Reuse of Domestic Wastewater by Membrane Technologies towards Sustainable City Development

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Abstract. Supply of sustainable clean water is an activity that must be carried out towards smart cities. Nevertheless, the availability of water is decreasing both in quality and quantity. Wastewater including domestic wastewater is a potential source that can be reused as clean water supply dealing with water scarcity. This is due to domestic wastewater is produced continuously in large amount. In addition, reuse can reduce the total cost of handling wastewater. One modern technology that can be used for domestic wastewater treatment is membrane technology. Characteristics, various types, advantages, disadvantages, and challenges of membrane technology for domestic wastewater were discussed. This paper presents a review of domestic wastewater reuse by using membrane technology. More specifically this paper discusses domestic wastewater.

1. Introduction
Nowadays water is becoming scarcer in parts of some industrialized countries and also in developing countries. By 2025, it is estimated that the world will use around 30% more water than in 2000 [1]. One potential approach to overcome water scarcity is the use of water recycling technology to recover fresh water from wastewater. It should be noted that even wastewater more than 90% is water.

All water users produce wastewater with waterborne sanitation systems [2]. The main sources of water pollution are domestic wastewater [3]. On the one hand, domestic wastewater contains pathogens that can cause disease spread when it is not managed properly [2]. On the other hand, untreated domestic wastewater could generate a problem of environmental deterioration in rivers, lakes and other public water bodies [4].

Wastewater treatment technologies are applied to meet the highest levels of water quality required by industry or environment. However, the effluents from municipal wastewater treatment plant often fail to meet the national standard for effluent quality [5]. In recent decades, membrane technology has
been widely used in wastewater treatment [6-7]. Many advantages of membrane technology are it is used small land, without chemicals, produce high-quality effluents, easy operation [8]. Nevertheless, few review studies discuss the use of membrane technologies for recovering domestic wastewater treatment. Therefore, this article aims to reviews various types of membrane technology for domestic wastewater treatment along with its advantages and disadvantages.

2. Result and Discussion

2.1 Domestic Wastewater Characteristics

Domestic wastewater is defined as wastewater from household activities including bathing, washing, and toilet, originating from settlements or other sources, i.e., restaurants, lavatory, kitchen, offices, commercial establishments, hotels, apartments, dormitories, hospitals, and industry [2]. Domestic wastewater effluent becomes the main contributor to diverse water pollution [9]. Even today, it is still disposed to drainage, river, or lake without proper treatment before [10]. In fact, domestic wastewater contains pathogens that are harmful to human health. In the year 2001, a study obtained from the Ministry of Health in Oman indicated that there were 728 deaths caused by water contamination [11-12]. Therefore, based on this fact wastewater treatment is urgently needed before discharging to the environment [13-14].

The availability of domestic wastewater will always be abundant as long as there are humans in this world. The amount and type of wastewater produced in households are influenced by the behavior, lifestyle, and standard of living of the inhabitants as well as the technical and juridical framework by which people are surrounded [15]. The quantity of wastewater varied over time, and it was ranging from 39.61 to 49.93 L/p/d, while the quantity of black water and gray water were 20.38 L/p/d and 23.26 L/p/d respectively [16].

More specifically domestic wastewater contains high concentrations of nutrient and organic matter [16]. The characteristics of domestic wastewater are specifically represented by some physicochemical parameters, such as biochemical oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solids (TDS), pH, total suspended solids (TSS), dissolved oxygen (DO), total nitrogen (TN), phosphate, and potassium [17]. The other minority substances of domestic wastewater are toxic material, metal, bacteria, and detergent [18-19]. Some domestic wastewater characteristics are shown in Table 1.

