Paper No. 731

PERFORMANCE EVALUATION OF BENCH SCALE MEMBRANE BIOREACTOR (MBR) SYSTEMS

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Abstract:

Water is a precious resource for the survival of mankind, but we are losing it every day. We can replenish our ground water by treated wastewater recharge. The conventional methods to treat the wastewater are not meeting the recent discharge standards. Membrane bioreactor is the efficient way of treating wastewater by the combination of biological process and membrane technology eliminating the process of sedimentation. Three membrane bioreactors (MBR) were installed at bench scale and the performance parameters were investigated to access the efficiency of MBR technology and to evaluate the quality of treated wastewater for reuse purposes. The activated sludge from I-9 Sewage Treatment Plant, Islamabad was acclimatized with synthetic wastewater for a period of 30 days in MBR along with plastic (Kaldnes) media. Medium strength wastewater was prepared synthetically in the laboratory having a chemical oxygen demand (COD) of 500mg/L and COD:N:P of 100:10:2. The degradation of synthetic wastewater at a hydraulic retention time (HRT) of 8 hours was studied in three separate reactors which included 1) Conventional MBR (C-MBR), 2) Moving Biofilm MBR (MB-MBR) and 3) Anoxic-oxic Growth MBR (A/O-MBR). The aeration provided to SG-MBR and AG-MBR was 5-6 mg/L while 1-2 mg/L was provided in anoxic compartment and 5-6 mg/L in aerobic portion of the A/O-MBR. A pH of 7 to 8 was maintained by using Sodium Bicarbonate ($NaHCO_3$). Sludge retention time (SRT) was maintained at 30 days which resulted in mixed liquor suspended solids (MLSS) concentration between 6000 and 8000 mg/L. The COD removal efficiency above 97% was obtained in all the three MBRs. The Total Nitrogen (TN) removal efficiencies of C-MBR, MB-MBR and A/O-MBR were obtained as 59.81%, 68.82% and 83.18% respectively. Total phosphorous (TP) removal efficiencies of C-MBR, MB-MBR and A/O-MBR were recorded as 46.48%, 59.46% and 69.74%, respectively. Based on these results the performance of A/O-MBR was found efficient in terms of nutrients removal over the other two MBRs due to the production of heterogenic bacteria which are responsible for nitrification, de-nitrification as well as phosphorous removal.

Keywords: Membrane bioreactor (MBR), Kaldnes media, Nutrients removal, Nitrification, De-nitrification, Heterogenic bacteria.

INTRODUCTION

Water is vitally important and precious commodity for the survival of mankind. Every living thing needs it to live and it is a key component in determining the quality of our lives. The increasing demand of water usage has resulted in water scarcity in Pakistan. Population growth, associated water-related pollution and public health problems are major areas of concern. The critical subject is whether the developing world should follow the advance wastewater treatment technology or there is an alternative “Sustainable Sanitation” (Harleman and Murcott, 2001)

Pakistan’s urban areas have a need to develop water reuse applications from the existing wastewater sources to overcome the increasing water scarcity and degradation of water sources. Meanwhile water demand is exponentially increasing in urban development and

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becoming dependent upon availability of high quality water. It is estimated within the next 15 to 25 years a number of cities will face limited fresh water to meet increasing demand for horticulture (Hastuti et al., 2011). We can replenish this precious resource by treating our wastewaters efficiently. The principal objective of wastewater treatment is generally to allow municipal and industrial effluents to be disposed off without danger to human health or unacceptable damage to the natural environment. Irrigation with treated wastewater is both disposal as well as effective form of utilization.

In present era the conventional wastewater treatment technologies are not meeting the effluent discharge standards. The design of wastewater treatment plants is usually based on the need to reduce organic and inorganic loadings to limit pollution of the environment. Pathogen removal has very rarely been considered an objective but, for reuse of effluents in agriculture, this must now be of primary concern and processes should be selected and designed accordingly (Hillman, 1988). Treatment to completely remove wastewater constituents is technically possible, but is not economically feasible. However significant progress has been made in developing sound technical and viable economical approaches to produce high quality and reliable water sources from reclaimed wastewater.

