Journal of Membrane Science and Research 1 (2015) 79-84

Journal of Membrane Science and Research

journal homepage: www.msrjournal.com

Research Paper

Hollow Fiber Membrane Bioreactor for COD Biodegradation of Tapioca Wastewater

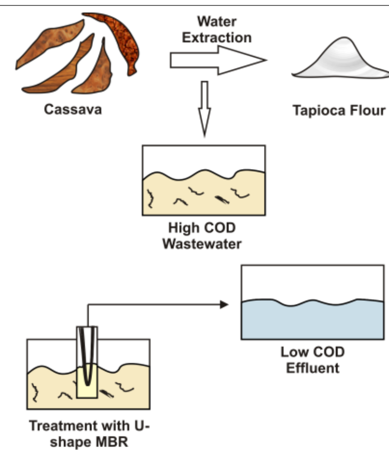
S. Subagjo, N. Prasetya, I.G. Wenten*

Department of Chemical Engineering, ITB, Jl. Ganesha 10, Bandung 40132, Indonesia

HIGHLIGHTS

- Membrane bioreactor was used for treating high COD tapioca wastewater.
- Both batch and continuous operation were studied in this present work.
- Fouling was more severe in high COD concentration.
- Aeration was quite effective in enhancing membrane flux.
- More than 94% COD removal and clear effluent could be obtained.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 2014-07-08
Revised 2014-09-03
Accepted 2014-09-20
Available online 2014-09-21

Keywords:
Tapioca wastewater
Membrane bioreactor (MBR)
COD removal
Wastewater treatment

ABSTRACT

The present work studied the application of membrane bioreactor (MBR) for tapioca wastewater processing that contained chemical oxygen demand (COD) ranging from 4000-9000 mg/L. A preliminary study was initially conducted in order to evaluate membrane performance with respect to its flux with MLSS concentration ranging from 4,500 to 10,500 mg/L. It was clear that fouling was observed during the initial period of study for the whole range of MLSS concentration resulting in drastic flux decline. Increasing trans-membrane suction pressure only yielded slight flux enhancement in 4,500 MLSS concentration. The contrast result was found for both 8,500 and 10,500 MLSS concentration. However, their flux performance could be increased by applying aeration to the system. In batch operation mode using tapioca wastewater, a slight decrease in COD removal was observed when lower hydraulic retention time (HRT) was applied. Lower HRT also suffered relatively sharper flux decline. However, COD removal was only slightly affected by HRT. In a continuous operation mode, it was observed that above 94% COD removal could be attained using HRT in about 24 hours. However, MBR suffered severe membrane fouling in the 4th day of operation resulting in a drastic flux drop below 1 lmh. The chemical cleaning mechanism employed in MBR was found to give the most prominent result since around 67% of flux recovery could be achieved.

* Corresponding author at: Tel: +62 818620014; Fax: +62 2511404
E-mail address: igw@che.itb.ac.id (I.G. Wenten)

1. Introduction

Located in the tropical climate zone, Indonesia has a huge potential in developing cassava. According to the data released by Statistics Indonesia in 2013, around 143 million tons and 5 ton/hectare could be achieved with respect to annual production and average productivity, respectively. This enormous potential then leads Indonesia to industrializing cassava for cases such as tapioca starch production.

There are several steps that are usually accomplished in order to produce tapioca, namely: peeling, rinsing, grinding, extraction, separation (settling or centrifuge) and drying. The tapioca processing industry is indeed water intensive since it is estimated that about 18 m3 of fresh water is needed to produce one ton of starch [1]. The water is mainly utilized for the washing and extraction process; thus it contains high organic materials once disposed to the environment [2]. It has been estimated that the value of chemical oxygen demand (COD) of wastewater is above 5,000 ppm [3-5] and can even reach up to 41,400 mg/L [2]. Without proper treatment, this condition then leads to a serious environmental problem.

Several attempts have then been performed to deal with wastewater coming from the tapioca industry. Water reuse has been proposed as one promising alternative to tackle the problem [2,5]. It has been estimated that about 5m3 reduction of water consumption per ton of cassava produced can be obtained when water that comes out from the starch separation unit is re-used in root washing and the pulp separation unit [1]. Another common approach to treat this wastewater is either through aerobic [6,7] or anaerobic treatment [8,9]. The anaerobic lagoon in Thailand has been proven to effectively remove COD, cyanide content and total suspended solid (TSS) from tapioca wastewater as much as 90% [10]. The addition of nitrogen and further processes of the effluent, however, becomes the main drawback of the technology. Another possibility is to use up-flow anaerobic sludge blanket (UASB) where granular biomass and the three-phase separator (biomass, water and biogas) are utilized [11]. The performance of UASB has been proven well to reduce COD above 90% [12]. However, the drawback of the technology lies on its longer start-up period and insufficient quantity of seed sludge [2]. A modification in UASB is then proposed as can be seen in the anaerobic baffled reactor (ABR) [13]. Its utilization to simultaneously treat tapioca wastewater and produce hydrogen for energy sources has been studied [14]. Furthermore, a hybrid anaerobic reactor combining fixed-film and the UASB system [15] and anaerobic tapered fluidized bed reactor (ATFBR) [16] have been proven to simultaneously reduce COD and produce methane gas for sago wastewater treatment. Up to 90% of COD removal could be attained by such a method.

