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Response of Membrane Bioreactor to Feed Starvation Shock Load

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Abstract: The impact of feed starvation condition on the biological characteristics and the performance of an aerobic submerged Membrane Bioreactor (MBR) system was investigated. The synthetic wastewater treated in MBR under steady-state condition showed 95% removal of COD, 98% removal of TOC and suspended solids, 88% of TKN removal and 30% removal of phosphate. The system was subjected to a feed starvation shock load for five days and the response of the system in the process of recovering back to pre-shock steady-state condition was studied. After five days of shock loading, the effluent quality deteriorated showing traces of substrate leakage in effluent, large fraction of biomass wash off and reduction in microbial activity inside the reactor. The biological solids in the reactor reduced gradually from 15 g/L to 6 g/L, which took around a month for the biomass to revert back to its normal growth phase. The system required seven days to recover back to steady condition. Overall, the study showed a faster recovery of organic, solid, nutrients removal; however, the system took a month to regain the amount of biomass lost during feed starvation shock load.

Key words: Membrane bioreactor, feed starvation, shock load, activated sludge, wastewater treatment.

Introduction

Tighter controls on discharge limits of wastewater treatment systems have necessitated more elaborate and perhaps more expensive solutions than conventional biological treatment process (Cicek, 2003; Visvanathan et al., 2000). One of the recent modifications of conventional biological treatment processes is the Membrane Bioreactor (MBR) process. MBR is a combination of activated sludge process with membrane filtration where membrane system is used to separate the sludge from the effluent instead of a settling tank (Ye et al., 2005). Membrane bioreactor process has been applied widely in different wastewater treatment (Yamamoto et al., 1989; Trouve et al., 1994) and for water reuse and reclamation (Monti et al., 2001). MBR has proved to be an innovative technology with considerable advantages over conventional treatment methods and has provided a greater degree of treatment for varied pollutants than any other treatment process under steady state conditions.

Potential harmful environmental changes are usually called shock loads (Gaudy and Gaudy, 1981). Because of the variable nature of industrial wastes, reactor stability to shock loading is one of the most important aspects to be considered in the design of biological treatment systems. A reactor must show tolerance to fluctuations in characteristics of wastewater such as COD, temperature, pH and flow as these are most difficult to control in wastewater streams. In recent years significant attention is given in examining the behaviour of reactors after upsets or shock loads.

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Feed starvation is considered to be one of the type of shock load where no external substrate is applied, thus called as famine phase (Li et al., 2006). The microorganisms use organic matter as a carbon source for providing energy and cellular material. Catabolism transforms the organic pollutants into useful energy. The energy is consumed to satisfy maintenance functions and to fuel the anabolism of new biomass into metabolites (Oviedo et al., 2003). Hence, when substrate is not provided to the biomass, it is placed under stress. Such feed starvation shock may arise when there is temporary failure in the pipelines, which carry the wastewater to the treatment process; when wastewater is produced in batches; and during any natural calamity when the system is unable to operate. The objective of the study was to evaluate the performance and stability of MBR under sudden feed starvation shock load conditions and investigate its ability to recover back to steady state condition.

Materials and Methods

Experimental Design

The experimental set up consisted of a membrane bioreactor with a hollow fiber membrane immersed in it as depicted in Figure 1. The size of the bioreactor was 480 mm × 260 mm × 100 mm with a working volume of 6 L. The membrane is a polyethylene hollow fiber membrane with pore size and surface area of 0.42 μm and 0.2 m^2 respectively.

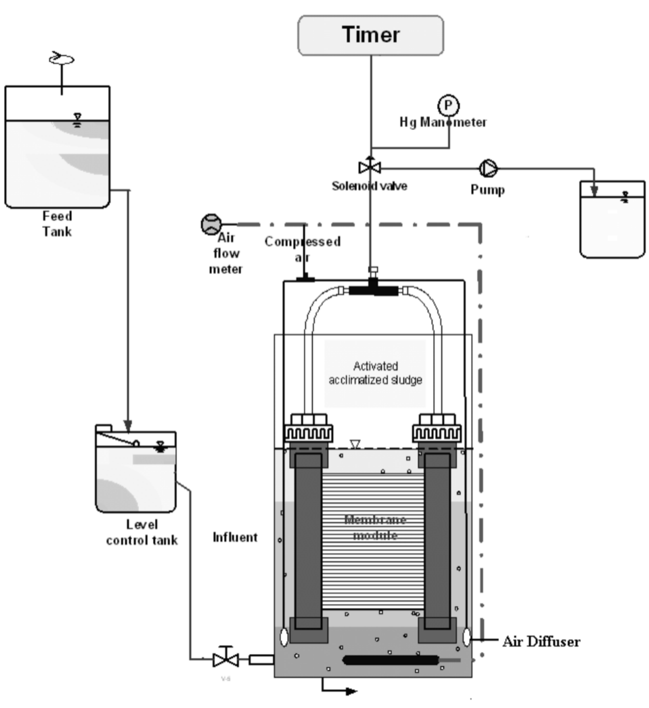

Figure 1: Schematic diagram of laboratory scale Membrane Bioreactor.

