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Effect of sludge pretreatment on the performance of anaerobic/ anoxic/ oxic membrane bioreactor treating domestic wastewater

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ABSTRACT: In the present study, two bench-scale anaerobic/ anoxic/ oxic submerged membrane bioreactors were used to study the effect of thermochemical sludge disintegration system on the excess sludge production. Among the two membrane bioreactors, one was named experimental membrane bioreactor and another one was named as control membrane bioreactor, where a part of the mixed liquor was treated with thermo chemical and was returned back to membrane bioreactor. Thermo chemical digestion of sludge was carried out at fixed pH (11) and temperature (75 °C) for 24 % chemical oxygen demand solution. The other one was named control membrane bioreactor and was used as control. The reactors were operated at three different mixed liquor suspended solids range starting from 7500 mg/L to 15000 mg/L. Both of membrane bioreactors were operated at a flux of 17 LMH over a period of 240 days. The designed flux was increased stepwise over a period of one week. During the 240 days of reactor operation, both of membrane bioreactors maintained relatively constant transmembrane pressure. The sludge digestion had no impact on chemical oxygen demand removal efficiency of the reactor. The results based on the study indicated that the proposed process configuration has potential to reduce the excess sludge production as well as it didn't deteriorate the treated water quality.

Keywords: *Membrane bioreactor; Sludge reduction; Thermochemical pretreatment; Transmembrane pressure*

INTRODUCTION

During operation of biological wastewater treatment processes, a part of activated sludge should be withdrawn and disposed in order to maintain appropriate level of biomass concentration in the reactor. The expense for the treatment of the excess sludge has been estimated to be as much as 50-60 % of the total expense of wastewater treatment plant (Nowak, 2006; Hooshyari *et al*., 2009; Pasztor *et al*., 2009; Rajesh banu *et al*., 2009; Zhang *et al*., 2009). Recently various sludge disintegration techniques have attracted attentions as promising alternatives to reduce sludge production. Among these, thermal and chemical treatments were mostly widely studied and adopted in many commercialized processes. In these studies a part of the recycled sludge was pretreated and was returned to the wastewater stream for further biodegradation. In overall, the basis for the sludge reduction process is an effective combination of the methods for sludge disintegration and biodegradation of the treated sludge (Rajesh banu *et al*., 2008; Liu *et al*., 2010; Cheng *et al*., 2011). Introduction of sludge disintegration into other wastewater treatment processes such as membrane bioreactor (MBR) may also be an interesting approach. The membrane processes are characterized by immersing the membrane modules as solid liquid separation units directly in the aerobic basin, were developed for wastewater treatment (Yamamoto and Win, 1991; Goyal *et al*., 2008; Xia *et al*., 2008). MBR process has been known as a process with relatively high decay rate and less sludge production due to much longer biomass retention in the reactor.

The present study utilizes the advantages of both MBR and sludge pretreatment process for the reduction

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of excess sludge. The objectives of this study were to evaluate the effects of sludge disintegration on the rate of sludge production and the performance of MBR. Combined treatment of alkali and temperature were tested for sludge pretreatment. In this scheme, alkaline treatment serves not only as a sludge solubilizing reagent but also act as a buffering agent to prevent pH drop. The major experimental part of the study was carried out at Department of Civil and Environment Engineering, Sungkyunkwan University, Korea for a period of 8 months and during the study period, the performance of the reactor was evaluated by comparing it with control reactor.

MATERIALS AND METHODS

Wastewater

The primary settled domestic wastewater from Sungkyunkwan University, Korea was used as a feed for the present study. The characteristics of the primary settled wastewater were given in the Table 1.

A2O - MBR

The working volume of the reactor anaerobic/ anoxic/oxic-membrane bioreactor (A2O-MBR) was 83.4 L. A baffle was placed inside the reactor to divide it into anaerobic (8.4 L) anoxic (25 L) and aerobic basin (50 L). The wastewater was fed into the reactor at a flow rate of 8.4 L/h (Q) using a feed pump. A liquid level sensor, planted in aerobic basin of A2O-MBR controlled the flow of influent. The hydraulic retention time (HRT) of anaerobic, anoxic and aerobic basin was 1, 3 and 6 h, respectively. In order to facilitate nutrient removal the reactor was provided with two internal recycle (IR). IR1 connects anoxic and anaerobic and IR 2 (Q=3) was between aerobic and anoxic. Anaerobic and anoxic basins were provided with low speed mixer to keep the mixed liquid suspended solids (MLSS) in suspension. Dissolved oxygen (DO) concentration in the aerobic basin was maintained at 3.5 mg/L and was monitored continuously through online DO meter. The solid liquid separation happens in an aerobic basin with the help of the membrane. Five flat sheet types of membranes with the pore size of 0.23 µm were used for the study. The characteristic features of the membranes used were given in the Table 2.