| No | Location                     | COD     | BOD     | TSS     | Ammonia  | Orthophosphate | Nitrite          | Reference |
|----|------------------------------|---------|---------|---------|----------|----------------|------------------|-----------|
| 1  | Brantas River                | -       | -       | -       | 0.13-1.4 | -              | 0.102-0.423     | [20]      |
| 2  | WWTP Malang                  | 148-3,921 | 84-1,860 | 18-50   | -        | -              |                  | [20]      |
| 3  | Home Industry of tofu, Tahu Lampaseh Aceh | 6,500  | 1,177   | 3,575.5 | 1.81     | -              |                  | [13]      |
| 4  | Home Industry of tofu, Tahu Sumedang | 5,000  | 3,810.2 | 129.3   | 95.5     | -              |                  | [13]      |
| 5  | Genteng, Surabaya            | 15      | 8       | 38.91   | 0.44     | -              |                  | [21]      |
| 6  | Tegalari, Surabaya           | -       | -       | 7.36    | 1.86     | 0.12           |                  | [21]      |
| 7  | Dukuh Pakis, Surabaya        | -       | -       | 35.79   | 1.61     | 0.052          |                  | [21]      |
| 8  | Office Building              | 160-220 | -       | -       | 3.8-6.97 | -              |                  | [4]       |
| 9  | Household in Bandung         | 442.07  | 269     | 115     | 5.624    | -              |                  | [22]      |
| 10 | Household                    | -       | 258     | 63      | 5.9      | 50             |                  | [23]      |
Membrane technologies have been implemented in many water and wastewater treatment plants. The following sectors describe the application of membrane technologies for domestic wastewater treatments.

- **Combination of Biophysical Membrane.**
  Physical processes achieve substantial clarification of water. As such, they are reasonably effective in decreasing the organic pollutant load of grey water before being reused. Simple filtration based on fibrous or granular depth filters presents no absolute barrier to suspended matter. Physical methods first developed from deep sand filter to membrane filtration [24]. Therefore, biological treatment is required to remove biodegradable material especially for systems that deal with large distribution networks such as hotels or community-based recycling schemes. Biological and physical treatment are combined into a membrane bioreactor (MBR) which arrange to submerge and side stream to guarantee a reduction in organic contamination [25].

- **Anaerobic Membrane Bioreactor**
  Anaerobic membrane bioreactor (AnMBR) is a combination of membrane modules with anaerobic bioreactor. The AnMBR has the potential to be a more sustainable wastewater treatment technology than conventional processes because of its low requirements for energy and nutrients, low sludge
production and the potential to generate methane of the anaerobic process [26]. Membrane fouling in AnMBRs has been found to be affected by the mixed liquor composition that consists of a complex mixture of materials in suspended and colloidal forms. The suspended materials, as measured by TSS, have been identified as a key factor in membrane fouling [27-28]. Hence, it could be expected that the cake layer fouling might be mitigated by reducing the concentrations of TSS. The materials that are present in a colloidal form, as represented by colloidal COD, have also been reported to be significant contributors to fouling in MBRs and AnMBRs [24, 27, 29].

- **Aerobic Membrane Bioreactors (Ae-MBRs)**

  Aerobic membrane bioreactors (Ae-MBRs) are more effective to the conventional process for wastewater treatment due to good biochemical oxygen demand (BOD) removal and the lack of a need for a secondary clarifier. The advantages of Ae-MBRs include the ability to obtain a high mixed liquor suspended solids (MLSS) concentration in the reactor [30]. Stability of performance during fluctuations in flow and organic loading, low excess sludge production, and relatively short hydraulic retention times [31-32]. However, a major disadvantage of Ae-MBRs should be conducted frequent membrane cleaning to avoid excessive membrane fouling [32]. The energy demands of all aeration systems, including Ae-MBRs and activated sludge, are also high compared to those needed for anaerobic treatment techniques [33].

- **Anaerobic fluidized bed membrane bioreactor (AFMBR)**

  The AFMBR has primarily been used as the secondary treatment reactor to treat the effluent from several different types. The effluent can contain high concentrations of dissolved methane which must be removed before discharge to avoid release to the atmosphere [34].