The Membrane bioreactors are composed of two primary parts, the biological unit responsible for the biodegradation of the waste compounds and the membrane module for the physical separation of the treated water from mixed liquor. The membrane component of the MBR eliminates the need for a clarifier and is performed using low pressure membranes i.e. Microfiltration (MF) or Ultrafiltration (UF). This technology is suitable for urban area which has limited space for wastewater treatment and ability to remove pathogens, nutrients, and suspended solids (Hastuti et al., 2011). MBR technology is advancing rapidly around the world both in research and commercial applications (Meng et al., 2009). Despite the increasing number of studies and full-scale applications of MBR systems, directions and trends in academic research as well as commercial developments require further investigation (Yang et al., 2006). The MBR with a submerged membrane module can be an attractive choice for the upcoming generations of biological wastewater treatment plants providing two clear advantages, comparatively improved and excellent effluent quality and smaller footprints with minimal aesthetic nuisance. The core application area so far has been to improve the industrial wastewater treatment (Sombatsompop, 2007). Moreover MBRs may actively be employed in domestic wastewater treatment as well because MBRs are operated at high mixed liquor suspended solids (MLSS) concentrations and inhibit the excessive sludge production, resulting in high removal efficiency of chemical oxygen demand (COD), nutrients (NH_3-N, NO_2^{-1}, NO_3^{-1} and PO_4^{-2}) removal and bacterial disinfection (Su et al., 2007). Another useful application of MBRs is to treat the landfill leachate (Yang et al., 2012).

Although MBRs are very efficient in treating wastewater but at the same time we need to develop more suitable set ups for achieving further technological improvements in the system. In this paper the performance evaluation of bench scale MBRs has been evaluated where the treatment performance of MB-MBR using Kaldnes media A/O-MBR was compared with C-MBR.

MATERIALS AND METHODS

Experimental set-up

Three bench scale acrylic made MBRs were set up at IESE wastewater laboratory. MBRs were categorized based on their design and operating conditions as:

1. Conventional MBR (C-MBR)
2. Moving Biofilm MBR (MB-MBR)

3. Oxic-Anoxic MBR (A/O-MBR)

The effective volume of each tank of C-MBR and MB-MBR was 12 L for the study. Perforated plates divided the reactor into three compartments, membrane being installed in the middle one. Perforated plates helped in mixing of the sludge in the reactor as well as maintaining proper aeration in each compartment of the reactor. Hollow fiber (HF) membrane (Mitsubishi Rayon, Japan) was immersed in middle compartments of both reactors having a nominal pore size of 0.1 µm and surface area of 0.2 m^2. The plastic (kaldnes) media was used as moving biofilm carrier media and it circulates within all the three compartments of MB-MBR having a dry volume of 20%. The schematic diagram of C-MBR is shown in Figure 1.

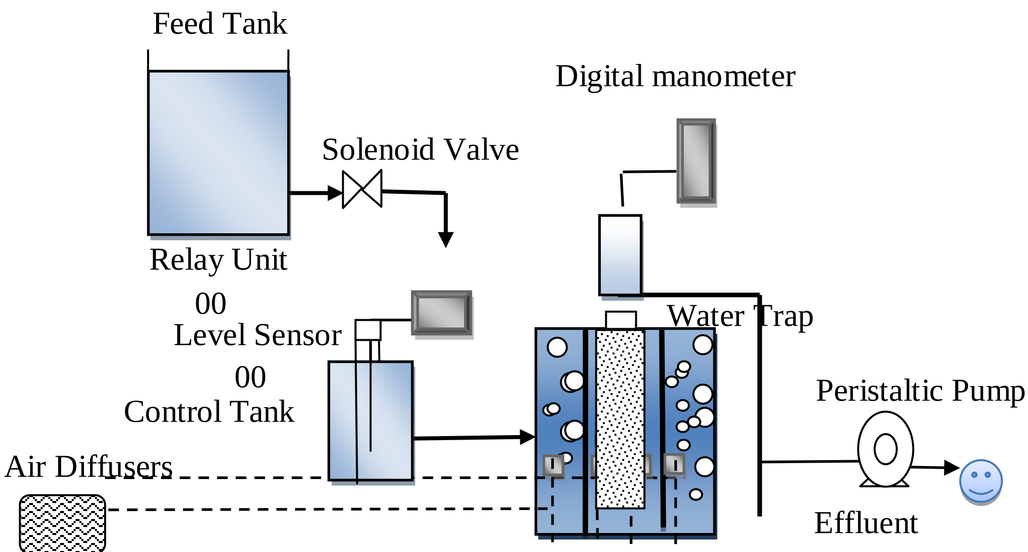

Figure 1: Schematic diagram of C-MBR

A third laboratory scale acrylic made MBR was set up, having a 15 L volume tank for the study. Perforated plate divided the reactor into two Compartments, with a ratio of 1:2 of the total volume. Membrane was installed in the smaller compartment as shown in Figure 2. The plastic (Kaldnes) media with 20% effective volume was introduced in both compartments. A mechanical mixer (Cole-Parmer, Model 50007-25, USA) was installed in the larger compartment to make anoxic condition as well as to keep media in suspension. The mechanical mixer was operated in cyclic mode as 2 minutes OFF and 10 minutes ON.