In addition, non-conventional approaches have also been studied. Kaewkanettra and co-workers have another approach to treat tapioca mill wastewater [17]. They utilize microbial fuel cell (MFC) in order to simultaneously degrade COD and generate electricity. Tapioca wastewater showed better performance in regard to power density in comparison to other wastewater thanks to its higher conductivity. About 88% of COD removal can be achieved while energy density could be harnessed as much as 1.8 W/m^2. Furthermore, by product reclamation can also be an alternative in waste minimization. For example, a single cell protein can be produced from tapioca wastewater utilizing Torula yeast with COD reduction and protein yield are around 73% and 0.5 kg/kg COD removed, respectively [5].

Recently, the membrane bioreactor (MBR) has been proposed as a promising solution in addressing wastewater issues. There are several advantages by using MBR such as: system compactness since it no longer needs primary and secondary clarifiers, high effluent quality, less sludge production and higher volumetric loading rates [18]. There are two operation modes in MBR: side stream and submerged. The former installs a membrane outside the bioreactor while the later directly incorporates a membrane into the bioreactor system.

Its satisfactory performance has been proven from laboratory to bench scale for municipal wastewater treatment and gives satisfactory results with respect to COD reduction and completion of the nitrification process [19-22]. However, a main drawback in using MBR is related to fouling tendency that contributes to lowering the membrane flux [23]. Thus, in order to maintain membrane flux performance, it has been suggested that MLSS concentration should be maintained in the range of 10-20 g/L [24,25].

In this study, a novel approach for tapioca wastewater treatment was proposed. The submerged membrane bioreactor was utilized in order to reduce COD content in tapioca wastewater. This operation mode is chosen because it can save more energy compared to side stream operation [21,23]. The main advantage of this approach is located on its waste minimization because the clear effluent produced from MBR can be re-used in the tapioca industry. To the best of our knowledge, there has been no similar study before concerning this specific purpose. This study, particularly, will focus on the MBR performance with respect to its flux stability and COD removal.

2. Materials and methods

The preparation of tapioca wastewater, activated sludge and system configuration is explained below.

2.1. Tapioca wastewater

Tapioca wastewater was synthesized and individually prepared by performing common methods in tapioca production. Cassava used in this study was purchased from Dago Traditional Market. The cassava was initially peeled. Afterwards, tap water was used to rinse the peeled cassava before it was chopped. Water extraction was then employed followed by the separation process. Water coming out from rinsing, extraction and separation were mixed to form tapioca wastewater. Its characteristics were then analyzed as summarized in Table 1.

Table 1
Characteristic of tapioca wastewater.

No	Parameter	Value
1	COD (mg/L)	3,000-15,000
2	Oil and fat (mg/L)	145-545
3	pH	6.7
4	TKN (mg/L)	157
5	TP (mg/L)	0.882

2.2. Membrane preparation

In this study, hollow fiber ultrafiltration membrane was prepared by GDP Filter Indonesia. Polyacrylonitrile (PAN) was chosen as membrane material due to its hydrophilic characteristic. The pore size of the membrane was about 100 kDa. The outer and inner diameter of one membrane fiber was 1 and 0.5 mm, respectively.

The fibers were then constructed as a membrane module consisting of 85 fibers. As much as 3 membrane modules were employed in this study, and the effective membrane area was about 0.188 m^2.

2.3. Activated sludge

Activated sludge was taken from a food-industry wastewater treatment plant. Before utilizing the sludge in the tapioca wastewater treatment process, the sludge was acclimated in order to get well adapted in tapioca wastewater. The acclimation process was initiated by adding glucose and nutrients into an aerated tank containing activated sludge. Afterwards, tapioca wastewater was introduced into the tank with a gradual daily increase. These steps were repeated until the desired biomass concentration was achieved.

2.4. MBR configuration

The configuration of the MBR system is depicted in Figure 1. Tapioca wastewater was fed from the raw sewage tank to the bioreactor tank that contains ultrafiltration membrane through a diaphragm pump. The size of the bioreactor tank was 48.5×23.5×50 cm. A suction pump was employed in the bioreactor tank to provide suction pressure acting as a membrane driving force. The suction pressure was adjusted by a valve opening. Furthermore, an air sparger was also placed at the bottom of the tank to provide an aeration system. Air supply was completed by installing an air compressor outside the bioreactor tank. In the tank, both degradation and filtration process would simultaneously occur. The membrane effluent was then collected in the permeate tank.

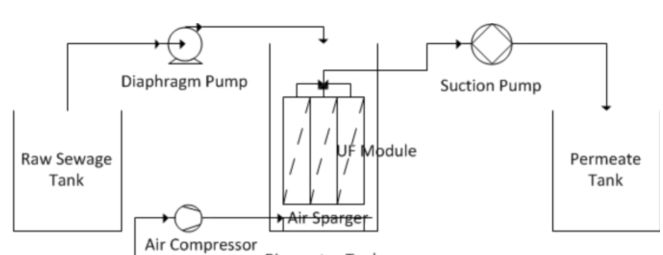


Fig. 1. Schematic diagram of MBR system.

