Membrane Bioreactor Coupled with Sequential Batch Reactor: A Supportive Technology in Effluent Recycling Of API Manufacturing Industries

Srinivasarao Gangavarapu, Uma Maheswara Rao Ganguru, Sunil Kulkarni, Narasimha MurthyBrahmandam, Srinivasa Anumula

Abstract— **Membrane Bioreactor (MBR) combined with Sequential Batch Reactor (SBR) was operated for treatment of wastewater generated in a medium scaleActive Pharmaceutical Ingredients (API) manufacturing unit. Parameters considered to investigate the performance of pilot plant wereChemical Oxygen Demand (COD), Biological Oxygen Demand (BOD) and Total Suspended Solids (TSS). However, to support the investigation, effluent Total Dissolved Solid (TDS) was also characterized. The studies indicated92.3 percent reduction in COD, 96.0 percent in BOD and 100 percent in TSS, and no significant effect on TDS reduction was found.The effluents streams taken up for study were characterized, neutralized, equalized and fed in SBR, which is a fill and draw activated sludge process driven by micro biological mass. The SBR out lets werereduced73.0, 79.9 and 76.3 percent by load in terms of COD, BOD and TSS respectively. The SBR outlets were fed in MBR, which is a membrane based reactor, where a further reduction of COD, BOD and TSS by72.0, 79.7 and 100 percent respectively was achieved. After successful pilot studies, it was found that the MBR combined with SBR can be operated positively for wastewater treatment in API manufacturing units, where effluent can be recycled after Reverse Osmosis (RO) polishing.**

Index Terms— **API Unit, BOD, COD, MBR, Re-cycle, SBR, Wastewater**

I. INTRODUCTION

Increasing industrialization trend in the worldwide has raised in generation of industrial effluents inlarge quantities. A large number of industrial sectors, and huge amount of production, have usually large changes in product mix, making difficulty in industrial wastewater treatment [1],[2]. MBR (Membrane bio-reactor), is an admirable modern wastewater treatment technology, having several benefits over conventional activated sludge processes [3]. It is a membrane separation technology and bio-organic combination of a new wastewater treatment technology. By

utilizing membrane, MBR separates the activated sludge and other biological/Organic matter in wastewater[4]. MBR process is called as a hybrid system, as it works with biological treatment in conjunction with separation. Operation of MBR with combination of conventional activated sludge system produce high quality treated effluent, which can be potentially suitable for recycle [5]. MBR can be operated at sludge concentrations up to 18000 - 19000 mg/l [6].

The technology of MBRcan be utilized in biochemical engineering processes, where it can be employed as suspended growth bioreactor (such as; fermentation, bio-oxidation, nitrification and denitrification)and also for solid liquid separation [7].Lab operated MBR systemconsisting of up flow anaerobic sludge blanket reactor shown approximately98% Chemical Oxygen Demand (COD)removal and 100% in Total Suspended Solids (TSS) removal inmunicipal wastewater [8].The principle behind MBR operation is almost same as activated sludge process, exceptingthat separation the water and sludge through settlement, where the MBR uses the membrane whichis more efficient and less in need of oxygen concentration in water [9].

Since past few years, due to several benefits, which includes excellent permeate quality, low sludge production, small foot print, and flexibility in future expansion, submerged MBR processes have practiced in domestic and municipal wastewater treatment [5] [10]. Application ofMBR technology for industrial wastewater treatment has also added attention because of the strength of theprocess, high organic loadings and very specific biorefractory. The technical features of the reactor play an important role in solid separation and biomass selection [11]. However, the efficiency in the removalof the organic load determined by the type of industrial process that has been employed.

The Sequential Batch Reactor (SBR) is a fill and draw activated sludge process. The SBR consisting wastewater enters partially filled SBR, containing biomass, which is acclimated to the waste water constituents during preceding cycles. Once the reactor is full, it behaves like

Srinivasarao Gangavarapu: Head, API Environment Head, Mylan Laboratories Limited, Hyderabad, India.
Uma Maheswara Rao Ganguru: Mylan Laboratories Limited, Hyderabad, India.
Sunil Kulkarni: Head, EHS, APAC, Mylan Pharmaceuticals Private Limited, Global Hyderabad.
Narasimha Murthy Brahmandam:,Head, Corporate Environment, Aurobindo pharmaceuticals, Hyderabad, India.
Srinivasa Anumula: Manager, Mylan Laboratories Limited, Hyderabad, India.

a conventional activated sludge system, but without continuous influent or effluent flow. The aeration and mixing is discontinued after the biological reactions are complete. The biomass settles, and the treated supernatant is removed. Excess biomass is wasted at any time during the cycle[12].