The wastewater was simulated sewage, which contained the following per litre of water: 278 mg glucose, 278 mg starch, 52.8 mg KH_2PO_4, 66 mg $MgSO_4.7H_2O$, 6 mg $MnSO_4.7H_2O$, 6 mg $CaCl_2$, 0.3 mg $FeSO_4$, 111 mg $NaHCO_3$, 167 mg $(NH_2)_2CO$ (Huang et al., 2000). The characteristics of the simulated sewage are presented in Table 1. The wastewater was fed to the reactor from a tank provided with a stirrer to maintain homogeneity of influent feed. An air pump, a diffuser located beneath the membrane module and two stone diffusers at the sides were used to provide aeration. The membrane filtered effluent was continuously removed at a flow rate of 750 mL/h using a peristaltic pump connected to the membrane module through solenoid valve operating with a filtration cycle of 10 min "On" and 2 min cut "Off". An influent pump controlled by water level sensor was used to maintain the liquid level in the bioreactor throughout the experimental period. The experiment was conducted at a hydraulic retention time of eight hours and a dissolved oxygen concentration of 2-4 mg/L. The MLSS concentration in the reactor was maintained at 10-15 g/L. The pH of the reactor was maintained between 6.3 and 7.2.

Table 1: Characteristics of Simulated Sewage

Sl. No.	*Parameters*	*Value*
1.	pH	7.3 - 7.5
2.	Conductivity (μS/cm^2)	1526 ± 15
3.	Biochemical Oxygen Demand (BOD) (mg/L)	620 ± 20
4.	Chemical Oxygen Demand (COD) (mg/L)	1268 ± 50
5.	Total Kjeldhal Nitrogen (mg/L)	134 ± 5
6.	Phosphate (mg/L)	25 ± 2
7.	Total Solids (mg/L)	2250
8.	Total Dissolved Solids (mg/L)	583 ± 50
9.	Total Suspended Solids (mg/L)	1500±100
10.	Total Organic Carbon (mg/L)	330 ± 20

Reactor Operation

The MBR was operated and stabilized for 30 days at a HRT of 8 h. During the steady state condition, the effluent quality was studied in terms of COD, TOC, TSS, TKN and phosphate. The biomass characteristics of the reactor were studied by quantifying MLSS and MLVSS concentration.

After 30 days of steady state operation, the reactor was subjected to feed starvation shock load for five days after which the reactor was reverted back to pre-shock or normal steady-state condition. During the shock the reactor was not fed with simulated sewage and kept in idle state for five days by just providing aeration to the reactor (Oviedo et al., 2003). The feeding of simulated sewage was restarted after five days and the reactor returned to steady state continuous operation. The impact of the feed starvation shock load on the performance of the reactor was studied by comparing the effluent quality in terms of COD, TOC, TSS, TKN and phosphate removal under steady-state and shock loading conditions. Even the biomass characteristics were studied under shock loading conditions. The reactor was operated under normal condition for few days to monitor the long-term consequences of shock loads.

Analytical Methods

Measurement of COD, TKN (Total Kjeldhal Nitrogen), phosphate, total suspended solids in the influent and effluent and MLSS and MLVSS in the sludge were done according to the Standard Methods for the examination of Water and Wastewater (1998). TOC was analyzed using TOC analyzer micro N/C model manufactured by Analytica Jena (Germany). The microbial population was determined by Total Plate Count (APHA, 1998). All the samples were analyzed in triplicates.

Results and Discussion

Removal of Organic Matter

The COD and TOC concentration of the effluent during steady-state and shock loading condition are depicted in Figures 2(a) and (b). The influent COD and TOC was maintained at 1268 ± 50 mg/L and 330 ± 20 mg/L, respectively. During the steady state condition, the average COD and TOC concentration of the effluent were 64 mg/L (95% removal) and 9.3 mg/L (98% removal), respectively. On the first day after the 5-day shock load, the effluent COD and TOC showed a drastic increase to 132 mg/L and 151 mg/L respectively. This sudden increase might be due to the release of organic material contained in the cellular protoplasm resulting from the death of microorganisms. Similar results have been reported by Oviedo et al. (2003). Also the cells would have undergone autodigestion resulting in the release of materials inside the cell to outside liquid medium (Gaudy and Gaudy, 1981). When the reactor was reverted back to pre-shock condition, slowly and gradually the COD and TOC started to decrease and they recovered back to steady-state condition after 6 days. On the 6th day of recovery, the TOC in the effluent was below the steady state indicating the use of carbon source by the microorganism after the long starvation period as reported by Li et al. (2006).