A common tube which interns connected to a suction pump connected the each module. A provision was made in the common tube to measure the transmembrane pressure (TMP) during suction. The suction pump was operated in sequence of timing, which consists of 10 min switch on, and 2 min switch off.

Thermo-chemical digestion of sludge

MLSS from aerobic basin of MBR was withdrawn at the ratio of 1.5 % of Q/day and subjected to thermo chemical digestion. Thermo chemical digestion was carried out at the fixed pH 11 (NaOH) and temperature (75 °C) for 3 h. Besides acting as a solubilisation agent the added alkali sodium hydroxide can serve as a neutralizing agent of solubilised biomass and act as an alkalinity supplement during nitrification. It is also possible that the solublised biomass can be subjected to anaerobic degradation and the resulting fuel gas can be used for sludge pretreatment.

Table 1: Characteristics of the wastewater

Unit (mg/L)	TCOD	SCOD	SS	TN	TP	Alkalinity
Average	190	130	66	35	4.5	165
Standard Deviation	42	22	12	6	1	20

Table 2: Characteristics of the membrane used

Parameters	Value
Pore size	0.22 µm
Material	Polyvinylidene fluoride
Area	0.1m^2/module
Dimension	24 cm × 34 cm × 10 cm

Chemical analysis

Chemical oxygen demands (COD), MLSS, mixed liquor volatile suspended solids (MLVSS) of the raw and treated wastewater were analyzed following methods detailed in APHA *et al.*, (2005). The analysis of extra polymeric substances (EPS) in biomass was made through a thermal extraction method. The mixed liquor was centrifuged (4000 rpm for 20 min) in order to remove the soluble EPS from bound EPS. After collecting the soluble EPS, the remaining pellet is washed and resuspended in saline water (0.9 % NaCl solution). The extracted solution was then separated from the sludge solids by centrifugation under similar condition (4000 rpm for 20 min), the supernatant obtained at this stage were being referred to as bound EPS solution. The EPS solution was then measured in terms of protein and carbohydrate contents by Lowry method with bovine serum albumin (BSA) as standard (Lowry *et al.*, 1951) and by phenolic-sulfuric acid method with glucose as standard (Dubois *et al.*, 1956) respectively. The sum of protein and carbohydrate represented the total EPS content.

RESULTS AND DISCUSSION

Fig. 1 presents data of MLSS profile during 240 days period of reactor operation. One of the advantages of MBR reactor was it can be operated in high MLSS concentration. The reactor was seeded with enhanced biological phosphorous removal (EBPR) sludge from the Kiheung, sewage treatment plant, Korea. Both the reactors were startup with the MLSS concentration of 5700 mg/L. MLSS starts to increase steadily with increase in period of reactor operation and reached a value of 7200 mg/L on day 40. From then onwards, MLSS concentration was maintained to the desired range of 7500 mg/L (Run 1). At the end of 60 day stable period of reactor operation, a part of MLSS was withdrawn at a rate of 1.5 %Q/day and subjected to be thermochemical treatment. Run II was initiated on day 120 by not withdrawing excess sludge. As a result of that, MLSS began to accumulate in the system and reaches a value of 10400 mg/L for EMBR and 10600 mg/L for CMBR on day 130. From then onwards sludge withdrawal

