Development of Integrated Decentralized Sanitation System using Aerobic Membrane Bioreactor

Melissa Montalbo [1)], S.M.S.M.K. Samarakoon [1)], *C. Visvanathan[1)], Kensuke Fukushi,[2)] and KazuoYamamoto[2)]

[1)] Environmental Engineering and Management Program, Asian Institute of Technology,
P.O.Box 4, Klong Luang, Pathumthani 12120, Thailand email: visu@ait.ac.th
[2)]Environmental Science Center, University of Tokyo,
7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, Japan
*Corresponding author

Abstract

Inspired from the concept of ecosanitation, an integrated decentralized sanitation system using aerobic membrane bioreactor is developed. This system is a holistic management approach that aims to develop a method to treat domestic wastewater and solid waste that would treat solid waste and reclaim wastewater effluent in a decentralized manner. The method includes an incorporation of the domestic wastewater and the liquid fraction of kitchen waste that contains the organic components, directing it in an aerobic membrane bioreactor (MBR) treatment module. As for the solid portion of the waste, it will be stored in a holding tank which is to be collected and pumped into an anaerobic digester within the village or the community. To further investigate its feasibility, a study was conducted in an aerobic membrane bioreactor with the objective of determining the performance in terms of effluent quality at HRT of 2, 4 and 6 hours. The MBR obtained a 98% COD removal and 95% TKN removal efficiency, throughout the experiment and in HRT of 2 hours, respectively. Taken as a whole, the proposed scheme is considered a good option for water sanitation and environmental conservation.

Keywords: decentralized sanitation, domestic wastewater, membrane bioreactor, water reuse

1. Introduction

Most rural areas in Asian countries are suffering from lack of proper sanitation. As a result of this poor management, domestic wastewater becomes a threat to public health and the environment. In order to facilitate an effective wastewater treatment design, it is necessary to consider the characteristics and sources of the wastewater. The wastewater generated from toilet is termed as black water and contributes a significant amount of organics, nitrogen and phosphorus. Black water can be further classified as yellow water (urine) and brown water (human feces). Grey water consists of water from clothes washing, bathing and dishwashing, which is relatively less polluted.

Principal technologies for domestic wastewater treatment can be classified as either on-site sanitation (decentralized) or off-site (centralized) sanitation systems. The off-site sanitation approach is usually found in rich countries that can afford constructions of huge pipelines, organized operation and maintenance, lots of manpower, and effectively vast wastewater treatment plants. However, this system is not possible in low-income or developing countries.

Thus, on-site treatment sanitations have been the alternative. Decentralized systems have been applied in rural and urban areas for several decades both in developed and developing countries because of its low investment costs and simplicity in operation and maintenance. The most common form of on-site wastewater treatment is the septic tank.

Solid Waste Scenario

The solid waste produced per capita often varies in different countries depending on its geographical location, climatic factor, economic status, and consumption pattern. In general, the primary fraction of the waste generated is dominated by biodegradable portion such as the food waste. Garbage collectors collect these wastes and it either ends up in an unsanitary dumpsite or in some other non-engineered landfill. This practice does not only pollute the environment due to biogas and leachate production in the landfills and dumpsites, but also affect the health of the people living near the area.

Integrated Decentralized Sanitation – Aerobic MBR System

Ecological sanitation is a conceptual shift in the relationship between people and the environment with its objective to protect human health and the environment, while reducing the use of water in sanitation systems and recycling nutrients to help reduce the need for artificial fertilizers in agriculture (EcoSanRes, 2004). Motivated from the success of ecosanitation, an integrated decentralized sanitation system using aerobic membrane bioreactor is developed. This system is a unique management plan that intends to not only sanitize the household, but also reclaim the wastewater for secondary reuse and treat the solid waste in a decentralized manner, rather than dumping in some barren land or non-engineered landfill. The scheme described in figure 1 incorporates the domestic wastewater and liquid portion of the kitchen waste, which was extracted, using a grinder, mixed together to make a combined wastewater. This combined wastewater will be fed into the proposed aerobic membrane bioreactor treatment module (Fig. 2). MBR was chosen as the proposed treatment as it has coupled the 3 major processes of wastewater treatment: sedimentation, biological reaction, and filtration. It also provides higher wastewater degradation performance in terms of quality effluent compared to conventional septic tanks. Since it is a compact system, therefore it is very convenient to be applied in residential households.