2.5. Cleaning method

After continuous operation of MBR, the membrane was then cleaned using three different methods: flushing, backflushing and chemical cleaning. Flushing was conducted by cleaning the membrane surface by demineralized water for about 10 minutes. Meanwhile, backflushing was performed by introducing demineralized water from the permeate side towards the feed side for about 10 minutes. For chemical cleaning, NaOH 0.1% w/v was used. The solution was fed from the feed side. Chemical cleaning was performed for about 10 minutes. After each cleaning method, the demineralized water flux of the membrane was evaluated.

In this study, wastewater characteristic, MLSS and COD both in the influent and effluent stream from the membrane bioreactor were measured according to the Standard Method published by the American Public Health Association (APHA, 1992). Duplo replication was conducted in all measurements.

3. Results and Discussion

3.1. MBR preliminary study

In this study, PAN was used as membrane material with an average pore size around 100 kDa. First of all, the membrane characteristic was evaluated towards the demineralized water flux. During this study, the trans-membrane pressure (TMP) was varied between 0.1 and 0.4 bar. From the obtained results, water flux can still be linearly increased as TMP is elevated and its slope was around 90.8. This trend was predictable since fouling had not yet occurred on the membrane surface. Furthermore, the specific permeability of this membrane was found at around 100 L/m^2.h.bar and did not change with respect to TMP. This shows that pore swelling did not occur during this study.

Afterwards, the performance of the membrane was evaluated towards activated sludge with various MLSS concentrations (4,500 mg/L; 8500 mg/L and 10,500 mg/L) and operating TMP (0.13 bar and 0.16 bar) was performed. The results are presented in Figure 2 (0.13 bar) and 3 (0.26 bar).

From the above figures, it was quite clear that all various conditions underwent similar flux behavior. The MBR flux would initially decline until it reached a stationary point and did not further fluctuate. This phenomenon was due to the cake layer formed during the filtration process. Since MBR was operated in vacuum condition, activated sludge would be embedded on the membrane surface where they formed a cake layer. The cake layer then contributed in increasing overall resistance of the MBR system; thus a flux decline did occur.

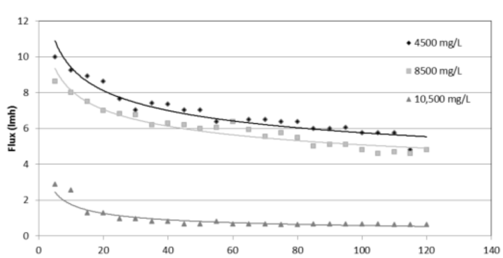


Fig. 2. Flux behavior with various MLSS concentration (TMP=0.13 bar).

It could also be observed that by operating trans-membrane suction pressure at 0.13 bar, MLSS concentration did not seem to signifcantly affect the membrane flux for MLSS concentration ranging from 4500-8500 mg/L. This result was in line with previous investigations [26] showing that within MLSS concentration ranging from 3,600-8,400 mg/L and 0.2 bar suction pressure, membrane flux was independent with respect to MLSS. When the MLSS concentration was further increased to 10,500 mg/L, the value of membrane flux declined to below 1 l.m-2.h-1 (or lmh), sharply. The phenomenon might be explained by two main reasons. Firstly it was due to the increase of fluid viscosity especially because our study used MLSS concentration above 10,000 kg/m^3 that was considered significant in causing higher fluid viscosity [25]. The result then also confirmed the previous study showing that higher fluid viscosity led to lower flux [27]. Secondly, from physical observations, it was quite obvious that slimy substances -that could be considered as extracellular polymeric substance (EPS)- were present in the highest MLSS concentration. As previously observed, such substances had also been deemed to cause TMP increase in MBR operation since they were more prone to adhere to membrane surfaces [28,29]. In our case, it might be possible that such substances also held water that was going to pass through the membrane since it was mainly constituted by carbohydrates and protein, thus hampering the water to get through the permeate side.

Moreover, from the above figures, it could also be seen that higher trans-membrane suction pressure led to a more severe trend of flux decline in the initial periods. This result then confirmed the previous study [23,26]. The sharp decline flux might be attributed to more severe foulants deposition on the membrane since higher trans-membrane suction pressure did not only enhance the permeate flux but also dragged more foulants towards the membrane due to the convective flow; thus exacerbating the membrane fouling phenomenon.

Furthermore, the influence of trans-membrane suction pressure could also be related with respect to the steady state value of the MBR flux. From the above results, it could be observed that increasing trans-membrane suction pressure did not proportionally lead to an increase in membrane flux. Flux increase was only observed in the lowest MLSS concentration used in this study. Even in this case, lifting up two folds of the value would only result in a slight increase of about 14%. A stark contrast occurred in both cases of 8,500 and 10,500 mg/L MLSS concentration when all of the operating pressures gave similar trends with respect to TMP and the steady state membrane flux. The flux decline percentage for 8,500 and 10,500 mg/L of MLSS concentration was about 13 and 30%, respectively.