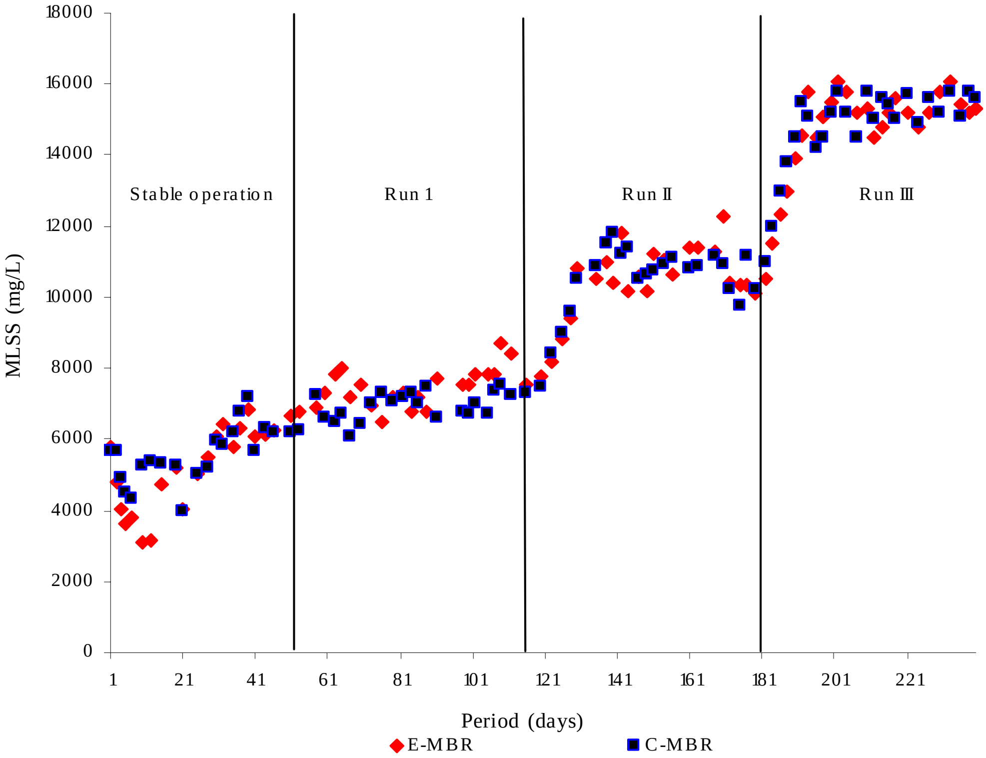

Fig. 1: MLSS profile during the period of study

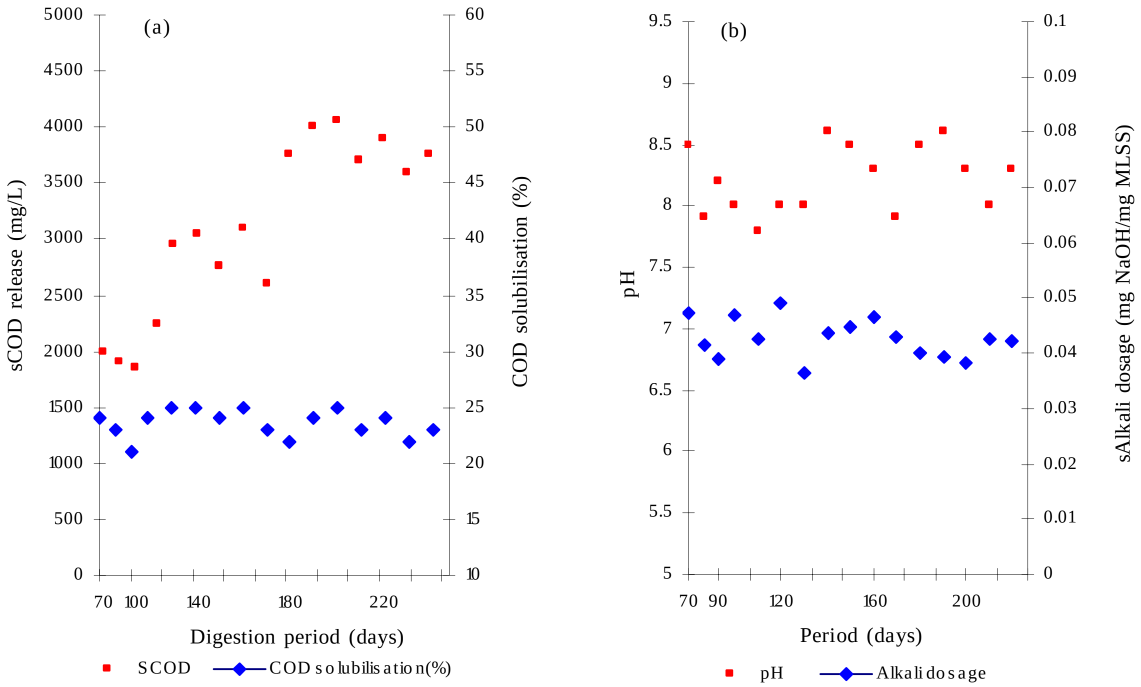

Fig. 2: Effect of thermochemical digestion on mixed liquor solubilisation (a) and pH (b)