Generally, 70% of kitchen waste can be considered as organic in nature. If these kitchen wastes are sorted within the homes, rather than mixed with other household solid waste like plastic and paper, it may become a valuable component in the biological process of degradation of wastewater. Thus, the integrated decentralized sanitation system incorporated the liquid portion of the kitchen waste into the domestic wastewater to increase its organic content and thereby increase the MBR degradation performance. In this way, about 40-50% of the municipal solid waste stream gets reduced, enabling better options for recycle and disposal.

Anaerobic digestion of solid waste has been found to become a major focus in waste management throughout the world. It does not only eliminate the waste but also produce biogas, which could be a source of energy when converted to power. In this study, the residue of the kitchen waste after grinding will be mixed with the solid part of the black water in the holding tank. In addition, sludge withdrawn from the membrane bioreactor will also be disposed into the holding tank. The holding tank, designed to create a temporary storage for the biodegradable solid waste in the household, will later be diverted into the anaerobic digester available in the community, as clearly expressed in figure 1. As installing an individual anaerobic digester per household will not be economical, thus it is practical to operate in a centralized manner or in clusters of households.

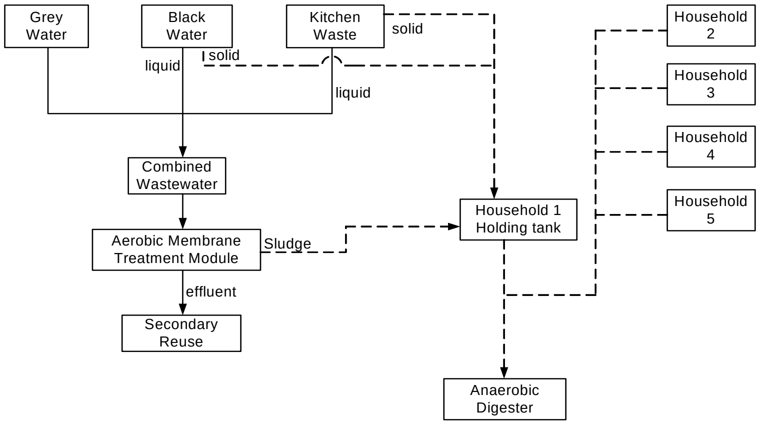

Figure 1 Integrated decentralized sanitation using aerobic MBR system

2. Experimental Study

In order to further the applicability of the integrated decentralized sanitation concept, an experimental study was conducted in laboratory scale. The objective of the study is to investigate the performance of MBR in terms of effluent quality at different operating conditions. Biofouling, which is the main constraint in most MBR studies, was also considered. The membrane used in the study was supplied was Mitsubishi Rayon, Japan with a pore size of 0.4 µm and surface area of 0.2 m^2.

The daily domestic wastewater and kitchen waste generation were estimated in a real household prior to the experiment. From these data, synthetic wastewater was prepared to represent domestic wastewater with partial urine separation. The synthetic wastewater compositions were as follows: glucose, 272 mg/L; soya protein, 290 mg/L; NH_4Cl, 97.1 mg/L; KH_2PO_4, 26.1 mg/L; $CaCl_2$, 10 mg/L; $MgSO_4 \bullet 7H_2O$, 10 mg/L; $FeCl_3$, 3 mg/L; $NaHCO_3$, 200 mg/L. Kitchen waste was collected from the cafeteria of Asian Institute of Technology (AIT), Thailand, then grinded to extract the liquid portion and mixed into the synthetic wastewater. The seed sludge for the MBR was collected from Thammasat University wastewater treatment plant, Pathumthani, Thailand. It was then acclimatize to the lab scale MBR treatment system, which is presented in figure 2. The design is composed of 2 compartments: anoxic tank and membrane bioreactor. The anoxic compartment is included in the system to achieve denitrification of the wastewater, while the membrane bioreactor compartment will complete the degradation of the organic compounds.

Investigations were done in 3 hydraulic retention times (HRT) of 6, 4 and 2 hours at permeate flux of 0.125, 0.187, 0.360 m^3/m^2-day, respectively. In the 3 HRT conditions, mixed liquor suspended solids (MLSS) and COD were maintained between 9,000-10,000 mg/L and 650 mg/L, respectively.