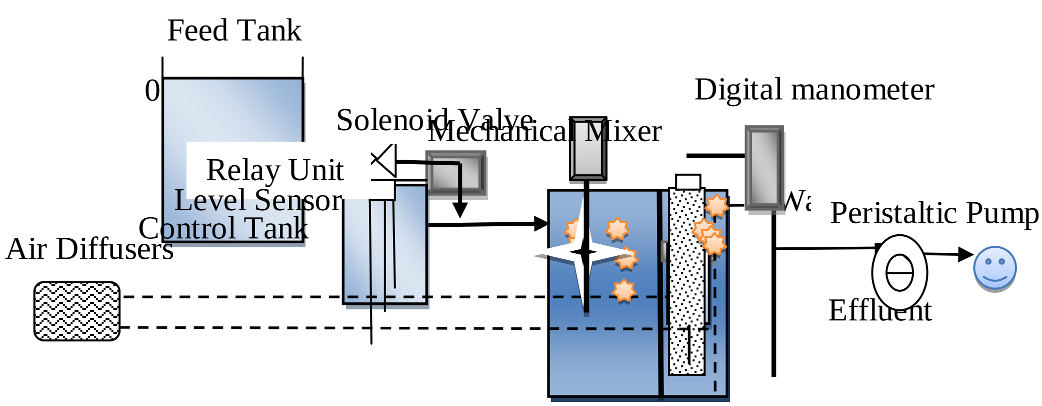

Figure 2:Schematic diagram of A/O-MBR

Acclimatization of sludge and media with synthetic wastewater

Wastewater was prepared synthetically in the laboratory having a COD of 500 mg/L and COD:N:P of 100:10:2. To maintain a pH of 7-8, $NaHCO_3$ was used as pH buffer. The activated sludge from I-9 Sewage Treatment Plant, Islamabad was acclimatized with synthetic wastewater for a period of 30 days in MBR along with Kaldnes media.

Table 1: Chemical Composition of Synthetic waste water

Chemicals	Formula	Quantity (mg/L)
Hydrated Glucose	$C_6H_{12}O_6.H_2O$	500
Ammonium Chloride	NH_4Cl	191
Potassium Di-Hydrogen Phosphate	KH_2PO_4	54.85
Calcium Chloride	$CaCl_2$	5
Magnesium Sulphate	$MgSO_4.7H_2O$	5
Ferric Chloride	$FeCl_3$	1.5
Manganese Chloride	$MnCl_2.4H_2O$	1
pH buffer	$NaHCO_3$	142.5

The specific properties of the Kaldnes media used during the research study are as listed in Table 2.

***Table 2**:* Specific Properties of Plastic (Kaldness) Media

Properties	Description
Dimensions	1 cm dia.
Dry Volume	20 %
Wet Volume	8 %
Material	K3 Type Plastic

Membrane characteristics

The main features of the membrane modules used in the MBRs are presented in Table 3.

Table 3: Hollow-fiber (HF) membrane characteristics

Item	Characteristic
Manufacturer	Mitsubishi Rayon Engineering Co. Ltd., Japan
Membrane material	Polyethylene
Pore size	0.1 μm
Filtration area	0.2 m^2
MLSS	5,000-12,000 mg/L recommended (3,000 - 15,000 mg/L)
Filtration flow rate	Constant
Suction pressure	5-30 kPa
Intermittent suction	Operating time ≤ 13 min; relaxing time ≥ 2 min
Temperature	15-35^{o}C

MBR operational conditions

- Peristaltic Pump (Master Flex, Cole-Parmer, USA) was used to periodically draw permeate at a cycle of 10 min filtration, 2 min relaxation, maintaining HRT of 8 hrs. Sludge retention time (SRT) was set to 30 days and nitrogen loading rate (NLR) of 0.15 Kg/m^3/d organic loading rate (OLR) was kept at 1.5 Kg/m^3/d.
- Air pumps provided sufficient air flow rate to keep the media in suspension, scour the membrane fibers along with maintaining dissolved oxygen (DO) concentration of 5-6 mg/L except the anoxic zone of A/O-MBR where DO concentration was maintained at 2 mg/L.
- Diffused aeration was provided in the reactor by the help of air diffusers.
- Flow meter was used to monitor the aeration rate at 7 L/min. (3 L/min in the membrane compartment and 4 L/min in the side compartments in C-MBR and MB-MBR). Similarly 3 L/min aeration rate was maintained in the membrane compartment of A/O-MBR.
- Trans-membrane pressure (TMP) was recorded using Data logging manometer (Sper-Scientific 840099, Taiwan) as indicator of membrane fouling tendency. The membranes were operated till the TMP reached to a limit of 30 KPa.