Total Suspended Solids Removal

The TSS concentration during steady state and shock loading condition is depicted in Figure 2(c). During steady-state condition, the average TSS concentration of the effluent was 20 mg/L. On the first day after the shock the suspended solids concentration was 135 mg/L which was six times higher than the steady state. However, it started to decrease from the second day of normal operation and reached steady-state condition within six days. The increase in the suspended solid concentration was due to the wash out of dead microorganisms from the reactor in the effluent.

Nutrient Removal

The TKN and phosphate concentration during steady state and shock loading condition is depicted in Figures 2(d) and (e). During the steady-state condition the average TKN and phosphate removal in MBR effluent was 88% and 30% respectively. After the starvation shock load, the TKN concentration in the effluent increased drastically from an average value of 15 mg/L to 93 mg/L on the first day after shock. This might be due to cellular lysis of microorganism under starvation condition inside the reactor, which has resulted in the release of large amount of protein in the effluent. The increase in effluent TKN concentration might also be due to the lack of utilization of nitrogen. The loss of biomass has triggered a temporary reduction in nitrification performance. Hence, corresponding to the washouts of biomass, TKN in the effluent increased. Similar result was also reported by Frederickson (2005). Immediately the next day after reversion to steady-state condition, the TKN concentration in the effluent started to decrease and reached the steady-state condition within six days of continuous operation.

Similar condition was also seen in the case of phosphate removal. The phosphate concentration increased from an average value of 16 mg/L to 59 mg/L on the first day after the starvation shock load. Phosphate acts as a storage product in a cell (Gaudy and Gaudy, 1981). Thus, when the biological system was subjected to starvation shock load, the biomass cells had undergone autolysis and as a result, the stored products were liberated, which were washed out along with the biomass in the effluent.