This result then confirmed the previous study showing that the submerged MBR flux was not proportional to the pressure difference employed [23]. In relatively lower MLSS concentration, the influence of trans-membrane suction pressure still did prevail due to the less severe cake formation compared to other systems; thus trans-membrane suction pressure still led to an increase in membrane flux. In higher MLSS concentrations, more severe cake formation did occur, making it unaffected with respect to trans-membrane suction pressure, and even a slight flux decline was observed. This phenomenon could be explained by cake thickness and compaction as previously used to explain more severe flux decline in MBR operated at higher pressure [26]. As trans-membrane suction pressure was increased, the cake layer that formed either inside or on the membrane surface would also be thicker and more compact since additional foulants would be transported to the membrane. This condition then led to higher resistance in the membrane system that contributed to a lower flux value.

In this study, aeration effect was also observed using 10,500 mg/L in MLSS concentration and two velocity variations: 6 and 12 L/minutes. Trans-membrane suction pressure was adjusted to 0.13 bar since it was clear from the previous section that applying high TMP did not positively affect the MBR flux. The result is presented in Figure 4.

From Figure 4, it could be seen that membrane flux was significantly increased when aeration was applied in the MBR system. However, increasing two folds of aeration velocity did not seem to enhance membrane flux any further. Thus, both of the aeration velocities observed gave a steady state flux value around 7 l/m^{2}h.

It had been previously proven that applying aeration had a significant role in the MBR system since it contributed to cleaning action in the membrane [30] by promoting turbulence to wash away thin sludge film of the cake layer [31]. Thus, it was effective in reducing cake-formation in the MBR system, resulting in a decrease in trans-membrane suction pressure [24]. It was then clear that aeration applied in this system did provide a local cross-flow mechanism and shear across the membrane surface and resulted in lowering cake resistance over the membrane and thus enhancing the steady state membrane flux. However, the existence of critical aeration velocity was also observed: a value where further increase of air flow would not proportionally decrease the trans-membrane suction pressure [24]. Determining the value is important in order to not over-supply the air into the system causing excessive power consumption [24]. Besides, the high intensity of aeration was also not suggested since it could also change biomass characteristics through sludge flocs breakage and higher production of soluble microbial products (SMP) that contributed to creating more severe fouling [31]. This might also become the reason why no increase in MBR flux was observed, namely because there was an equilibrium between cake washing and foulants formation by SMP. Thus, it did seem that 6 L/min in aeration was quite sufficient to be applied within the system.

3.2. MBR batch operation

In MBR batch operation, tapioca wastewater was pumped to the bioreactor. As stated in the previous section, since 12 L/min of aeration velocity had surpassed the critical value and also to avoid excessive power consumption, 6 L/min of aeration velocity was used in this study. The membrane performance was then evaluated with respect to hydraulic retention time (HRT) between 8 and 24 hours and the result is presented in Figure 5.

HRT or detention time (DT) is defined as the time that a fluid particle remains in a reactor and can be formulated as the volume of fluid in the reactor divided by flow rate into the reactor. The value is important since it will affect the completion of reaction especially with respect to nitrogen and phosphorus removal [32]. DT in a real reactor is usually less than theoretical DT [18]. Previously, several studies had also shown that HRT had affected MBR performance [32-34].

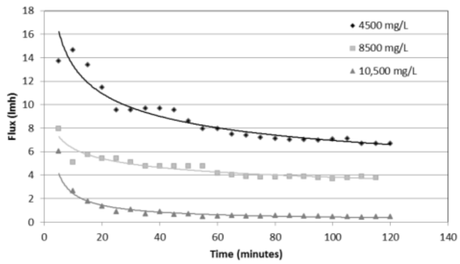


Fig. 3. Flux behavior with various MLSS concentration (TMP=0.26 bar).

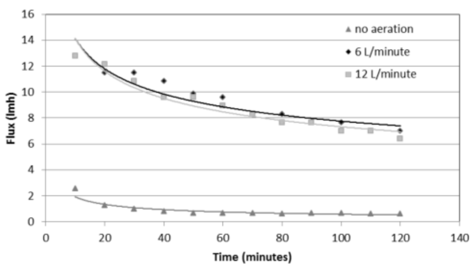


Fig. 4. MBR flux using aeration.

In this study, two values of HRT were evaluated: 8 and 24 hours. These values were chosen to represent two extreme cases: high and low organic loading rate (OLR). The first value of HRT was determined based on previous research showing that very low HRT (4-5 hours) could negatively impact MBR performance [29]. Thus, 8 hours was chosen to represent high OLR condition. In this case, the value of OLR was 0.75-1.5 kg COD/day. In contrast, 24 hours in HRT was used to give performance comparison when MBR was operated in low OLR conditions, namely within the range of 0.25-0.5 kg COD/day.