Wastewater generates from API units is a complex mixture of organic and inorganic substances. Non process wastewater is basically characterized by inorganic salts whereas the composition of process wastewater is a mixture of both organic and inorganic constituents including various solvents with varying proportions. However, the composition of wastewater varies from product to product and hence is dependent on the type of product mixture manufactured [1].

Over the above advantage,we made an attempt to operate pilot scale MBR system combined with SBRto treat a medium scale product mix contained API manufacturing industrial effluents.

II. Materials and Methods:

A. Industrial Effluent

In the selected API manufacturing unit, the effluents are collected and segregated as high and low concentration streams. If COD >15000 mg/l and TDS (Total dissolved solids)>8000 mg/l, it is considered as high concentration streams. If the effluent stream contains COD of < 15000 mg/l and TDS of <8000 mg/l, it is considered as low concentration streams.The segregation is based on the concentration limits of either of the parameters as high or low concentration streams.

Present study is focused on low strength concentration streams. The characteristics of effluents used for treatment is tabulated in Table 1.

B. Sequenced Batch Reactor

The SBR, contained 4 numbers of Roller Compacted Concrete (RCC) compartments with holding capacity of 200 KL (Kilo Liter) each, and the compartments are connected to a RCC Decant tank with total holding capacity of 50 KL. The SBR compartments are equipped with diffused aeration with blowing capacity of 450 m3/hr. Supplementation of feed to SBR done by the feed pump with maximum capacity of 15m3 per Hour. Followed by the Decant tank, a Lamella settler was provided where the overflow feed to the MBR and the sludge was collected to the Sludge collection Tank. All the effluents before feeding to SBR were neutralized and equalized in dedicated tanks. Schematic of pilot plant is provided as Fig.-1.

C. Membrane Bioreactor

The MBR unit consists of a membrane case consisting multiple membrane cartridges, which are connected to a manifold with transparent tubes. The diffuser case has diffuser pipes inside. Membrane sheets are made from chlorinated polyethylene with nominal pore size of 0.4µm. Treated water permeates through the membrane sheets and internal spacers to come out via the nozzle. Product of the MBR(which is also called as permeate) can be supplemented to Reverse Osmosis (RO) system for further polishing and the rejects which collects from nozzles send to sludge tank for further decanting process. Removal of debris, garbage or any other solid substances from the influent was achieved by passing through a fine screen or mesh (1 mm to 3 mm). The design operational conditions are 3000 to 5000 mg/l MLSS, Viscosity less than 100 mPa · sec and Dissolved oxygen concentration is 1 mg/l or more.

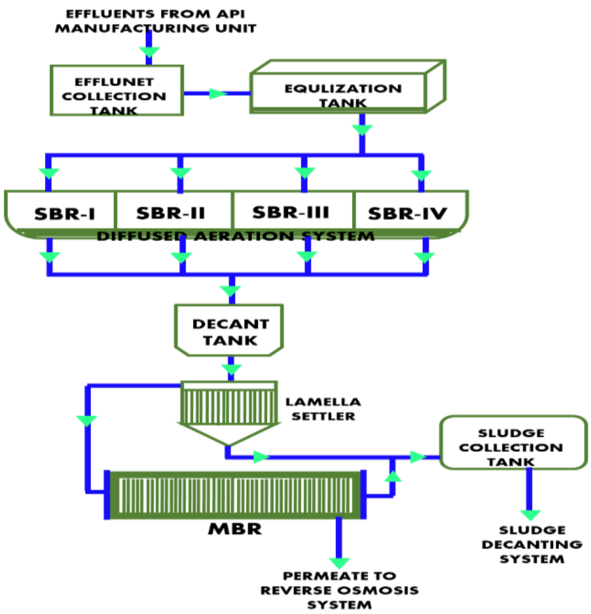

Fig. 1 Schematic of pilot scale plant operated for treatment of API manufacturing industrial wastewater.