The MBR set up was operated for 140 days under the following conditions:

Table 4: Operating conditions

Parameter	Condition
SRT	30 days
HRT	8 hours
OLR	1.5 Kg/m^3/d
NLR	0.15 Kg/m^3/d
F/M	0.2
pH	6-7
MLSS	6-8 g/L

Analytical Methods

The parameters that were investigated, the technique adopted to determine each parameter and the equipment/material used are reported in Table 5

Parameter	Method	Equipment/Material	Reference
MLSS/ MLVSS	Filtration-Evaporation	1.2 µm (GF/C, Whatman); 105^{o}C oven (MLSS); 550^{o}C Muffle Furnace (MLVSS)	APHA , 2005
COD	Close reflex	COD tube/vial; 150^{o}C oven	APHA , 2005
NH_4^+-N, NO_2^--N, NO_3^--N	Hach Reagents	Spectrophotometer (DR 2010, Hach)	APHA , 2005
PO^{-4}-P	Molybdovanadate	Spectrophotometer (DR 2010, Hach)	APHA , 2005

Table 5: Analytical Parameters, Methods and Equipment

RESULTS AND DISCUSSION

The previous studies (Jamal et al., 2011) and (Jamal et al., 2012) have already evaluated the performance of MBRs. These studies proved MBR technology's capability to treat the wastewater for reuse purposes. Previously, the studies by Jamal et al. (2011) were carried out with sponge media as biofilm carrier having 20% dry volume of the reactor. In the present study, the sponge media was replaced by plastic (Kaldnes) media and A/O-MBR was introduced. Results revealed that the nutrients (TN and TP) removal was more efficient in A/O-MBR due to the production of nitrifying and denitrifying bacteria in anoxic zone of A/O-MBR. The anoxic zone may have also facilitated the growth of phosphorous accumulating microorganisms (PAOs).

COD Removal

All the three MBRs gave almost more than 95% COD removal for entire period. There is the slight difference in COD removal of all three MBRs however A/O-MBR shows relatively better COD removal among the three MBRs as shown in the following figure.