From the above figure, it did seem that using lower HRT would produce a slight increase in initial flux compared to higher HRT. However, both of these values would yield in a similar steady state flux value. It then meant that using lower HRT resulted in relatively sharper flux decline in comparison with higher HRT. The phenomenon might be caused by several reasons such as an increase of EPS products by filamentous bacteria [29]. When lower HRT was applied, filamentous bacteria grew faster since dissolved oxygen content also dropped. The increase of EPS content was then considered to significantly contribute to increasing cake layer resistance by lowering its permeability factor resulting in a more severe flux decline [32]. Furthermore, it could also be caused by higher flux obtained at the initial condition since it would be very likely to drag more foulants to the membrane surface, contributing to building a more severe cake. This result then proved the conclusion that lower HRT resulted in a higher tendency of membrane fouling [35].

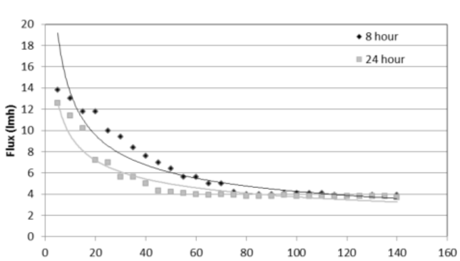


Fig. 5. Effect of HRT on MBR flux.

In order to further evaluate the MBR performance, both operating conditions were also assessed towards COD in the permeate as shown in Table 2.

It was quite obvious that both variations gave satisfactory results with respect to COD degradation since above 97% of degradation could be achieved. Moreover, it was also observed that longer HRT would lead to slightly higher degradation of organic contaminants in tapioca wastewater. Similar results had also been obtained using synthetic wastewater [29,36]. The phenomenon might be attributed to lower organic loading rate (OLR) in higher HRT. Previous studies had showed that higher OLR would lead to slightly lower efficiency in COD removal; resulting in relatively higher COD content in the effluent stream in comparison to when the lower OLR was applied either for aerobic [37,38] or anaerobic conditions [15,16,39]. This might be due to the fact that higher OLR contributed to decreasing contact time between biomass and organic contaminants causing decreased mass transfer that eventually led to relatively poorer performance [39]. In addition, even though it was also observed that higher biomass concentration was present in MBR that operated in lower HRT, this condition did not give any positive influence towards the completion of the degradation process of organic contaminants due to the food excess [36]. However, other results had also shown that using small HRT could still yield satisfactory results with respect to COD removal since it did not cause a drastic decrease in COD removal. Thus, consideration for using higher OLR was also suggested to optimize reactor capability [37].

Table 2
COD concentration in tapioca wastewater and MBR permeate.

HRT (hours)	COD (mg/L)		Degradation (%)
	Tapioca wastewater	Permeate	
8	7200 - 9200	80 – 260	97.1 – 98.8
24	7200 - 9200	80 – 140	98.5 – 98.8

3.3. MBR continuous operation

Having been evaluated with regard to its performance in batch mode, a continuous process was performed in order to assess its applicability for industrial tapioca wastewater usage. In this experiment, biomass concentration used was about 13,000 mg/L and COD concentration in tapioca wastewater varied between 4800-8800 mg/L. The aeration rate used in this operation was about 6 L/min. The result in the MBR continuous operation with respect to its flux, trans-membrane suction pressure and MLSS concentration is presented in Figure 6.

From this figure (see Figure 6), it could be seen that MBR flux suffered continuous decline after reaching its highest value at around 3 lmh. Meanwhile, trans-membrane suction pressure that was maintained at around 0.4 bar at the first period of the experiment, experienced a twofold increase at the final period of the experiment. A similar trend also prevailed for MLSS concentration when concentration as much as 22,000 mg/L was obtained at the completion of MBR operation.

In the first period of the experiment, an increase in membrane flux might be related to an increase in trans-membrane suction pressure. In the previous section, it was observed that an increase in trans-membrane suction pressure for MLSS concentration of about 10,500 mg/L did not yield in flux increase due to the fluid viscosity. However, even though in this continuous MBR experiment the MLSS concentration was 13,000 mg/L, the suction pressure applied was almost ten-fold lower compared to the previous section. Lower operating pressure then meant a lower flux was obtained, leading to less foulants that were attracted to the membrane compartment. This resulted in less deposition formed on the membrane; thus increasing the trans-membrane suction pressure still had a positive impact on membrane flux.

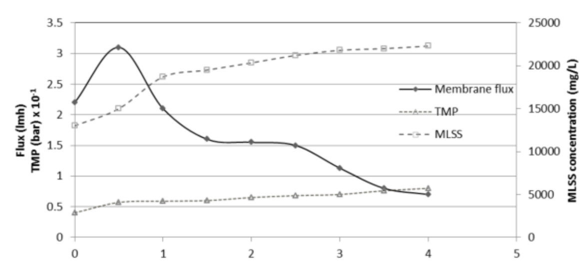


Fig. 6. Membrane flux, TMP and MLSS concentration behavior during MBR continuous operation.