- **Anaerobic Dynamic Membrane Bioreactor (An-DMBR)**

  The An-DMBR is combination of an anaerobic treatment process and membrane filtration technology in a flat sheet membrane. Under the gravity-driven mode, the flux and effluent turbidity in AnDMBRs generally present a multistage variation tendency (rapid initial decline followed by a slow decrease) [35]. The control of DM layer fouling was noticed to be the most important issue, followed the toxicity effect caused by potential inhibition substances (such as high concentrations of ammonia and VFAs) [36].

- **Ultrafiltration combined Ozone**

  This application is for domestic laundry wastewater reclamation and reuse. Ozone was incorporated into an ultra filtration system to produce higher quality reclaimed water from domestic laundry wastewater [37]. The amount of methylene blue active substance (MBAS), builder and other oily substances in the wastewater could cause the COD concentration, and depending on laundry working mode, the wastewater quality was varied. In this study, synthetic and domestic laundry wastewater was used. Bhattacharyya et al., (1973) [38] reported that normal laundry wastewater consisted of surfactant, carboxyl methyl cellulose (CMC), vegetable oil, Ca, P, SiO₂, bleach and soil. Permeate flux could be effectively maintained by ozonation. Ozone was estimated to be effective to control the membrane fouling by the increased organic degradation.

- **Reverse Osmosis (RO)**

  Application of RO membrane is for treatment of municipal wastewater. Ultrafiltration (UF) and microfiltration (MF) membranes can produce feed water of significantly better quality than the conventional pre-treatment process, which consists of lime clarification, followed by media and cartridge filtration [39]. Membrane fouling encountered in wastewater reclamation systems is related to the quality of the feed water and the nature of membrane polymer, designated as composite fouling [40]. By applying UF membrane as pre-treatment, fouling rate is reduced. The major effect of applying membrane pre-treatment is a reduction of the concentration of particulate matter in the feed water. Therefore a reduction in the fouling rate can be attributed in this case to the reduction of cake layer formation on the membrane surface or its higher permeability. MF and UF membrane pre-treatment has little effect on concentration on organic matter in the feed water. Natural organic matter has a high affinity to hydrophobic membrane material [41, 42, 43]. Monnot et al., (2017) [44] tried to
use NF and RO as a complementary treatment after MBR to treat domestic waste separated from urine. Experiments were carried out on a laboratory scale with synthetic feed solutions containing representative natural urine organic matter. NF and RO can eliminate more than 95% of total organic carbon which consists mainly of humic acid and fulvic acid. Other than that, NF can only reduce conductivity by less than 45% while RO removes more than 80% of ions which will make reuse of water becomes feasible.

3. Conclusion

Water scarcity is a potential for the development of the smart city. This is due to not only by decreasing the quality of water source but also decreasing the quality of water source. Therefore, reuse of domestic wastewater toward the smart city is very promising. Membrane technologies either as a single process nor combine with the conventional process are promising for this case.