was again initiated and MLSS was maintained around 11000 mg/L. Like wise Run III was initiated on day 180 and MLSS was maintained in the range of 15000mg/L.

Fig. 2a depicts the influence of thermochemical treatment on sludge solubilisation and sCOD release. For sludge pretreatment recommended temperature by Vlyssides and Karlis (2004) was used. Whereas the pH used for sludge disintegration was 11 and was found to be little lower than the optimum value of 12 (Neyens *et al*., 2003). While working on sludge digestion in aerobic reactor using the combination of ozone and alkali, Young *et al*. (2007) have reported that the usage pH 12 for sludge disintegration makes the process difficult to maintain pH inside the reactor between 7 and 8.

Considering the difficulties faced by Young *et al.* (2007) the present study uses pH 11 instead of 12. Sodium hydroxide was used as an alkali in the present study. Among the various alkalis tried for chemical hydrolysis, sodium hydroxide was found to be most efficient for inducing cell lysis (Rocher *et al*., 1999). Alkali added reacts with the cell walls in several ways including saponification of lipids in the cell walls, which leads to solubilisation of membrane. Disruption of sludge cells leads to leakage of intracellular material out of the cell. The soluble COD (sCOD) after digestion was measured and found to be in the range of 1850 to 4050 mg/L. sCOD was found to increase with increase in MLSS concentration subjected to sludge digestion.

The released sCOD can be helpful for denitrification process as it may act as a carbon source if the feed used was a low strength organic wastewater. It is known that solubilisation efficiency was used as an index for the efficiency of sludge disintegration. The solubilisation efficiency was calculated by using the equation formulated by Yeom *et al*. (2002). The thermo chemical sludge solubilisation efficiency was found to be in the range of 22 to 25 %. The presently observed solubilisation value was comparable to values reported by previous workers (Rajesh banu *et al*., 2008; Uan *et al*., 2010).

From the Fig. 2b it is clearly evident that an alkali dosage in the range of 0.039 to 0.46 mg NaOH/mg MLSS was required to achieve an average COD solubilisation efficiency of 24 %. This dosage was equivalent to 350 to 420 mg/L of NaOH. Whereas, researchers working on sludge pretreatment using alkali NaOH alone,