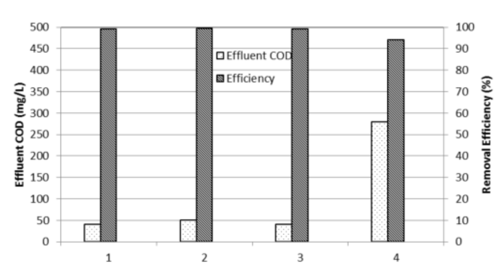


Fig. 7. COD removal in continuous MBR operation.

However, the phenomenon would not last long. When tapioca wastewater was introduced into the system, the MLSS concentration started to rise due to the biomass growth that led to more solutes in the system. As could be predicted, this condition would lead to the flux declining phenomenon due to the more severe cake formation on the membrane.

Furthermore, it could also be inferred that the continuous MBR system was operated above the critical condition. It was based on the trans-membrane suction pressure that continued to rise but was not followed by flux increase. The increase of TMP then represented the severe fouling that occurred on the membrane. Also, applying aeration in this case did not seem to give any positive impact since it could not significantly sweep out the cake layer formed on the membrane and thus failed to lift up the membrane flux.

Furthermore, an evaluation with respect to COD removal in continuous MBR operation is presented in Figure 7. From this figure, it could be seen that COD removal could be satisfactorily maintained above 94%. COD in the MBR effluent stream was consistently suppressed below 100 mg/L except for the last day of operation when it reached 280 mg/L with a slight decline in efficiency removal.

Even though its long-term performance had not yet been observed and could not be concluded, this short-term experiment had proven the ability of MBR to significantly reduce the COD content of tapioca wastewater. Generally speaking, within the similar range of OLR, COD removal efficiency in this study was better in comparison with other previous methods as can be seen in Table 3. As can be seen in Figure 8, being accompanied by the clear effluent produced further justified the superiority of the submerged MBR method for tapioca wastewater processing. This low-content COD and clear effluent was then highly possible to be re-used in the tapioca industry.

However, there was also a considerable COD reduction efficiency in the 4^{th} day of operation. This phenomenon might be mainly attributed to the fluid viscosity in the system. Since MLSS continued to increase, fluid viscosity in the system would also rise. Previous observations had shown that maintaining MLSS concentration above 10 kg/m^3 had led to an abrupt increase in viscosity [25]. In this study, about twofold higher of MLSS concentration was observed against the value. This condition then led to the uneven distribution of oxygen coming from the aeration system. In this condition, the air bubble tended to become larger rather than dispersed, thus disturbing the performance of microorganisms to undergo biodegradation of COD [23]. Furthermore, it was also reported that a disturbance in oxygen transfer might also cause death to microorganisms that were located in the inner layer of filtration cake [40]. This meant that fewer microorganisms were available in the system resulting in reduction in COD removal efficiency.

Table 3
Performance comparison of COD removal efficiency for various tapioca/starch wastewater treatments.

Treatment method	Organic Loading Rate (kg COD/m^3.day)	COD removal (%)	Source
Aerobic MBR	14.4 – 26.4	94-99	This study
Aerobic fluidized bed reactor	1.35	95.6	[7]
	26.73	51.8	
Horizontal flow anaerobic reactor	11.8	87.1	[9]
Anaerobic baffled reactor	5	55	[13]
	10	40	
	16.15	14.02	[14]
	22.5	19.28	
Anaerobic fluidized bed reactor	14.4 - 83.7	92	[16]

Furthermore, another drawback with respect to MBR performance was also observed since it could be seen that the flux had fallen to below 1 lmh even only within 4 days of operation (see Figure 6). MBR cleaning should then be performed. Several cleaning mechanisms (flushing, backwashing and chemical cleaning using NaOH 0.1% w/v) were then conducted in order to evaluate membrane flux recovery. The result with respect to membrane permeability toward demineralized water compared to its initial condition is shown in Figure 9.

It was quite obvious from the figure that all of the cleaning mechanisms conducted in this study did not successfully recover the initial membrane permeability. The lowest flux recovery was obtained when flushing was performed. Only 30% of initial membrane permeability could be recovered by the process. The value was then enhanced once the backflushing mechanism was employed. About twofold of membrane permeability was achieved compared to flushing. Similar levels of superiority were also seen in chemical cleaning compared to flushing. However, it only slightly increased membrane permeability compared to backflushing method.

Fig. 8. Visual sample observation of (A) mixed liquor and (B) permeate from MBR.

As has been summarized by Meng and his co-workers, there are three types of fouling that occur during the MBR process: removable, irremovable and irreversible fouling [35]. The first one can be easily removed by physical cleaning while chemical cleaning is needed to remove the irremovable one. The rest is grouped as irreversible fouling, namely those which cannot be cleaned either by physical or chemical cleaning. From the figure above, it can be clearly seen that both backflushing and chemical cleaning yielded almost similar results. Only a slight enhancement was observed after chemical cleaning was performed. It then showed that the main fouling contributors in this experiment were removable and irreversible. Irremovable fouling that was not quite apparent in this experiment might be caused by a relatively short period of MBR operation time since longer operation time of MBR can produce more persistent irremovable fouling even though it is not operated within the non-fouling region [41].