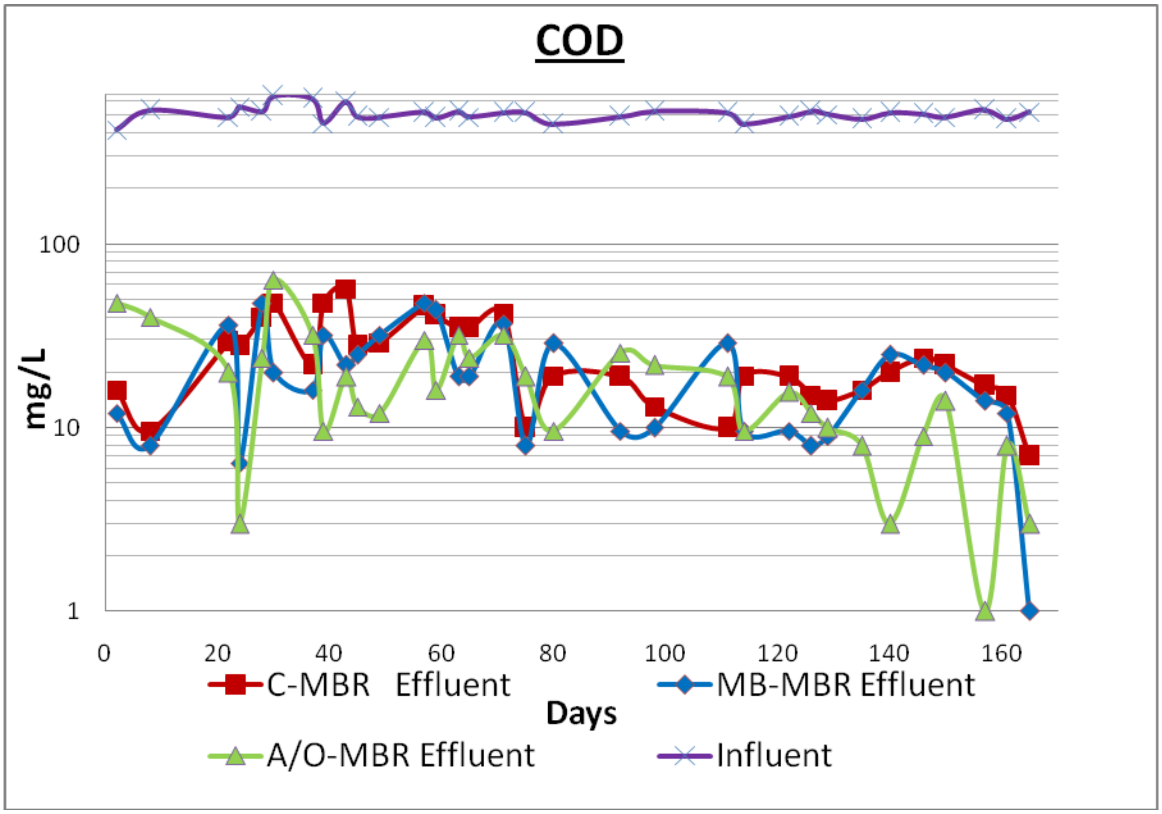

Figure 3: Influent and effluent COD

Nutrients removal

NH_4-N removal

The C-MBR was able to remove 90% NH_4-N from influent synthetic wastewater. The MB-MBR gave 95% NH_4-N removal due to nitrification by the biofilm developed on the plastic media. A/O-MBR exhibits relatively high quality effluent, almost 96% removal due to nitrification followed by de-nitrification in the anoxic zone. Nitrification converts NH_4-N into $NO_2^{-1}$and NO_3^{-1} i.e. low concentration of NH_4-N in A/O-MBR and MB-MBR's effluents. Figure shows the influent and effluent trend in all MBRs.

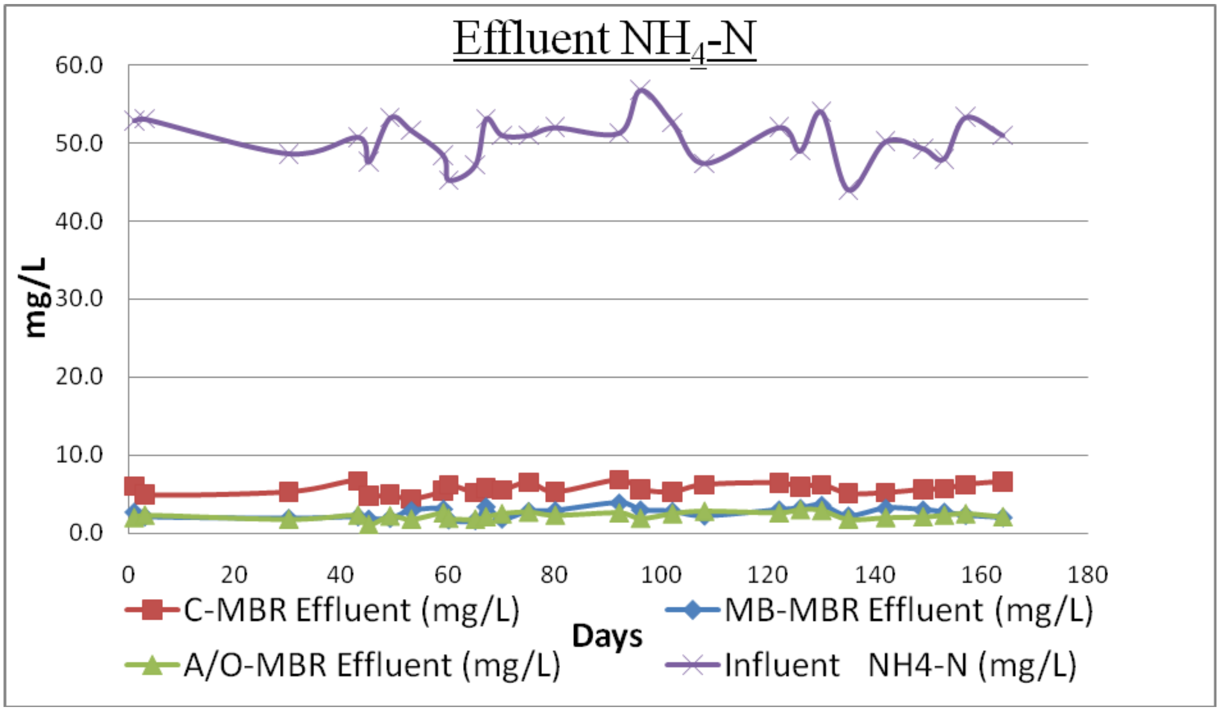

Figure 4: Influent & effluent NH_4-N of C-MBR, MB-MBR & A/O-MBR.