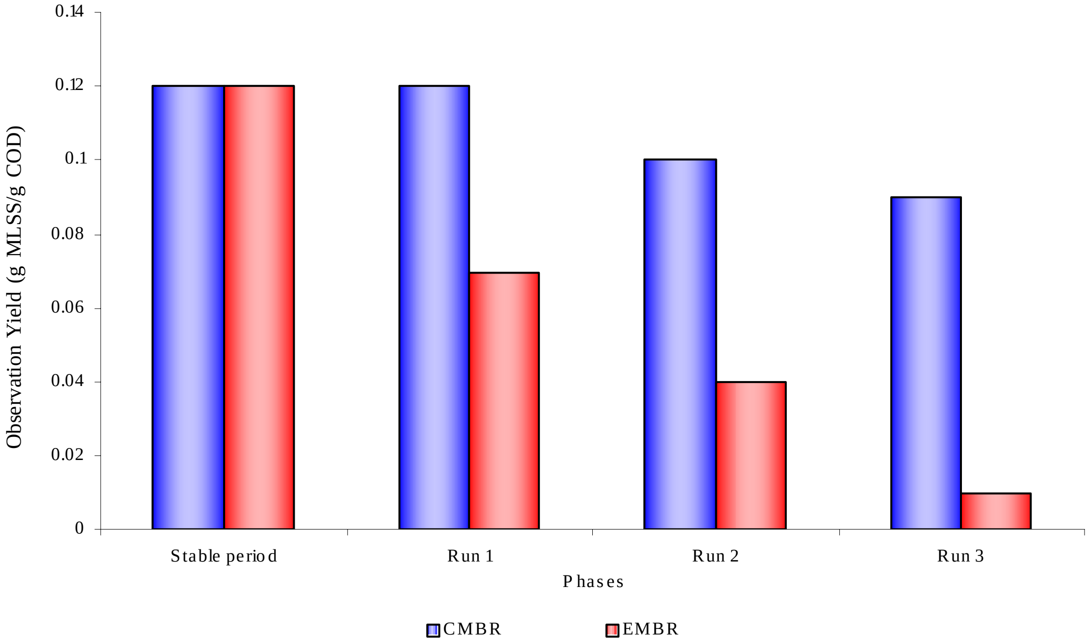

Fig. 3: The average observed yield during the period of study

required an alkali dosage of around 2 g/L to achieve 24 % sludge solubilisation (Kim *et al.*, 2003). From that it is evident that the combination of thermal and alkali sludge pretreatment could reduce the considerable amount of alkali usage. This will help in significant decrease of total treatment cost. Another advantage of thermochemical combination is that, the added alkali serves as a neutralizing agent to buffer the pH drop due to the sludge solubilisation. The other methods of sludge disintegration techniques such as acid ozone, and thermal produce solubilised sludge with acidic pH (Kim *et al.*, 2003) and it require further buffering before it reintroduced for successive treatment. The pH of the solubilised sludge was found to be in the range of 8 to 9.5. This slight alkaline solution can also be used to buffer pH loss in A2/O reactor during nitrification process. In overall, the combination of alkali and thermal treatment appears to be effective in reducing the alkali cost as well as controlling the pH in the reactor.

The observed yields (Yobs) for control membrane bioreactor (CMBR) and experimental membrane bioreactor (EMBR) were calculated and presented in Fig. 3. The average Yobs for the stable period was found to be 0.12 gMLSS/gCOD for both CMBR and EMBR. The presently observed Yobs value was comparatively lowers than a value of 0.4 gMLSS/gCOD reported for the conventional activated sludge processes (Metcalf and Eddy, 2003). The difference in observed yield of these two systems is due to its working MLSS concentration. The thermo chemical sludge pretreatment was started on day 60 for EMBR. CMBR was used as a control to study the effect of sludge pretreatment on sludge production.

Fig. 5 explains data on average Yobs for the three different phases namely run I, II and III. These phases demonstrate the role of sludge disintegration in controlling the excess sludge production. The Yobs for run I was found to be 0.12 gMLSS/gCOD for CMBR and 0.07 gMLSS/gCOD for EMBR, respectively. It is interesting to note that the Yobs for CMBR was also start to decrease from 0.12 to 0.09 gMLSS/gCOD when MLSS was increased from 7500mg/L (Run I) to 15000 mg/L. The decrease in Yobs with increase in MLSS concentration is attributed to low biomass production at high MLSS concentration. (Visvanathan *et al.*, 2000). In the case of EMBR, the observed yield for run III was found to be lower than its previous two runs, namely I and II. The Yobs for run III, II and I were found to be 0.01, 0.04 and 0.07gMLSS/gCOD, respectively. This is due to the fact that at run III, more amounts of biosolids were subjected to be sludge digestion and also due to low biomass production at high solid concentration.

The daily sludge production was calculated by following methods detailed in Uan *et al.* (2009). By summing up the daily sludge production during the study period, the total accumulated daily sludge production ($DSP_{accumulated}$) was calculated.

$$DSP_{accumulated} = \sum_{day=1}^{i} DSP_{day}$$

Graphic representations of daily accumulated sludge versus the three different runs were presented in Fig. 4. During the initial period of stable operation solid production for EMBR and CMBR was nearly the same. At run I the solid production for EMBR and CMBR accounts for 195 SS/g and 323 SS/g, respectively. This accounts for 39.5 % of sludge reduction and was calculated from the graph. Similar to our study working on sludge reduction in activated sludge process, Rocher *et al.* (1999) have reported about 30 % sludge reduction. The total amount of sludge accumulated for run II and III were found to be 159 and 116 SS/g for CMBR and 64 and 33 SS/g for EMBR. From the data, it is evident that, when compared to CMBR, the EMBR reduced 60 and