D. Treatment of API effluents

All effluents generated in API manufacturing units are collected in dedicated effluent collection tank before sending for equalizationwhere the effluents were neutralized (i.e., correcting the pH by adding caustic lye solution or HCl) and equalized by blowing air from the bottom of the equalization tank. The range of pH maintained was 6.5 to 8.5. The neutralized and equalized effluent fed to SBR, which is a fill and draw activated sludge system, having the facility of equalization, aeration, and clarification. After feeding certain quantity of effluent, aeration was started and no effluent were allowed during this time. MLSS was maintained between 2000 to 4000 mg/l and DO levels are between 1 to 2 mg/l. Turned off the aeration for at least 2 hours to allow the biomass to settle and drawn the clear supernatant from SBR to decant tank. The decant tank overflow collected in lamella clarifier where effluents clarified extremely. Clarifier outlet was passed through MBR system where diffuser air of 1.25 to 1.87 m3/min required. Effluent flow quantity was followed as per system design. The entire system and individual units performance was investigated with the help of physical, chemical and biological parameters in various intervals (i.e., end of the day 1, 2, 3, 4, 5… and 30).Values were considered after stabilizing the system.

III. RESULTS AND DISCUSSION:

A. Effluent Characteristics and Hydraulic Loads

In the present investigation, effluents were characterized in various stages of pilot scale operations, and obtained values are presented in table 1. Raw effluents loads, fed to the pilot plant werewithin the designed specifications. The average feed quantity was 65 and 64 Kiloliter per Day (KLD) for SBR and MBR respectively. For ease of discussion, henceforth,loads of all parameters, viz., COD, BOD, etc are presented in terms of kilograms/day (KPD) based on average volumes of feeds to SBR or MBR.

Table. 1: Characteristics of Wastewater

S.No.	Parameter	Unit	Raw effluent/ SBR Feed	SBR Outlet/ MBR Feed	MBR Outlet	Method of Analysis
1	pH	---	7.89	7.96	7.68	pH Electrode method
2	COD	mg/l	8712	2318	658	HACH COD track, USA
3	BOD	mg/l	3262	652	128	HACH BOD track, USA
4	TSS	mg/l	1573	364	0	Gravimatory, millipore
5	TDS	mg/l	3387	3372	3235	Gravimatory, watt man

B. SBR performanceand Loads

The average COD fed to system was 561.8 KPD (Kilograms Per Day), the BOD, TDS and TSS loads were 210.6, 217.1 and 101.4 KPD respectively. The Outlet of SBR contained loads of 148.8, 41.9, 215.8 and 23.4 KPD for COD, BOD, TDS and TSS respectively. In pilot scale fill and draw activated sludge process (SBR), 73.0 percent of COD reduction was achieved. The BOD reduction was 79.9percent, also the TSS reduction was 76.3 percent.However, there is no significant reduction in TDS, as TDS removal cannot be performed in biological system. Fig. 2 showing overall SBR performance in loads reduction.

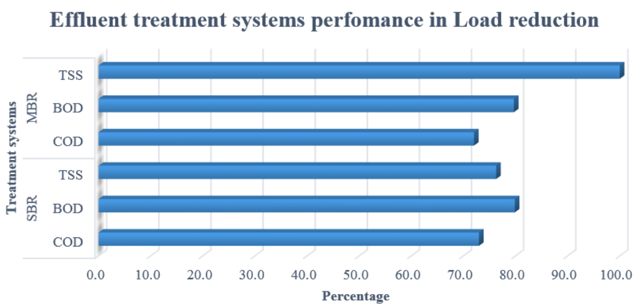

Fig. :2Treatment systems (i.e., SBR & MBR) performance in loads reduction of various parameters.

C. MBR performance and Loads

The MBRwas fed by the outlet of the SBR, the MBR permeate contained average COD of 42.3 KPD, whereas the BOD load reduced from 41.9 to 8.2 KPD. However, the outlet is almost free from TSS. The thirty days average COD reduction was72.0 percent. It was79.7 percent for BOD whereas TSS was nil. The membrane system operated in the present system is designed especially for 100 percent removal of TSS in wastewater. Overall MBR performance in loads reduction is presented in Fig. 2.

Various pilot scale studies were conducted, pilot scale studies in similar manner conducted with MBR combined with a two-phase anaerobic digestion (TPAD) system for treating chemical synthesis-based pharmaceutical wastewater [13]. A full-fledged pilot scale investigation waste made for rejection of 14 pharmaceutical pollutants, 6 synthetic hormones, 2 antibiotics, 3 personal care products and 1 flame retardant chemical from drinking water and wastewater, however, the attempt was failed in elimination of above pollutants [14]. Pharmaceutical wastewater treatment with a pilot-scale plant was studied by a membrane bioreactor (MBR) process in southern Taiwan, the investigation reported that there is no suspended solids in outlet of MBR also the author reported that the MBR system can be used to treat high-strength and fluctuating strength wastewater [15].