NO_2^{-1} Removal

A/O-MBR gave maximum NO_2^{-1} removal than the other two MBRs due to enhanced nitrification process in anoxic conditions.

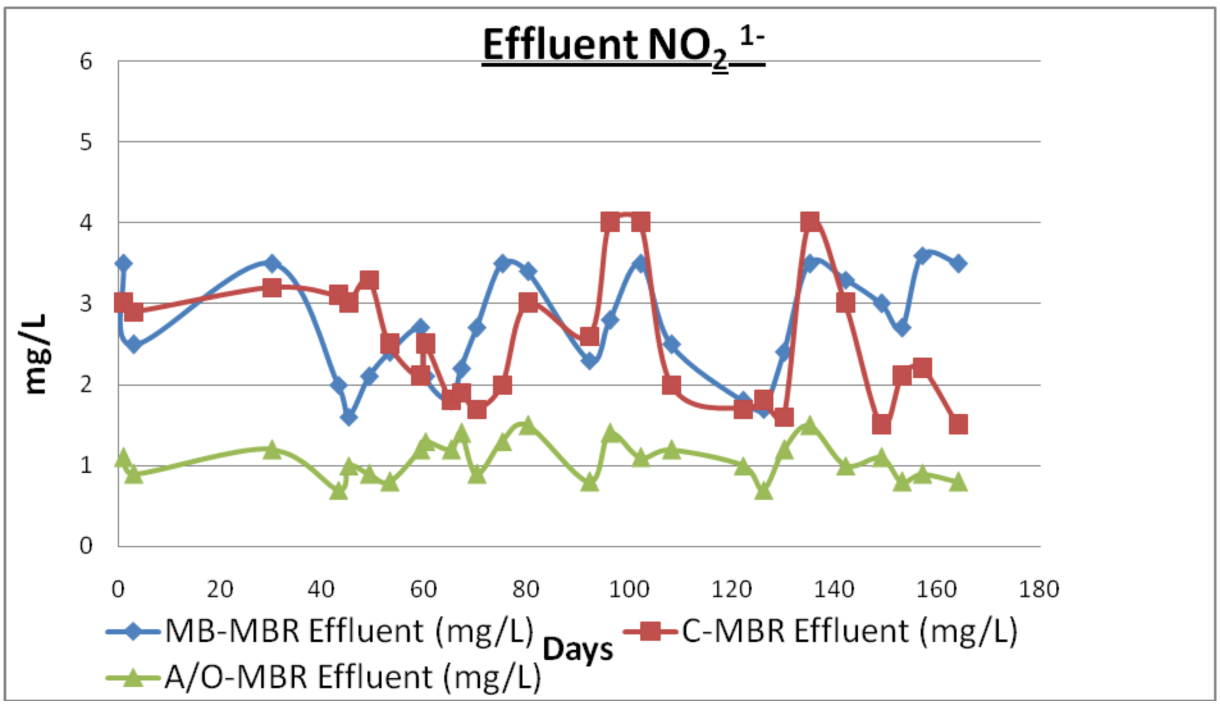

Figure 5: NO_2^{-1} in effluents of all MBRs

NO_3^{-1} Removal

AO-MBR was most efficient in terms of NO_3^{-1} removal due to nitrification and de-nitrification in anoxic zone. AO-MBR gave 5 mg/L of NO_3^{-1} in effluent on average. While C-MBR and MB-MBR effluents were found to be 12 mg/L and 10 mg/L, repectively.