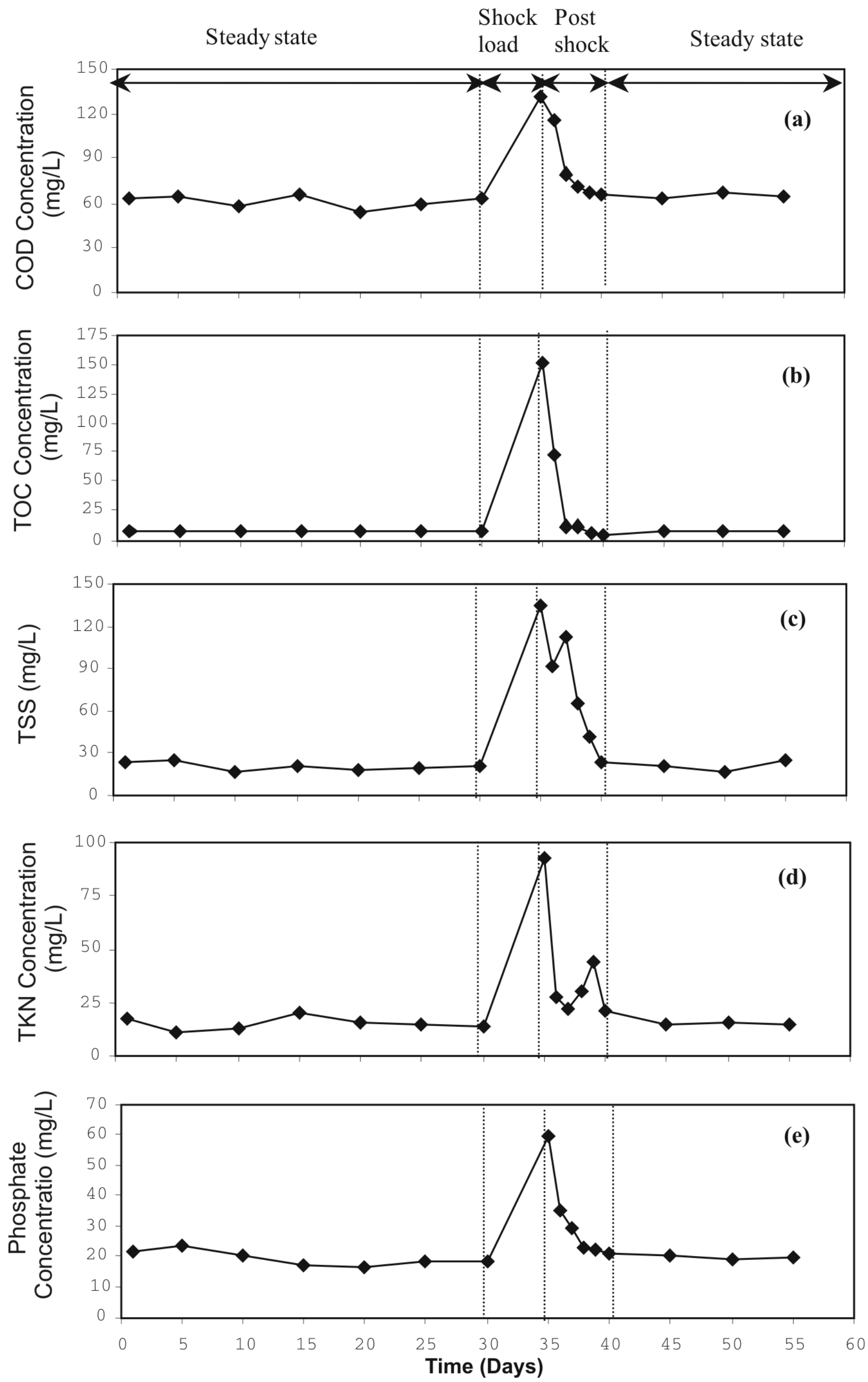

Figure 2: Variation of MBR effluent quality under steady state and shock load conditions—(a) COD, (b) TOC, (c) TSS, (d) TKN and (e) phosphate.

Microbial Activity in the System

During the feed starvation shock load, the microbial population existing in the system showed a sharp decrease. Almost all the biomass was completely destroyed from the system, as clearly indicated by the reduction in the number of Total Colony forming units from 18×10^6 CFU/mL to 4×10^6 CFU/mL. There was also a substantial decrease in MLSS and MLVSS concentration as depicted in Figure 3. This would have been due to the scarcity or non-availability of organic material in the system (Oviedo et al., 2003). The decrease was continuous even after return of the system to pre-

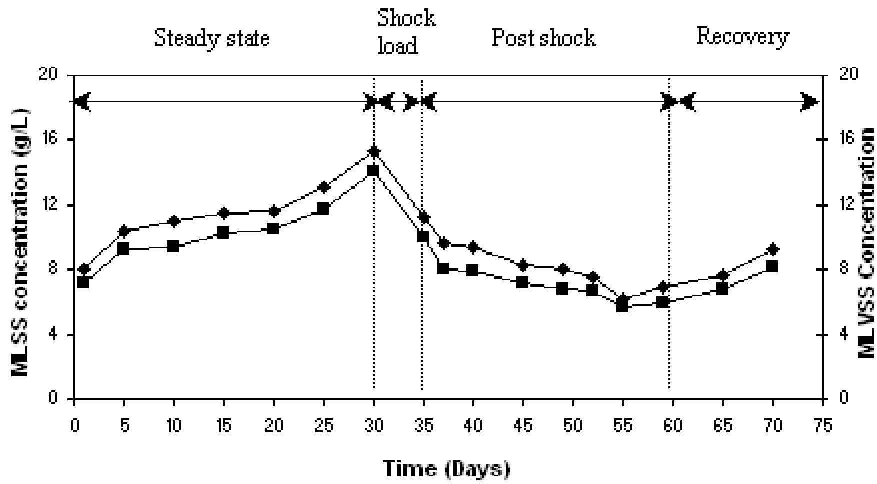

Figure 3: Variation of MLSS and MLVSS in MBR under steady and shock loading condition.

shock condition. A size reduction on the surviving colonies was also observed. Size reduction is one of the adaptational responses to starvation condition (Kjellberg et al., 1987). Starvation would have reduced the metabolism of bacteria, terminated the biological process in the flocs and caused non-living bacteria in the sludge. According to Sponza (2002), the accumulation of non-living bacteria and excretions from the cells due to lysis caused increase in polysaccharide and proteins in the flocs. Thus, only those organisms capable of metabolizing the substrates to gain energy for maintenance are left in the reactor.