4. References

[1] Mizuki F, Mikawa K and Kurisu H 2012 Intelligent Water System for Smart Cities Hitachi Review 61(3) 147
[2] Asian Development Bank 2017 Urban wastewater management in Indonesia: Key Principles and Drafting Local Regulations ISBN 978-92-9257-965-4 (Print), 978-92-9257-966-1 (e-ISBN)
[3] Mungkasa O and Wahyudi D 2010 Portrait of Indonesia's sanitation development, Jakarta.
[4] Vandith V A, Setiyawan A S, Soewondo P and Putri D W 2018 The Characteristics of Domestic Wastewater from Office Buildings in Bandung, West Java, Indonesia. indones.j.urban.environ.technol., 1(2) 199-214
[5] Wang C, Yu X, Lv H and Yang J 2013 Nitrogen and phosphorus removal from municipal wastewater by the green alga Chlorella sp. J. Environ Biol, 34(2),421-425
[6] Hidalgo A M, León G, Gómez M, Murcia M D, Gómez E and Gómez J L 2013 Application of the Spiegler–Kedem–Kachalsky model to the removal of 4-chlorophenol by different nanofiltration membranes Desalination 315 70-75
[7] Song W, Ravindran V, Koel B E and Pirbazari M 2004 Nanofiltration of natural organic matter with H2O2/UV pretreatment: fouling mitigation and membrane surface characterization J Membrane Sci, 241(1) 143-160
[8] Gao W, Liang H, Ma J, Han M, Chen Z L, Han Z S and Li G B 2011 Membrane fouling control in ultrafiltration technology for drinking water production: a review Desalination 272(1-3) 1-8
[9] Wijaya I M W and Soejidono E S 2018 Domestic Wastewater In Indonesia: Challenge In The Future Related To Nitrogen Content International Journal 15(47) 32-41
[10] Braga J K and Varesche M B A 2014 Commercial laundry water characterization Am J Anal Chem 5(01) 8
[11] Al-Wahaibi S 2004 A presentation on the environmental factors and their influence on human’s health. Director of Environmental Health and Malaria Eradication, Ministry of Health.
[12] Baawain M S, Al-Omairi A and Choudri B S 2014 Characterization of domestic wastewater treatment in Oman from three different regions and current implications of treated effluents Environ monit assess 186(5) 2701-2716
[13] Faisal M, Mulana F, Gani A and Daimon H 2015 Physical and chemical properties of wastewater discharged from tofu industries in Banda Aceh city, Indonesia RJPBCS 6(4) 1053-1058
[14] Lasut M T, Jensen K R and Shivakoti G 2008 Analysis of constraints and potentials for wastewater management in the coastal city of Manado, North Sulawesi, Indonesia J Environ Manage 88(4) 1141-1150
[15] Henze M, Harremoes P, la Cour Jansen J and Arvin E 2001 Wastewater treatment: biological
and chemical processes Springer Science & Business Media

[16] Wijaya I M W and Soedjono E S 2018 Physicochemical Characteristic of Municipal Wastewater in Tropical Area: Case Study of Surabaya City, Indonesia IOP Conference Series: Earth and Environmental Science 135(1) 012018

[17] Mohamed R M S R, Al-Gheethi A, Buyong R, Hashim N H, Matias-Peralta H M and Mohd-Kassim A H 2018 Nutrient Recovery from Domestic Effluent using an Indigenous Strain of Scenedesmus sp. CLEAN-Soil, Air, Water, 1800204

[18] Akpor O B and Muchie M 2011 Environmental and public health implications of wastewater quality African J Biotechnol 10(13):2379–87

[19] Sun Y, Chen Z, Wu G, Wu Q, Zhang F, Niu Z and Hu H Y 2016 Characteristics of water quality of municipal wastewater treatment plants in China: implications for resources utilization and management J Clean Prod 131 1-9

[20] Hendriarianti E and Karnaningroem N 2016 Evaluation of Communal Wastewater Treatment Plant Operating Anaerobic Baffled Reactor And Biofilter Waste Technology 4(1) 7-12

[21] Wijaya I M W, Soedjono E S and Fitriani N 2017 Development of anaerobic ammonium oxidation (anammox) for biological nitrogen removal in domestic wastewater treatment (Case study: Surabaya City, Indonesia) AIP Conference Proceedings 1903(1) 040013

[22] Firdayati M, Indiyani A, Prihandrijanti M and Otterpohl R 2015 Greywater In Indonesia: Characteristic And Treatment Systems Jurnal Teknik Lingkungan 21(2) 98-114

[23] Fajri J A, Fujisawa T, Trianda Y, Ishiguro Y, Cui G, Li F and Yamada T 2018 Effect of Aeration Rates on Removals of Organic Carbon and Nitrogen in Small Onsite Wastewater Treatment System (Johkasou) MATEC Web of Conferences 147 04008

[24] Judd S J and Till S W 2000 Bacteria breakthrough in cross-flow microfiltration of sewage Desalination (in press).