3. Results and Discussion

Performance of aerobic MBR

COD Removal

Figure 3 reports the variation of influent and effluent COD and its percentage removal efficiency. It could be observed that the influent COD varies largely because of the different compositions of kitchen waste per batch fed into the reactor. COD removal during the first run was fluctuating due to the changes made in the operating condition. In the middle of the first run, partial urine separation was done to increase the nitrogen content of the influent and supply enough nitrogen for the denitrifier's growth. After the stabilization of the microorganism during the first run, the COD removal was maintained at 98% with MLSS concentration maintained at 10,000 mg/L.

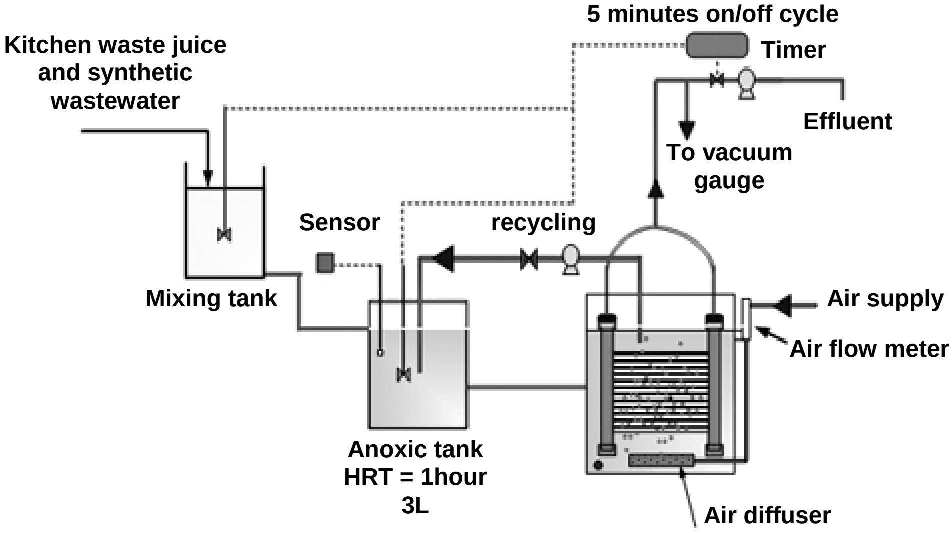

Figure 2 Continuous aerobic MBR experimental set up

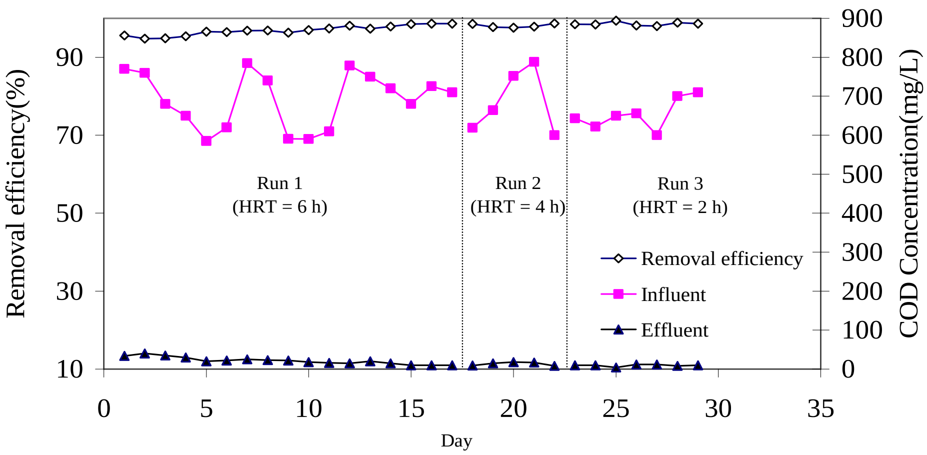

Figure 3 Variation of influent and effluent COD and its removal efficiency

Nitrogen Removal

The nitrogen removal was measured through the TKN concentrations in the influent and effluent. It is once again noticed that the influent concentration varies greatly due to the varying concentration of the kitchen waste juice. As shown in figure 4, the TKN removal efficiency was at 91%, 95% and 86% in run 1, 2, and 3, respectively. With run 3 showing the lowest removal efficiency, it could be stated that the operating condition at HRT of 2 hours was not favorable for the nitrogen removal.

Phosphorus Removal

The phosphorus removal efficiency was highest in run 2 at 92.6%, closely followed by run 3 at 90.6% and finally by run 1 at 87.4%. Due to the stable removal of phosphorus, results obtained at various HRTs could be concluded that the major pathway of phosphorus removal is the microbial assimilation. However, it might be necessary to investigate further by doing detailed phosphorus analysis of the sludge.