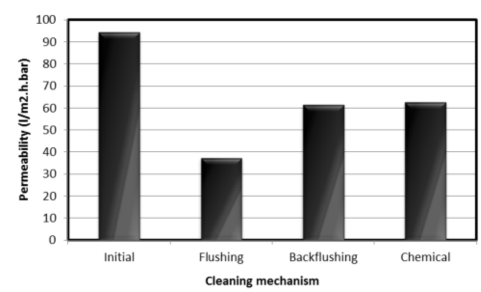


Fig. 9. Membrane permeability in initial condition and after cleaning mechanisms.

4. Conclusions

From the study, it was clear that both batch and continuous operation of MBR for tapioca wastewater treatment did give satisfactory results with respect to COD reduction since around 95% of biodegradation could be attained. This method was better compared with several conventional tapioca wastewater treatments. However, severe fouling phenomena still occurred that negatively impacted the MBR performance. Applying aeration is also not observed to significantly enhance the membrane flux and reduce membrane fouling. Several cleaning mechanisms were then performed: flushing, backflushing, and chemical cleaning. Flushing could only recover about 30% of the initial flux. This value was enhanced once backflushing was employed. Further cleaning using the chemical agent could not significantly increase the membrane flux. This showed that most constituents of membrane fouling were actually removable and irreversible. Overall, only 67% of the initial flux could be recovered. Nevertheless, this study had showed that MBR was quite effective in reducing COD and could be directly applied for tapioca wastewater treatment.

References

[1] O. Chavalparit, M. Ongwandee, Clean technology for the tapioca starch industry in Thailand, J. Clean. Prod. 17 (2009) 105-110.

[2] H.N.P. Mai, Integrated treatment of tapioca processing industrial wastewater: Based on environmental bio-technology, PhD-Thesis Wageningen University, 2006.

[3] D. Peters, D.T.A. Do Duc Ngai, Agro-processing Waste Assessment in Peri-urban Hanoi, CIP Program Report, 2000.

[4] D. Peters, D.D. Ngai, Agro-processing waste assessment and management in Peri Urban Hanoi, Vietnam, J. Sustain. Agric. 25 (2005) 69-95.

[5] S. Vigneswaran, V. Jegatheesan, C. Visvanathan, Industrial waste minimization initiatives in Thailand: concepts, examples and pilot scale trials, J. Clean. Prod., 7 (1999) 43-47.

[6] M. Rajasimman, C. Karthikeyan, Aerobic digestion of starch wastewater in a fluidized bed bioreactor with low density biomass support, J. Hazard. Mater. 143 (2007) 82-86.

[7] M. Rajasimman, C. Karthikeyan, Starch wastewater treatment in a three phase fluidized bed bioreactor with low density biomass support, J. Appl. Sci. and Environ. Manag. 11 (2007), http://dx.doi.org/10.4314/jasem.v11i3.55138.

[8] A. Ubalua, Cassava wastes: treatment options and value addition alternatives, African J. Biotechnol. 6 (2007) 2065-2073.

[9] X. Colin, J.-L. Farinet, O. Rojas, D. Alazard, Anaerobic treatment of cassava starch extraction wastewater using a horizontal flow filter with bamboo as support, Bioresour. Technol. 98 (2007) 1602-1607.

[10] B. Rajbhandari, A. Annachhatre, Anaerobic ponds treatment of starch wastewater: case study in Thailand, Bioresour. Technol. 95 (2004) 135-143.

[11] G. Lettinga, A. Van Velsen, S.W. Hobma, W. De Zeeuw, A. Klapwijk, Use of the upflow sludge blanket (USB) reactor concept for biological wastewater treatment, especially for anaerobic treatment, Biotechnol. Bioeng. 22 (1980) 699-734.

[12] P. Hien, L. Oanh, N. Viet, G. Lettinga, Closed wastewater system in the tapioca industry in Vietnam, Water Sci. Technol. 39 (1999) 89-96.

[13] H. Movahedyan, A. Assadi, A. Parvaresh, Performance evaluation of an anaerobic baffled reactor treating wheat flour starch industry wastewater, Iran. J. Environ. Health Sci. Eng. 4 (2007) 77-84.

[14] P. Thanwised, W. Wirojanagud, A. Reungsang, Effect of hydraulic retention time on hydrogen production and chemical oxygen demand removal from tapioca wastewater using anaerobic mixed cultures in anaerobic baffled reactor (ABR), Int. J. Hydrog. Energy 37 (2012) 15503-15510.

[15] J.R. Banu, S. Kaliappan, D. Beck, Treatment of sago wastewater using hybrid anaerobic reactor, Water Qual. Res. J. Canada, 41 (2006) 56-62.

[16] P. Rangasamy, I. Pvr, S. Ganesan, Anaerobic tapered fluidized bed reactor for starch wastewater treatment and modeling using multilayer perceptron neural network, J. Environ. Sci. 19 (2007) 1416-1423.

[17] P. Kaewkannetra, W. Chiwes, T. Chiu, Treatment of cassava mill wastewater and production of electricity through microbial fuel cell technology, Fuel, 90 (2011) 2746-2750.