Also the same studies conducted in the laboratory with a Submerged MBR plant for removal of pharmaceutically active compounds [16]. Various MBR based studies were conducted by the researcher for removal of various pollutants from municipal wastewater and household chemical wastewater, however, no significant effect was found un-removal of household chemical traces [17]. A laboratory study conducted in China with wool mill wastewater shown excellent effluent quality useful for recycle [18].

Fortified samples were also investigated for various synthetic compounds separation, however, no much effect was found on removal chemical compounds [19]. Sulfonamides, macrolides and trimethoprim compounds elimination with MBR in raw wastewater was investigated in several municipal wastewater treatment plants [20].

An investigation made with MBR post treatment of secondary wastewater contains 80% textile and 20% of municipal wastewater to recycle treated wastewater in industrial premises after RO polishing of MBR outlets [21], [22]. A pilot test with MBR supported by activated sludge process in textile industry shown efficient result in reduction of color, TSS and COD. The study achieved a reduction of 93% in COD and 99 % in TSS [23].In other study, an attempt was also made in textile industry to reduce organic load by using MBR combining with aerobic, anoxic and anaerobic systems, where less energy consumed for overall treatment process [24] [25].

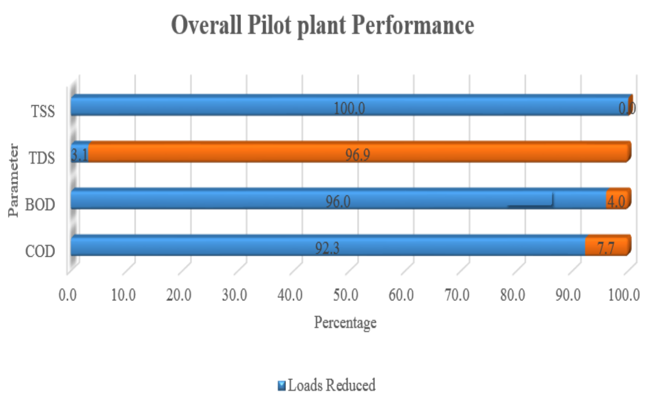

Fig. :3 Overall pilot plant performance in loads reduction.

IV. CONCLUSION:

The pilot scale operational studies employed with Membrane Bioreactor (MBR) combined with Sequential Batch reactor (SBR) shown a noble output, where the overall COD reduction was shown at 92.3 percent, and 96 and 100 percent in BOD and TSS respectively (Fig.3). The studies indicate that the API manufacturing unit wastewater can be affectively treated with MBR combined with SBR system, where the loads achieved in outlets are good to feed in Reverse Osmosis system to recycle wastewater and achieve zero wastewater discharge compliance.

REFERENCES

[1] Fernando, S.G.E.,The Book: Waste Water Treatment and Reutilization. Intech Open Access Publishers, 2011.

[2] Ming, Y. and De-Sheng, W., Experimental Study of Antibiotic Wastewater. Journal of MBR Treatment. Environmental Protection and Recycling Economy, 2010, 9, pp. 54-55.

[3] Judd, S.,The MBR Book: Principles and Applications of Membrane Bioreactors for Water and Wastewater Treatment. Elsevier, UK., 2010.

[4] Jianwen, Bin, S., Hang, F.L., et al. Test Membrane Bioreactor Wastewater Treatment Cephalosporin Pharmaceutical Study. Environmental Engineering, 2010, 28, pp. 65-66.

[5] Visvanathan, C., Aim, R.B. and Parameshwaran, K. Membrane Separation Bioreactors for Wastewater Treatment. Critical Reviews in Environmental Science and Technology, 2000, 30, pp. 1-48.

[6] Liaozhi, M. MBR Process of Fermentation Class Pharmaceutical wastewater Treatment Pilot Study. Journal of China Water & Wastewater, 2010, 26, pp. 131-133.

[7] Wang, L.K. and Menon, R. Treatment of Industrial Effluents, Municipal Wastes, and Potable Water by MembraneBioreactors. In: Wang, L.K., Chen, J.P., Hung, Y.-T. andShammas, N.K., Eds., Membrane and DesalinationTechnologies, Humana Press, USA, 2011, pp. 201-236.

[8] Ivanovic, I. Application of Biofilm Membrane Bioreactor (BF-MBR) for Municipal Wastewater TreatmentDoctoral Dissertation, Norwegian University of Science and Technology, Trondheim., 2011.

[9] Zheng, C.L., Zhao, L., Zhou, X.B., Fu, Z.M. and Li, A. Treatment Technologies for Organic Wastewater.INTECH Open Access Publisher, China., 2013.

