for their studies. Greywater does not include fecal contamination which otherwise is designated as sewage or blackwater [3]. The organic loading is the basic difference between greywater and blackwater [6]. The most environment friendly and inexpensive solution for the greywater recycling technique is Green infrastructure [5]. As greywater reuse systems require lot of horizontal space, it becomes a major drawback of current greywater treatment technologies. It is difficult to find free space in current metropolitan cities especially like Mumbai so a pilot greywater treatment setup instead of separate setup for greywater treatment will be a boon. In this study, an effort is made to use Green wall concept for the grey water treatment.

Table 1 Overview of Domestic Water Usage in Different Countries [12]

Domestic water use (%)	Countries				
	India	**Australia**	**UK**	**Denmark**	**Oman**
Bathroom	39	26	28	36	47
Laundry	20	15	12	14	7
Kitchen	23	5	19	21	37
Toilet Flushing	15	34	35	23	4
Other (garden, cleaning)	3	20	6	6	5

1.1 Green Wall Concept

A wall which is partially or completely covered with greenery is known as green wall [4]. A growing medium of soil or substrate along with an integrated water delivery system is included in a green wall. Based on the growth media used, green walls can be categorized into green walls with loose media, mat media, sheet media and structural media. Based on the research studies it was found that green wall concept was more sustainable and eco-friendly method of greywater purification [4, 11]. Currently the green wall across the globe has a huge demand of water with potable quality for its existence, hence they are considered as major water consumers [11]. Modification in the green wall media is believed to be the most eco-friendly, sustainable and also the least expensive solution in treating greywater, which also reduces the demand of potable water usage [11]. It is necessary to develop such systems which reduce the usage of potable water. Consistency in high removal rates of pollutant can be achieved if the vegetated treatment systems are well maintained. The current green treatment technologies have the major limitation of significant horizontal space requirement which is difficult to find in densely populated urban areas [4]. The solution for this problem is the emerging green wall concept. Green walls are gaining popularity across the globe as they provide multiple benefits [11]. In urban environment where the plants reduce temperatures in buildings, green walls are often found. Insolation is the major cause of heat buildup in urban areas. Using green wall the plant surfaces results in transpiration and hence reduces the rise in temperature. The utilization of vertical walls helps in making proper space utilization in buildings and office complexes. Green walls could also function for its aesthetic beauty and art in the urban environment [4]. Remediation of poor internal and external air quality can also be acknowledged using green wall concept.

Fig. 1. Green wall Model [5]

2. Experimental

The methodology adopted here consists of three different stages. Initial stage involves testing the efficiency of the growing media in treating greywater. Second stage focused on selecting a suitable greywater friendly plant. The third stage involves the testing of greywater with growing media along with selected plants. In this paper only the results of the first two stages are discussed. The methodology presented in Fig. 2 is adopted for selecting a suitable greywater friendly plant which is grown in the coirlite media.

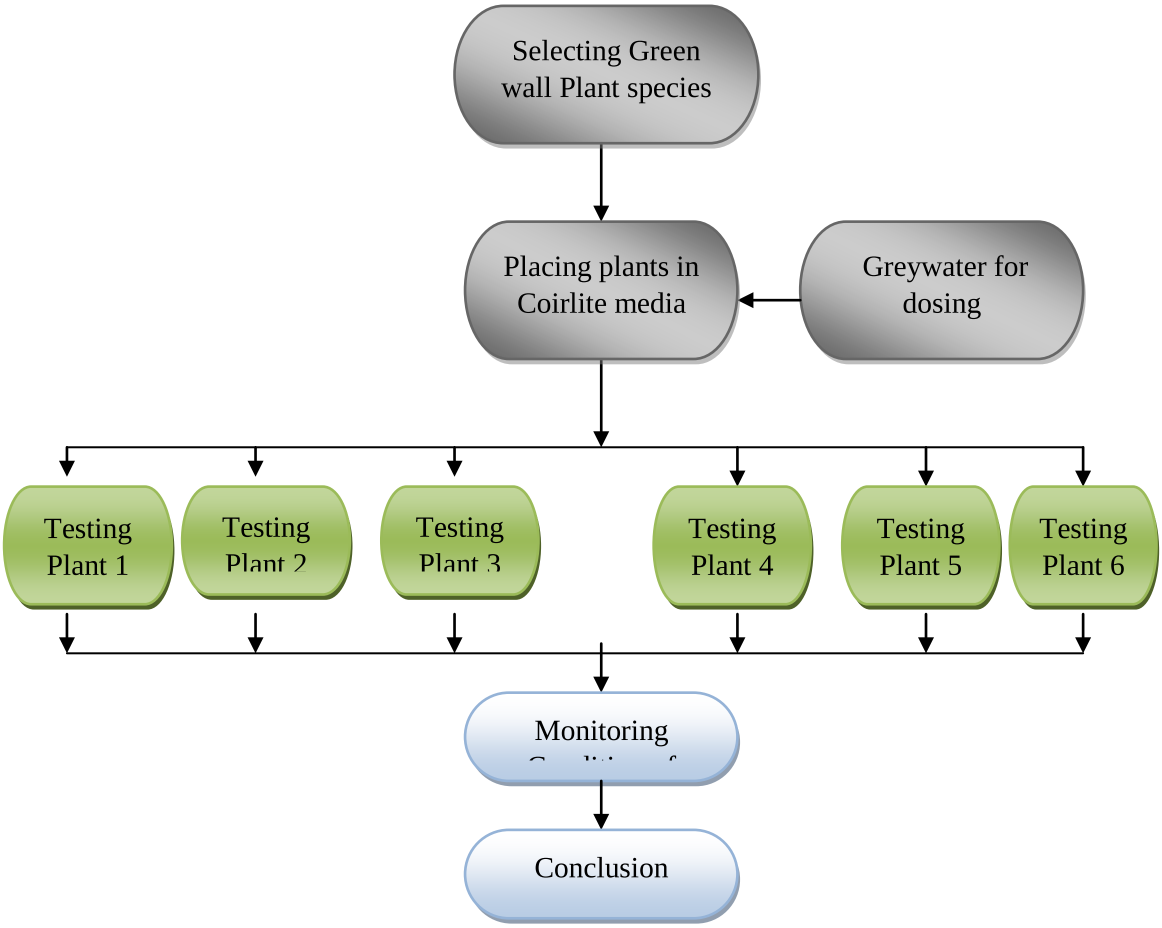

Fig. 2. Methodology for the selection of green wall plant species

3. Results and discussion

The first stage of investigation of testing the efficiency of the growing media using coirlite in treating greywater yielded the following results Table 2. The testing parameters included in the study were pH, COD (Chemical Oxygen Demand) and BOD (Biochemical Oxygen Demand). It is observed that around 50% reduction was observed in BOD and COD when grey water is applied through the growing media (coirlite).

Table 2 Test Results of Growing Media

Parameters Tested	Inlet (mg/l)	Outlet (mg/l)
pH	12.3	7.5
COD	290	136
BOD	125	61

4. Conclusions

The test results conclude that, the growing media of coirlite was found to be efficient in reducing the tested parameters. The media as such doesn't constitute a green wall, hence to reach to a conclusion of testing efficiency of entire green wall the media along with the plants and entire green wall setup needs to be tested and analyzed. As mentioned in methodology, the analysis of stage 3 results is in progress.

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