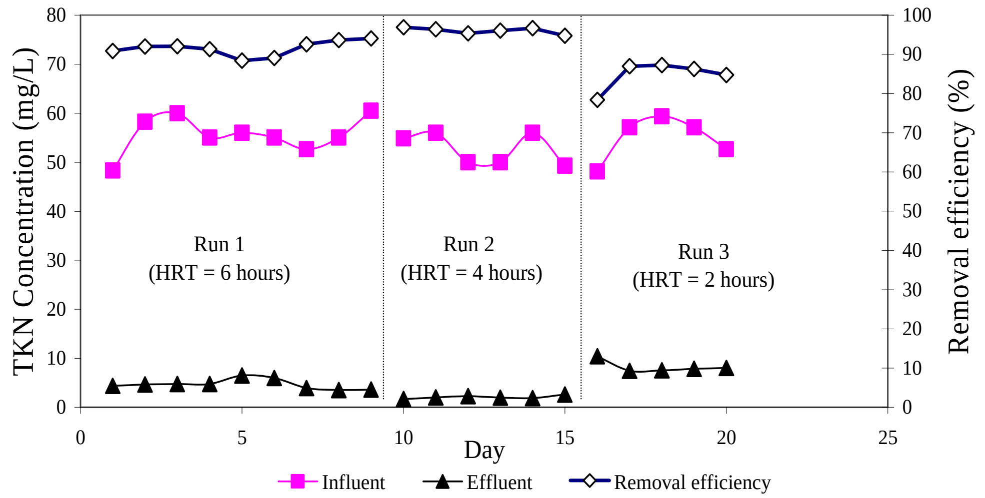

Figure 4 Variation of influent and effluent TKN and its removal efficiency

Comparison with Reuse Standards

Reclaimed water applications range from pasture irrigation to augmentation of potable water supplies. Water reclamation and reuse criteria are principally directed to health protection and may vary from country to country. In this study, various text and publications have been the sources of effluent criteria as enlisted in Table 1. In terms of COD removal, MBR has performed well, giving results at different experimental runs of below 20 mg/L. As of phosphorus, nitrate and nitrite level, only at HRT of 4 hours, is when the effluent became suitable for secondary reuse.

Table 1 Comparison of effluent characteristic for secondary reuse

Parameter	**Operating condition**			**Reuse Options**	
	Run 1 (HRT= 6 hours)	Run 2 (HRT= 4 hours)	Run 3 (HRT= 2 hours)	Range in secondary effluent	Treatment goal in reclaimed waster
COD/(mg/L)	13.5	10.33	10	50-150	<20-90
TKN(mg/L)	4.67	3.0	8.0	-	-
TP/(mg/L)	0.77	0.55	0.72	0.1-3.0	<1-20
NO_3^-(mg/L)	10.4	7.4	3.72	<10	<10
NO_2^-(mg/L)	0.12	0.143	-	<1	<1
Turbidity(NTU)	0.21	0.3	0.31	1-30	<0.1-30

Sources: *Metcalf and Eddy, 2003; Lazanova, et al., 2001; Crites and Tchobanoglous, 1998;*

Membrane Fouling

Figure 5 presented the variation in transmembrane pressure (TMP) during the entire duration of the experiment. At HRT of 6 hours, the membrane reached 27 days before it clogged (>60 KPa) due to unstable growth of microorganism, which was on its acclimatization stage. When the MLSS concentration was maintained at 10,000 mg/L, TMP also stabilized at around 17-19 days in run 2 and 3 with HRT of 4 and 6 hours, respectively. As the HRT was decreased to 2 hours, a sudden drop of TMP at 4-6 days was observed. Parallel to this result, a significant decrease in dissolved oxygen (DO) concentration in figure 7 was also noticed. Therefore, airflow rate was increased to 8.3 L/m^2-min that recovered the TMP to about 11 days.