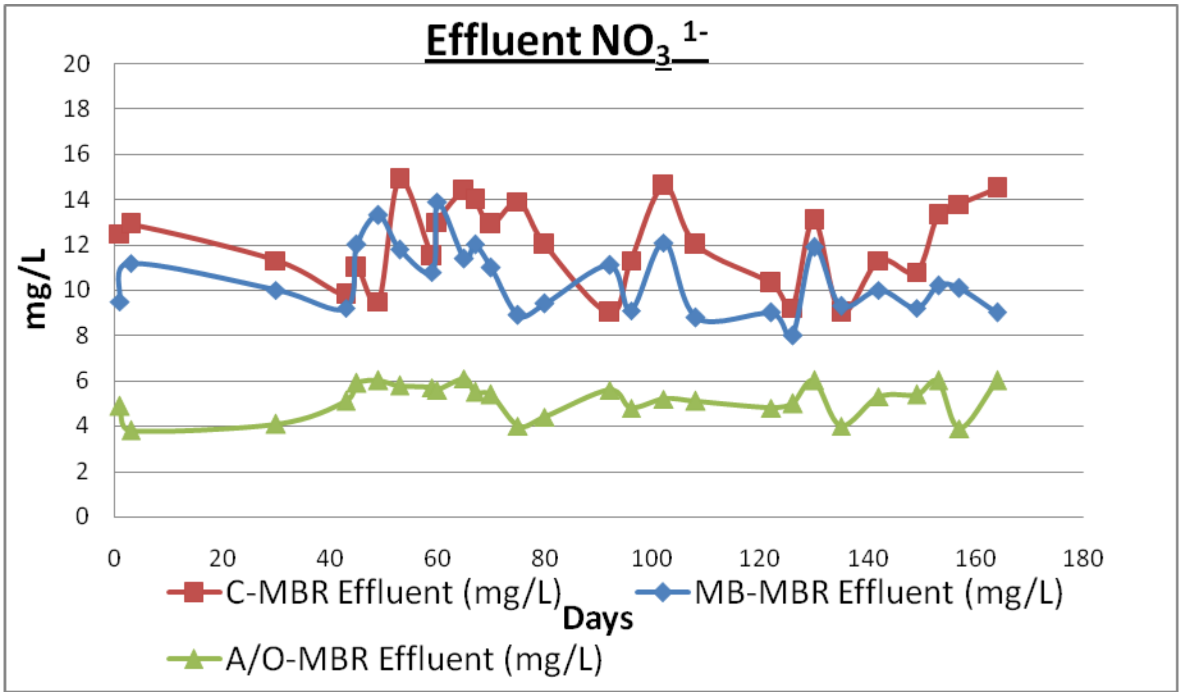

Figure 6: NO_3^{-1} in effluents of all MBRs

TN Removal

It was found that the maximum TN removal (83.2 %) was in A/O-MBR followed by 69 % TN removal in MB-MBR while 60 % in C-MBR. Better TN removal in A/O-MBR was due to the appropriate production of nitrifying and denitrifying bacteria.

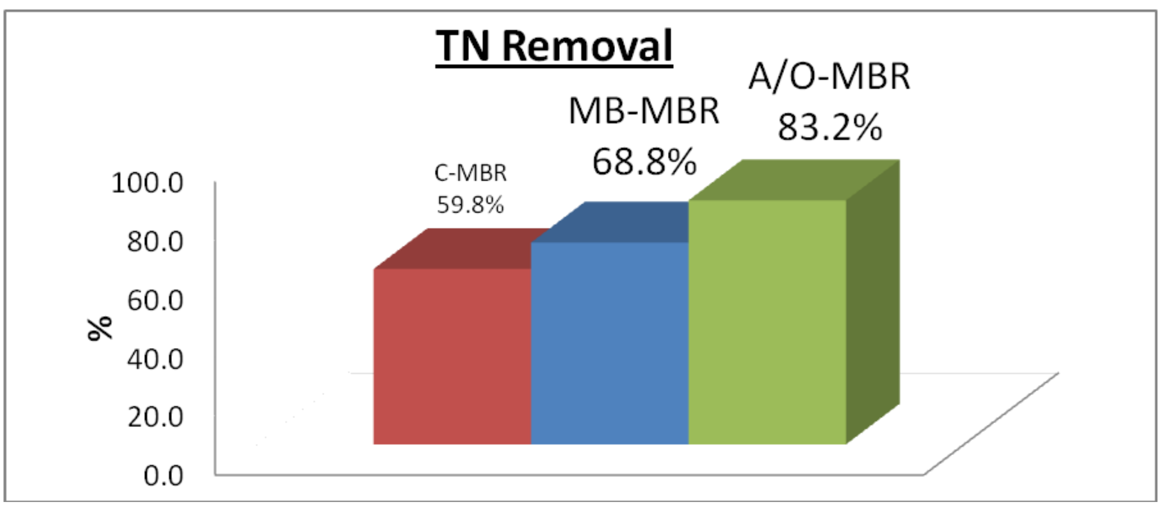

Figure 7: TN removal in all three MBRs

PO_4^{-3} – P Removal

The PO_4^{-3}-P removal is very important parameter in wastewater treatment as it can cause eutrophication along with NO_2^{-1} and NO_3^{-1}.The effluent quality with least concentration of PO_4^{-3} was found in the A/O-MBR. Phosphorous removal efficiencies of C-MBR, MB-MBR and A/O-MBR were as 46.48%, 59.46% and 69.74% respectively on average basis. C-MBR showed least removal efficiency because it had no anoxic zone and moving biofilm carriers in it.