[25] Kishino H, Ishida H, Iwabu H and Nakano I 1996 Domestic wastewater reuse using a submerged membrane bioreactor Desalination 106(1-3) 115-119

[26] Metcalf and Eddy Inc 2003 Wastewater Engineering: Treatment and Reuse, fourth ed. McGraw-Hill, New York

[27] Liao B Q, Kraemer J T and Bagley D M 2006 Anaerobic membrane bioreactors: applications and research directions Environ Sci Technol 36(6) 489-530

[28] Huang Z, Ong S L and Ng H Y 2011 Submerged anaerobic membrane bioreactor for low-strength wastewater treatment: effect of HRT and SRT on treatment performance and membrane fouling Water Research 45(2) 705-713

[29] Dagnew M, Parker W and Seto P 2012 Anaerobic membrane bioreactors for treating waste activated sludge: Short-term membrane fouling characterization and control tests J Membrane Sci 421 103-110

[30] Meng F, Chae S R, Drews A, Kraume M, Shin H S and Yang F 2009 Recent advances in membrane bioreactors (MBRs): membrane fouling and membrane material Water Research 43(6) 1489-1512

[31] Chang I S, Le Clech P, Jefferson B and Judd S 2002 Membrane fouling in membrane bioreactors for wastewater treatment J Environ Eng 128(11) 1018-1029

[32] Kimura K, Yamato N, Yamamura H and Watanabe Y 2005 Membrane fouling in pilot-scale membrane bioreactors (MBRs) treating municipal wastewater Environ Sci Technol 39(16) 6293-6299

[33] Fan B, Huang X 2002 Characteristics of a self-forming dynamic membrane coupled with a bioreactor for municipal wastewater treatment Environ. Sci. Technol 36 5245–5251

[34] Bae J, Shin C, Lee E, Kim J and McCarty P L 2014 Anaerobic treatment of low-strength wastewater: a comparison between single and staged anaerobic fluidized bed membrane bioreactors Bioresource Technol 165 75-80

[35] Hu Y, Wang X C, Ngo H H, Sun Q and Yang Y 2018 Anaerobic dynamic membrane bioreactor
(AnDMBR) for wastewater treatment: A review Bioresource technol 247 1107-1118
[36] Watanabea R, Qiaoa W, Nortond M, Wakaharae S and Lia Y Y 2014 Recent developments in municipal wastewater treatment using anaerobic membrane bioreactor: a review Journal of Water Sustainability 4(2) 101-122
[37] Seo G T, Lee T S, Moon B H and Lim J H 2001 Ultrafiltration combined with ozone for domestic laundry wastewater reclamation and reuse Water Sci Technol: Water Supply 1(5-6) 387-392
[38] Bhattacharyya D, Grieves R B, Schomp W G and Bewley J L 1973 Membrane Ultrafiltration of a Nonionic Surfactant J. AIChE 19 766–774
[39] Wilf M and Alt S 2000 Application of low fouling RO membrane elements for reclamation of municipal wastewater Desalination,132(1-3) 11-19
[40] Winters H 1998 Proc., IDA Conference, Madrid
[41] Devitt E C, and Weisner M R 1998 Proc., ADA Conference, Williamsburg, VA. 132
[42] Zhu X and Elimelech M 1995 Fouling of reverse osmosis membranes by aluminum oxide colloids J Environ Eng 121(12) 884-892
[43] Hong S and Elimelech M 1966 Proc., ADA Conference, Monterey, CA, 717
[44] Monnot M, Nguyen B, Lesage G and Heran M 2017 Performance of nanofiltration and reverse osmosis after membrane bioreactor for urban source-separated urine treatment and water reuse Desalin Water Treat 95 18-33

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