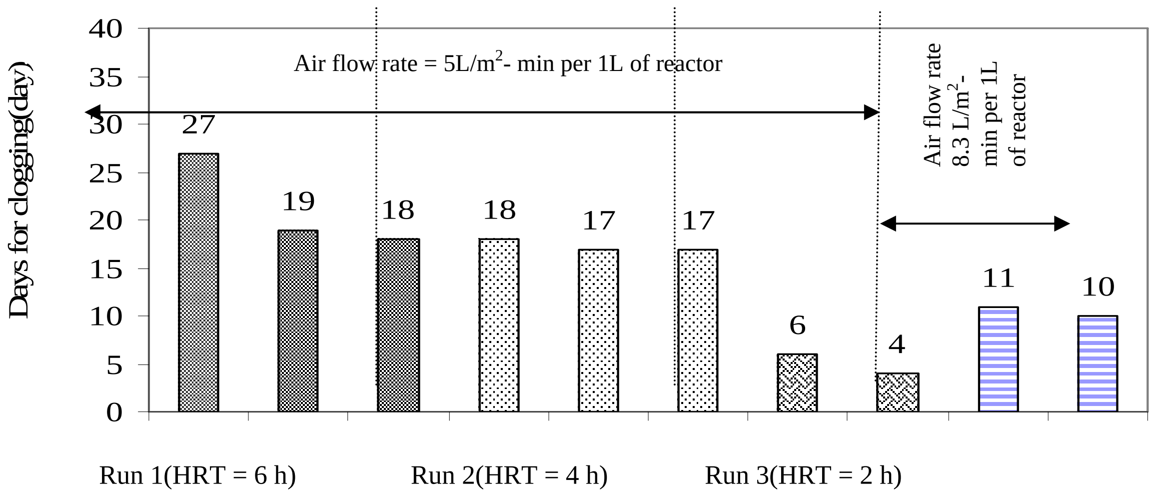

Figure 5 Rate of clogging at different experimental runs

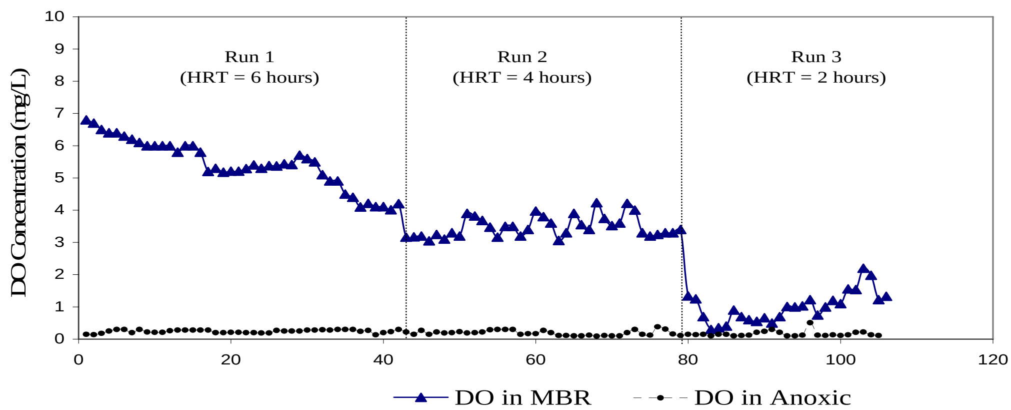

Figure 6 Dissolved oxygen concentrations at different experimental runs

A significant gradual decrease of DO concentration was observed, as the HRT was decreased from 6 hours to 2 hours (Fig. 6). This rapid consumption of oxygen could be due to the consequent increase of organic loading rate in the system. As the microorganism was adapted to the new HRT condition, it tends to consume more organic compounds in a shorter period of time. It is logical that the tendency of the microorganism is also to consume more dissolved oxygen for respiration. It is therefore necessary to increase the airflow rate upon decrease of HRT to supply sufficient amount of oxygen into the system and maintain the degradation performance of the microorganism. Also, it could be suggested that this interpretation may be investigated further by taking microbial biokinetic test.

EPS Effects

In most studies, EPS is hypothesized to be the cause of clogging in membrane bioreactors. In this study, EPS was determined in terms of carbohydrate and protein bounded in the sludge. Figure 7 depicts the concentration of EPS in the system at varying experimental conditions. It could be viewed that EPS at HRT 6 and 4 hours is almost in the same range while a steep increase was observed at HRT of 2 hours. It could be recalled that in figure 6, the clogging of membrane was rapidly observed during run 3, which operated under HRT of 2 hours. It was also in this operating condition where the EPS was observed to be in its peak. In addition, as commonly known, microorganism also evolves according to the demands of its changing environment. It might also be possible that due to microbial metabolic modifications that EPS has been produced extensively. Thus, it is proposed that EPS may be one of the causes of membrane clogging.