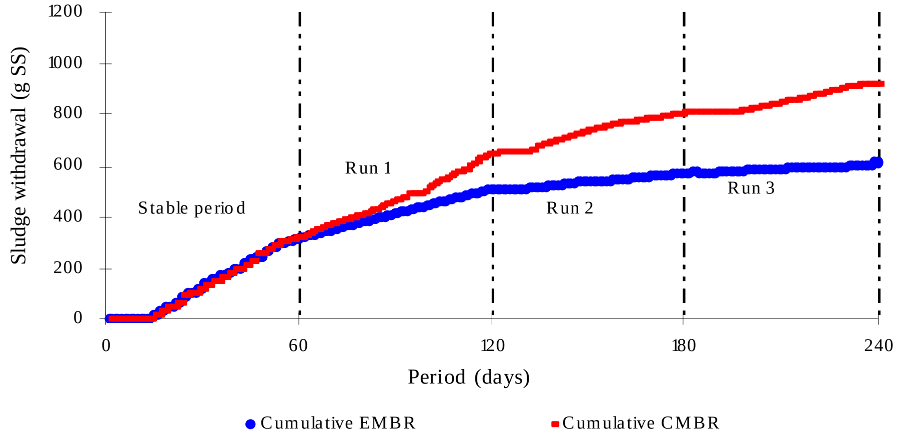

Fig. 4: Daily sludge production in MBRs during the period of study

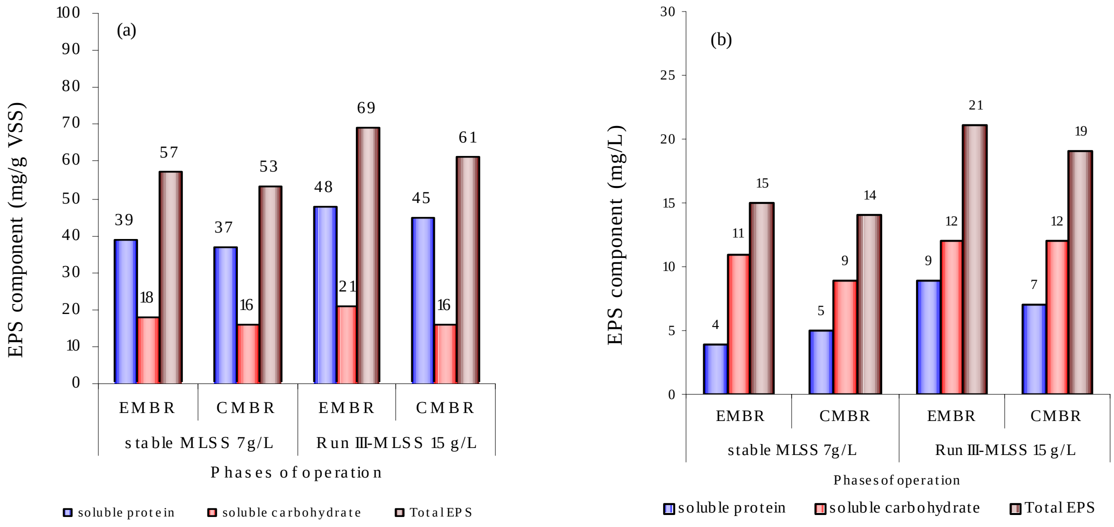

Fig. 5: EPS profile of the MBRs during the period of study

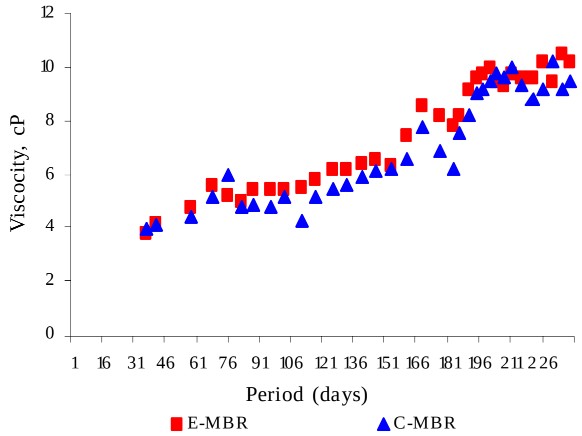

Fig. 6: Variation of viscosity in MBRs during the period of study

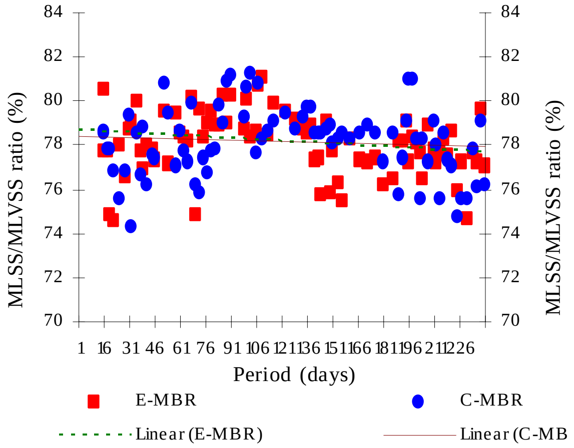

Fig. 7: MLSS/MLVSS profile of MBRs during the period of study

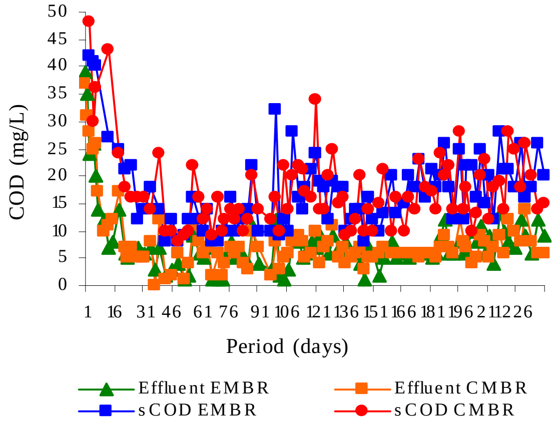

Fig. 8: Variation of COD profile in aerobic basin and effluent of MBRs

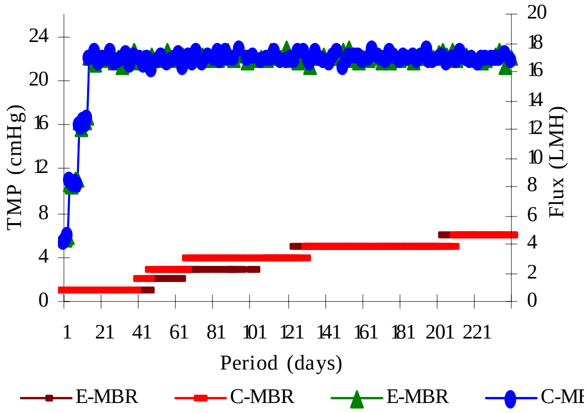

Fig. 9: Variation of TMP during the study period of MBRs

72 % of the total amount of sludge for run II and III, respectively.

EPS is one of the principle components responsible for biofouling of membrane (Kelly *et al*., 1993). Fig. 5a and b show the bound and soluble EPS components for EMBR and CMBR. The amount of total bound EPS was found to be higher at run III for both the MBRs. At run III both the MBR were operated with high MLSS and this may be the reason for elevated bound EPS at higher MLSS concentrations. The main source for soluble EPS (sEPS) in mixed liquor is Abiomass decay and cell lysis. The high concentration of sEPS led to hydrophobic sludge and was attributed membrane fouling by adsorption, a specific interaction between protein and membrane and by deposition during filtration (Sombatsompop *et al*., 2006). It is believed that cell lysis by sludge pretreatment increases the sEPS concentration of the mixed liquor. In this study, it was found that the soluble protein concentration of CMBR (19 mg/L) and EMBR (21 mg/L) was nearly the same at the end of run III. From the finding it can be concluded, that in EMBR the released sEPS was degraded and there is no buildup of sEPS. Viscosity of the mixed liquor plays a major role in limiting the oxygen transfer and foul MBR system (Wei *et al*., 2009). EPS can increase the viscosity of the liquids (Stal and Brouwer, 2003). In the present study there is no significant difference between the viscosities of both MBRs (Fig.6) through out the operational period. Viscosity of both reactors increases with increase in MLSS concentration. It is known that increase in MLSS concentration can increase the viscosity (Visvanathan *et al*., 2000). It appears that the sludge disintegration system does not increase the viscosity of the mixed liquor and presumably its fouling potential.