Response of the Sludge in the Reactor

The MLSS and MLVSS concentration showed much of variation after the shock load as shown in Figure 3. The MLSS and MLVSS concentration in the reactor during the steady state was 15.3 g/L and 14 g/L, respectively. After the feed starvation shock the biomass in the reactor started to decrease. The sharp increase in the Total Suspended Solids concentration in the effluent coincided with the decrease in the sludge concentration, possibly due to degradation and death of microorganism in the reactor. Similar observation was also reported by Oviedo et al. (2003). The decrease in the MLSS and MLVSS concentration was gradual and it lasted for about 20 days. The biomass started to recover to steady-state condition only after 20 days. The reactor biomass decreased to a MLSS of about 6 g/L and it took much longer time to recover and regain its growth phase.

The pH of the reactor contents underwent significant change over the course of the starvation period. The pH inside the reactor during steady-state condition was around 6.5 to 7.2 which increased to 8.2 during the feed starvation period. The pH returned to steady-state condition immediately after regular operating conditions. Similar pH increase was also observed by Oviedo et al. (2003), where initial pH increase was due to the release of ammonium into the medium that resulted due to protein hydrolysis and degradation of sludge constituents.

Conclusion

The MBR showed excellent organic, nutrient and suspended solids removal efficiency when operated at a steady state for about 30 days at a HRT of 8 h. The MBR was then subjected to a feed starvation shock load of five days. From this experiment performed under feed starvation condition, it is evident that under steady-state condition the MBR showed 95% removal of COD, 98% removal of TOC and TSS, 88% of TKN removal and 30% removal of phosphate. But upon feed starvation shock load, the performance of the MBR was affected, the effluent quality deteriorated and it showed substrate leakage in the effluent during the reversion to steady state condition. The system was able to recover to steady-state condition after six days of continuous operation of MBR.

Also the MBR showed 60% reduction in the biomass and its recovery was very slow and it took nearly 20 days of normal operation for the biomass to grow back and retain its growth phase. The MBR can recover back to steady-state condition much faster in terms of organic and nutrient removal but in terms of biological solids build up or recovery it takes about a month. Hence when such starvation shock load occurs, the MBR system takes a longer time to revert back since the biomass recovery is slow. Thus, the feed starvation of five days has a negative effect on the MBR system.

References

Gaudy, Anthony, F. Jr. and Elizabeth T. Gaudy (1981). Microbiology for Environmental Scientists and Engineers. McGraw Hill International Book Company.

APHA (1998). Standard methods for examination of water and wastewater, 20th Edition. APHA, Washington DC, USA.

Cicek, N. (2003). A review of membrane bioreactors and their potential application in the treatment of agricultural wastewater. *Can. Biosys. Eng*., **45:** 6.37-6.46.

Coello Oviedo, M.D., Lopez-Ramirez, J.A., Sales Marquez, D. and J.M. Quiroga Alonso (2003). Evolution of an activated sludge system under starvation condition. *Chemical Engineering Journal*, **94:** 139-146.

Kjellberg, S., Hermansson, M., Marden, P. and G.W. Jones (1987). The transient phase between growth and non-growth of heterotrophic bacteria with emphasis on the marine environment. ANN. *Rev. Microbiology*, **41:** 25-49.

Kristinn Cameron Frederickson (2005). The Application of Membrane Bioreactor for wastewater treatment on a Northern Manitoban Aboriginal community. Master of Science Thesis.

Li, Z.H., Kuba, T. and T. Kusuda (2006). The influence of starvation phase on the properties and the development of aerobic granules. *Enzyme and Microbial Technology*, **38:** 670-674.

Monti, S., Belli, L., Pavan, P., Battistoni, P. and F. Cecchi (2001). Proc 1st International Symposium Membranes, Tel Aviv.

Sponza, D.T. (2002). Extracellular polymeric substances and physiochemical properties of flocs in steady and unsteady state activated sludge systems. *Process Biochemistry*, **37:** 983-998.

Trouve, E., Urbain, V. and J. Manem (1994). Treatment of municipal wastewater by a membrane bioreactor: results of a semi industrial pilot scale study. *Water Science Technology*, **21:** 43-54.

Visvanathan, C., Ben Aim, R. and K.M. Parameshwaran (2000). Membrane separation bioreactor for wastewater treatment. *Critical Review Environmental Science Technology*, **30(1)**.

Xia Huang, Rui Lui and Yi Qian (2000). Behaviour of Soluble microbial products in a membrane bioreactor. *Process Biochemistry*, **36:** 401-406.

Yamamoto, K., Hiasa, M., Mahmood, T. and T. Matuso (1989). Direct solid-liquid separation using hollow membrane in an activated sludge aeration tank. *Water Science and Technology*, **21(4):** 43-54.

Ye, Y., Le Clech, P., Chen, V. and A.G. Fane (2005). Evolution of fouling during cross flow filtration of model EPS solution. *Journal of Membrane Science*, **264:** 190-199.