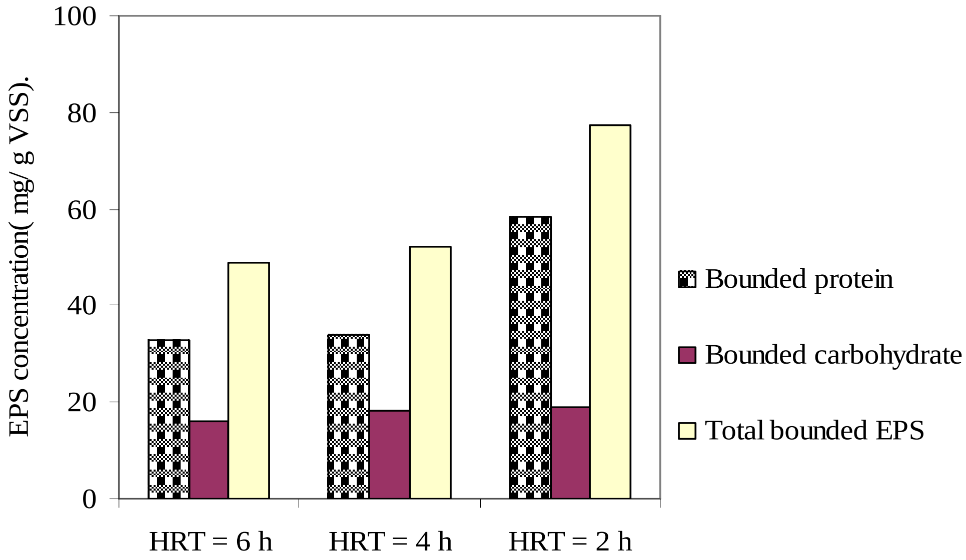

Figure 7 EPS concentration as different experimental conditions

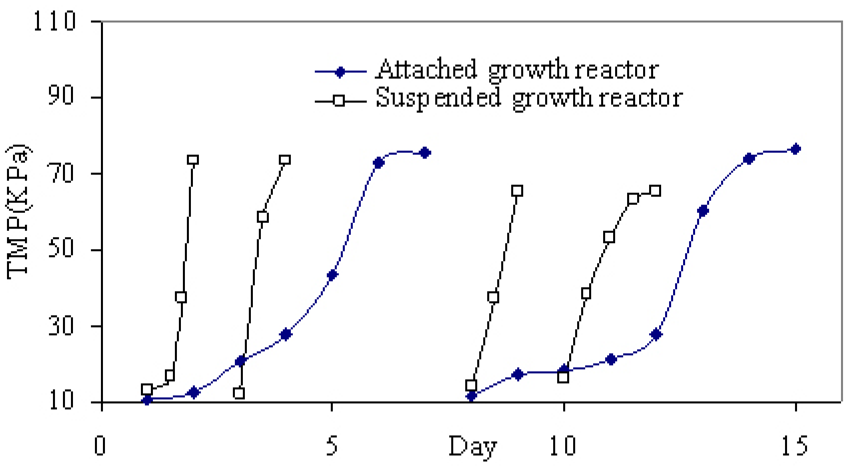

Figure 8 Variation of TMP in attached and suspended growth systems

Minimizing Membrane Fouling

In most membrane bioreactor studies, the main constraint is biofouling of the membrane. In order to achieve a maximum output in MBR, minimizing membrane fouling is very important. Hence, this study has tried to incorporate moving media into the reactor to investigate the performance of an attached growth system. Moving media was chosen, as an alternative option for it is cost effective and commonly available in the market. Experiments were run at MLSS concentration maintained at range of 9,000-10,000 mg/L and HRT of 2 hours. It is evident in Fig. 8 that the suspended growth reactor experienced faster clogging than the attached growth reactor basing from the variations in the TMP. Since the study was only limited at investigating the HRT of 2 hours, it is therefore recommended to further carry out experiments to obtain the optimum operational conditions for the attached growth system.

4. Conclusion

Basing from the experimental results, the following conclusions were derived. There was more than 98% COD removal efficiency regardless of HRT. Effluent quality in terms of COD, TKN and Phosphorus removal efficiency obtained from 4 hours HRT was considered the optimum operating condition. Consequently, effluent at this stage also gives the quality that passes the criteria for secondary reuse. Attached growth MBR obtained more promising results than suspended growth MBR. Overall, the proposed scheme is considered a good option for water sanitation and environmental conservation.

5. Acknowledgement

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