[18] L. Metcalf, H.P. Eddy, G. Tchobanoglous, Wastewater engineering: treatment, disposal, and reuse, McGraw-Hill, 1972.

[19] A. Pollice, G. Laera, D. Saturno, C. Giordano, Effects of sludge retention time on the performance of a membrane bioreactor treating municipal sewage, J. Membr. Sci. 317 (2008) 65-70.

[20] X. Huang, P. Gui, Y. Qian, Effect of sludge retention time on microbial behaviour in a submerged membrane bioreactor, Process Biochem. 36 (2001) 1001-1006.

[21] W.J. Davies, M.S. Le, C.R. Heath, Intensified activated sludge process with submerged membrane microfiltration, Water Sci. Technol. 38 (1998) 421-428.

[22] R.S. Trussell, R.P. Merlo, S.W. Hermanowicz, D. Jenkins, The effect of organic loading on process performance and membrane fouling in a submerged membrane bioreactor treating municipal wastewater, Water Res. 40 (2006) 2675-2683.

[23] K. Yamamoto, M. Hiasa, T. Mahmood, T. Matsuo, Direct solid-liquid separation using hollow fiber membrane in an activated sludge aeration tank, Water Sci. Technol. 21 (1989) 43-54.

[24] T. Ueda, K. Hata, Y. Kikuoka, O. Seino, Effects of aeration on suction pressure in a submerged membrane bioreactor, Water Res. 31 (1997) 489-494.

[25] Y. Shimizu, K. Uryu, Y.-I. Okuno, A. Watanabe, Cross-flow microfiltration of activated sludge using submerged membrane with air bubbling, J. Ferment. Bioeng. 81 (1996) 55-60.

[26] S.P. Hong, T.H. Bae, T.M. Tak, S. Hong, A. Randall, Fouling control in activated sludge submerged hollow fiber membrane bioreactors, Desalination 143 (2002) 219-228.

[27] T. Sato, Y. Ishii, Effects of activated sludge properties on water flux of ultrafiltration membrane used for human excrement treatment, Water Sci. Technol. 23 (1991) 1601-1608.

[28] S. Rosenberger, U. Krüger, R. Witzig, W. Manz, U. Szewzyk, M. Kraume, Performance of a bioreactor with submerged membranes for aerobic treatment of municipal waste water, Water Res. 36 (2002) 413-420.

[29] F. Meng, B. Shi, F. Yang, H. Zhang, Effect of hydraulic retention time on membrane fouling and biomass characteristics in submerged membrane bioreactors, Bioprocess Biosyst. Eng. 30 (2007) 359-367.

[30] J. Howell, H. Chua, T. Arnot, In situ manipulation of critical flux in a submerged membrane bioreactor using variable aeration rates, and effects of membrane history, Journal of Membrane Science, 242 (2004) 13-19.

[31] H.P. Chu, X.-Y. Li, Membrane fouling in a membrane bioreactor (MBR): sludge cake formation and fouling characteristics, Biotechnol. Bioeng. 90 (2005) 323-331.

[32] S.-R. Chae, Y.-T. Ahn, S.-T. Kang, H.-S. Shin, Mitigated membrane fouling in a vertical submerged membrane bioreactor (VSMBR), J. Membr. Sci. 280 (2006) 572-581.

[33] J.-S. Chang, C.-Y. Chang, A.-C. Chen, L. Erdei, S. Vigneswaran, Long-term operation of submerged membrane bioreactor for the treatment of high strength acrylonitrile-butadiene-styrene (ABS) wastewater: effect of hydraulic retention time, Desalination 191 (2006) 45-51.

[34] N. Fallah, B. Bonakdarpour, B. Nasernejad, M.R.A. Moghadam, Long-term operation of submerged membrane bioreactor (MBR) for the treatment of synthetic wastewater containing styrene as volatile organic compound (VOC): Effect of hydraulic retention time (HRT), J. Hazard. Mater. 178 (2010) 718-724.

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

[36] D.D. Sun, C.T. Hay, S.L. Khor, Effects of hydraulic retention time on behavior of start-up submerged membrane bioreactor with prolonged sludge retention time, Desalination 195 (2006) 209-225.

[37] W. Jianlong, S. Hanchang, Q. Yi, Wastewater treatment in a hybrid biological reactor (HBR): effect of organic loading rates, Process Biochem. 36 (2000) 297-303.

[38] H.S. Lee, S.J. Park, T.I. Yoon, Wastewater treatment in a hybrid biological reactor using powdered minerals: effects of organic loading rates on COD removal and nitrification, Process Biochem. 38 (2002) 81-88.

[39] S. Bodkhe, Development of an improved anaerobic filter for municipal wastewater treatment, Bioresour. Technol. 99 (2008) 222-226.

[40] J. Zhang, H.C. Chua, J. Zhou, A.G. Fane, Factors affecting the membrane performance in submerged membrane bioreactors, J. Membr. Sci. 284 (2006) 54-66.

[41] S. Ognier, C. Wisniewski, A. Grasmick, Membrane bioreactor fouling in sub-critical filtration conditions: a local critical flux concept, J. Membr. Sci. 229 (2004) 171-177.