From the Fig. 7 it is clearly evident that the volatile fraction of the mixed liquor solids in C-MBR and E-MBR are almost identical in the range of 75 to 80 %. Most of the inorganic fraction of the degraded cells did not accumulate in the reactor and presumably permeated through the membrane as ionic species. Similar to our study, while Aon sludge recycling in aerobic MBR reactor treating domestic wastewater Young *et al*. (2007) have reported, that there is no change in volatile fraction of the mixed liquor before and after the sludge pretreatment.

In contrast to our study Yasui *et al*. (1996) have reported a decrease in MLSS/MLVSS ratio by 10 % for MBR treating pharmaceutical wastewater over a period of 9 months. It may be due to the characteristics of wastewater and not due to the sludge pretreatment process as pharmaceutical wastewater contain lot of inorganic substances. In that case, the extent of inorganic accumulation may not depend upon the inorganic substances released from disintegrated cells. The observation in this study strongly indicates that most of the inorganic from the disintegrated cells do not accumulate in the reactor as particles.

Fig. 8 shows variation in COD removal efficiency of A2O-MBR reactor during the study period. It is evident from the figure that, the COD removal efficiency of A2O system remains unaffected before and after the introduction of sludge reduction practices. A t-test analysis showed that the differences between EMBR and CMBR are not statistically significant. However, it has been reported that, in wastewater treatment processes including disintegration-induced sludge degradation, the effluent water quality is slightly detoriated due to the release of nondegradable substances such as soluble microbial products (Yasui *et al*., 1994; Sakai *et al*., 1997; Yoon *et al*., 2004). The COD removal increased with increase in time during the initial phases of reactor operation and it attains steady state on day 19. From then onwards, the COD removal was in the range of 96-98 % (calculated from the graph). During stable operational period, the sCOD concentration in the aerobic basin of MBRs was found to be 12 to 32 mg/L for EMBR and 14 to 36 mg/L for CMBR respectively. Corresponding organic concentration in the effluent was varied from 2 to 14 mg/L for EMBR and 2 to 16 mg/L for CMBR respectively. From that, it can be concluded that the membrane separation played an important role in providing the excellent and stable effluent quality.

The suction pump was started after the first week of seeding and was based on the sCOD of the aerobic basin. The pump was started when sCOD in the aerobic basin was 35 mg/L. The designed flux for the membrane was 17 LMH. This was achieved by stepwise increase of flux from 25 % to 100 % over a period of three weeks.

Fig. 9 shows the transmembrane pressure (TMP) variation during the operational period. A sudden change in TMP is an indicator of membrane fouling (Hassani *et al*., 2008). It indicates that, transmembrane pressure increased slowly over a period of 240 days. At the end of 240 days of reactor operation, the TMP was found to be 6 cmHg. It appears that the sludge disintegration system does not play role in membrane fouling.

Similar to our study, while working on sludge reduction practices in MBR, Young *et al*. (2007) have reported that, the alkaline treatment of sludge didn't cause membrane fouling. From the above findings, it can be concluded that, stable operation of MBR process was possible without significant accumulation of biomass when a part of the biological solids were disintegrated with alkali at pH 11 and temperature at 75 °C. The TMP was maintained less than 6 cmHg, indicating no significant occurrence of membrane fouling. There is no increase in effluent COD concentration after the introduction of sludge pretreatment. It appears that the solubilized fraction of the mixed liquor obtained by the chemical sludge disintegration might be easily biodegraded by other microorganisms.

CONCLUSION

It can be concluded, that stable operation of MBR process was possible without significant accumulation of biomass when a part of the biological solids were disintegrated with alkali at pH 11 and temperature 75 °C. Thermochemical sludge digestion favors the solubilisation of excess sludge and makes it amenable for further biodegradation. The thermochemical sludge pretreatment resulted in 72 % excess sludge reduction. The system can run for a long period of time with any further detoriation in the effluent COD concentration. There is no significant increase in EPS concentration after the introduction of sludge pretreatment. The TMP maintained less than 6 cmHg indicating no significant occurrence of membrane fouling. Further studies focusing on fate of disintegrated sludge are in progress.

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