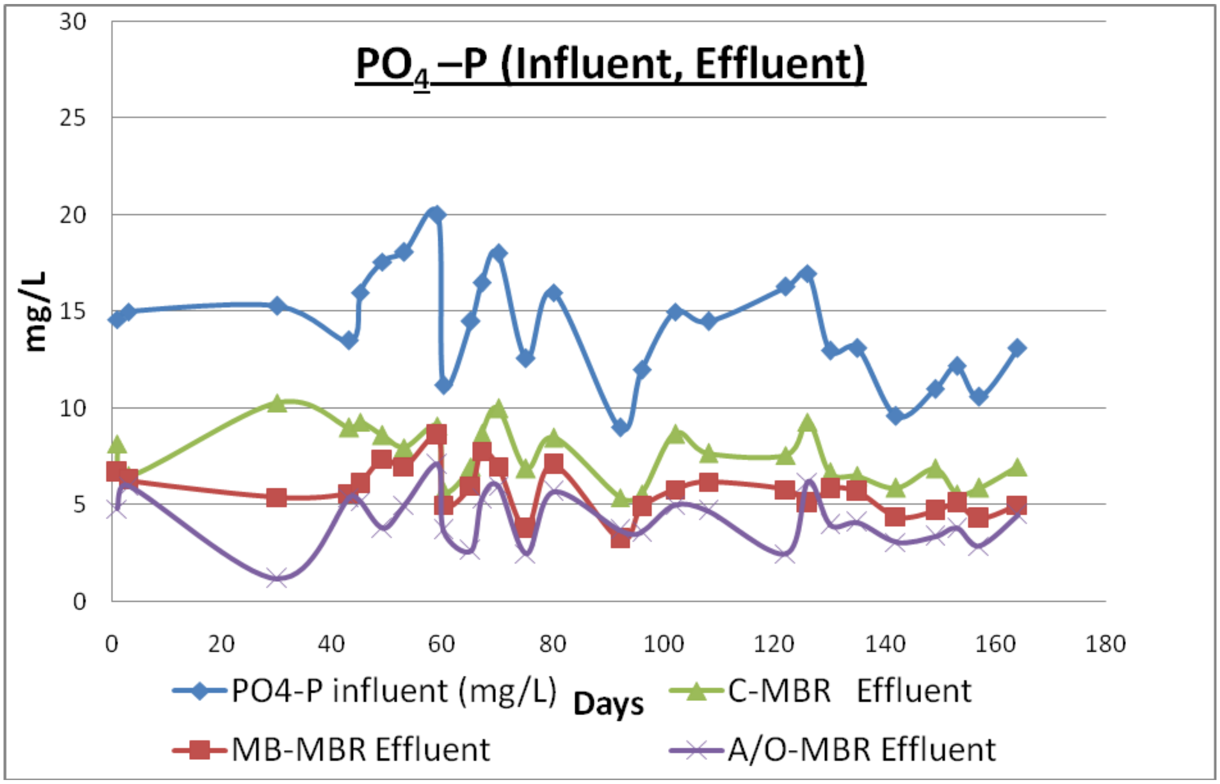

Figure 8: Influent & effluent PO_4^{-3} in all three MBR

CONCLUSIONS

This study revealed the following specific conclusions:

1. COD removal efficiency above 95% was achieved in all the three MBR systems namely C-MBR, MB-MBR and A/O-MBR
2. NH_4-N removal was found to be maximum in A/O-MBR due to effective nitrification process in anoxic zone and biofilm carriers.
3. A/O-MBR was efficient in the removal of NO_3^{1-} due to abundance of de-nitrifying bacteria as compared to the other MBRs.
4. PO_4 –P removal was highest in A/O-MBR due to anoxic zone attained by optimum mechanical mixing and biofilm carriers. It was also better in MB-MBR due to biofilm formation on moving biofilm carriers.

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