[10] Yang, W., Cicek, N. and Ilg, J. State-of-the-Art of Membrane Bioreactors: Worldwide Research and Commercial Applications in North America. Journal of Membrane Science, 2006, 270, pp. 201-211.

[11] Klinkow, N., Oleksy-Frenzel, J. and Jekel, M. Toxicity-Directed Fractionation of Organic Compounds in Tannery Wastewater with Regard to Their Molecular Weight and Polarity. Water Research, 1998, 32, pp. 2583-2592.

[12] Ronald F. PoltakManual of Sequencing Batch Reactor design and operational Considerations. New England Interstate water Pollution Control Commission, 2005, pp. 1-20.

[13] Chen, Z., Ren, N., Wang, A., Zhang, Z.P. and Shi, Y. A Novel Application of TPAD-MBR System to the Pilot Treatment of Chemical Synthesis-Based Pharmaceutical Wastewater. Water Research, 2008, 42, pp. 3385-3392.

[14] Kim, S.D., Cho, J., Kim, I.S., Vanderford, B.J. and Snyder, S.A., Occurrence and Removal of Pharmaceuticals and Endocrine Disruptors in South Korean Surface, Drinking, and Waste Waters. Water Research, 2007, 41, pp. 1013-1021.

[15] Chang, C.Y., Chang, J.S., Vigneswaran, S. and Kandasamy, J. Pharmaceutical Wastewater Treatment by Membrane Bioreactor Process—A Case Study in Southern Taiwan. Desalination, 2008, 234, pp. 393-401.

[16] Kimura, K., Hara, H. and Watanabe, Y. Removal of Pharmaceutical Compounds by Submerged Membrane Bioreactors (MBRs). Desalination, 2005, 178, pp. 135-140.

[17] Cirja, M., Zuehlke, S., Ivashechkin, P., Hollender, J., Schäffer, A. and Corvini, P.F., Behavior of Two Differently Radiolabelled 17α-Ethinylestradiols Continuously Applied to a Laboratory-Scale Membrane Bioreactor with Adapted Industrial Activated Sludge. Water Research, 2007, 41, pp. 4403-4412.

[18] Hoinkis, J. and Panten, V., Wastewater Recycling in Laundries—From Pilot to Large-Scale Plant. Chemical Engineering and Processing: Process Intensification, 2008, 47, pp. 1159-1164.

[19] González, S., Müller, J., Petrovic, M., Barceló, D. and Knepper, T.P. Biodegradation Studies of Selected Priority Acidic Pesticides and Diclofenac in Different Bioreactors. Environmental Pollution, 2006, 144, 926-932.

[20] Göbel, A., McArdell, C.S., Joss, A., Siegrist, H. and Giger, W. Fate of Sulfonamides, Macrolides, and Trimethoprim in Different Wastewater Treatment Technologies. Science of the Total Environment, 2007, 372, pp. 361-371.

[21] Rozzi, R., Armesto, J.J., Goffinet, B., Buck, W., Massardo, F., Silander, J. and Callicott, J.B. Changing Lenses to Assess Biodiversity: Patterns of Species Richness in Sub-Antarctic Plants and Implications for Global Conservation. Frontiers in Ecology and the Environment, 2008, 6, pp. 131-137.

[22] Rozzi, R., Draguicevic, J.M., Arango, X., Sherriffs, M., Ippi, S., Anderson, C., Acevedo, M., McGehee, S., Plana, J., Cortés, E. and Massardo, F., Desde la cienciahacia la conservación: El programa de educación y éticaambientaldelParqueEtnobotánicoOmora. RevistaAmbiente y Desarrollo de CIPMA, 2005, 21, pp. 20-29

[23] Malpei, F., Bonomo, L. and Rozzi, A., Feasibility Study to Upgrade a Textile Wastewater Treatment Plant by a Hollow Fiber Membrane Bioreactor for Effluent Reuse. Water Science & Technology, 203, pp. 47, 33-39.

[24] Brik, M., Schoeberl, P., Chamam, B., Braun, R. and Fuchs, W. Advanced Treatment of Textile Wastewater towards Reuse Using a Membrane Bioreactor. Process Biochemistry, 2006, 41, pp. 1751-1757.

[25] SaimaFazal*, Beiping Zhang, ZhenxingZhong, Lan Gao, Xuechuan Chen. Industrial Wastewater Treatment by UsingMBR (Membrane Bioreactor) Review Study, Journal of Environmental Protection, 2015. 6, pp. 584-598.