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Use of Membrane Bio-Reactor and Activated Sludge to Remove COD and BOD from Sewage Water in Saudi Arabia

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ABSTRACT

The main objective of this research was to evaluate the use of membrane bioreactor (MBR) in combination with activated sludge for the reduction of Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) from sewage water using a pilot scale plant in Riyadh, Saudi Arabia. Application of activated sludge coupled with MBR significantly reduced both the COD and BOD of treated sewage water. Overall, mean reduction of COD and BOD was 98.5 and 96%, respectively. Although, there was a decreasing trend in both the BOD and COD reduction from activated sludge stage to final treated water but the difference was not significant. The COD and BOD concentrations in the final treated water were within maximum permissible limits for irrigation. In conclusion, use of MBR and activated sludge proved to be safe and feasible sewage water treatment technology applicable in small community places where the sewage water production is limited and can easily be handled at least for landscape development for community service with minimal health and environmental hazards.

Key words: Membrane bioreactor activated sludge, aeration, sewage water, irrigation, health hazards, environmental pollution

INTRODUCTION

Groundwater resources in Saudi Arabia are limited and non-renewable. To cope with the increasing demand for water use in different sectors, exploitation of new water resources is essential. It has been observed that recent urban and rural development has increased waste water production manifold over the last two decades. These sewage waters contain biological, organic and inorganic pollutants to varying degrees. Besides this, the wastewater is very high in COD and BOD due to the presence of organic pollutants resulting from household sewage. These wastewaters are a potential source of health and environmental pollution if land disposed without any treatment. The domestic wastewater contains pathogens, suspended solids, nutrients (nitrogen and phosphorus), other organic and inorganic pollutants (Andrew *et al.*, 1997). To minimize the environmental and health hazards, these pollutants need to be reduced to permissible limits for safe land disposal of wastewater (Manju *et al.*, 1998; Poots *et al.*, 1978). Therefore, removal of the organic contaminants and pathogens from wastewater is of paramount importance for its reuse in different activities (Ali and Deo, 1992; Chen, 1997; Raj *et al.*, 1997). Present conventional wastewater treatment technologies adopted in industrialized nations are expensive to build, operate and maintain (Mazumder and Roy, 2000; Piet *et al.*, 1994; Mazumder and Kumar, 1999), especially for decentralized communities. Research work is in progress for the development of treatment technologies suited to these decentralized communities (Ajmal *et al.*, 1998; Wang *et al.*, 2005). Fly ash can be used as a promising adsorbent for removal of various types of pollutants from wastewater (Wang and Hongwei, 2006). Low-cost adsorbents of different origin like industrial waste material, bagasse fly ash and jute-processing waste can also be used for removal of organic matter from wastewater (Bhatnagar, 2007; Srivastava *et al.*, 2005; Banerje and Dastidar, 2005). The COD and BOD concentrations play an important role in the re-use of these waste effluents. Adsorption-based innovative technology (Devi *et al.*, 2002; Devi and Dahiya, 2006) developed with low-cost carbonaceous materials showed good potential for COD removal from the domestic wastewater. Devi and Dahiya (2008) studied COD and BOD reduction of domestic wastewater using discarded material based mixed adsorbents (mixed adsorbent carbon, MAC and commercial activated carbon, CAC) in batch mode. Under optimum conditions, maximum COD and BOD reduction obtained using MAC and CAC was 95.87, 97.45, 99.05 and 99.54%, respectively. The results showed that MAC offered potential benefits for COD and BOD removal from wastewater. Devi *et al.* (2008) made the assessment of reduction of Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD) of wastewater from coffee processing plant using activated carbon made up of Avacado Peels. The maximum percentage reduction of COD and BOD concentration under optimum operating conditions using Avocado Peel Carbon (APC) was 98.20 and 99.18%, respectively and with Commercial Activated Carbon (CAC) this reduction was 99.02 and 99.35%, respectively. As the adsorption capacity of APC is comparable with that of CAC for reduction of COD and BOD concentration, it could be a lucrative technique for treatment of domestic wastewater generated in decentralized sectors.

Jefferson *et al.* (2000) evaluated the potential of membrane aeration bioreactors (MABR), Biological Aerated Filters (BAF) and membrane bioreactors (MBR) for grey water recycling. The MBR demonstrated the highest efficacy towards grey water recycling in terms of the three main water quality determinants of carbonaceous biological oxygen demand ($CBOD_5$), turbidity and total coliforms, providing 100% compliance in all cases. Gander *et al.* (2000) evaluated the relative efficiencies of three membrane materials for use in a submerged membrane bioreactor treating domestic wastewater. They found that the Carbonaceous Biological Oxygen Demand ($CBOD_5$), COD, Suspended Solids (SS), NH3-N and turbidity removal was similar with both the polysulphone (PS) and the melt-blown polypropylene (NWPP) membranes. Melin *et al.* (2006) stated that membrane bioreactors (MBRs) are a promising process combination of activated sludge treatment and membrane filtration for biomass retention. They also highlighted that the membrane bio-reactors (MBRs) for municipal wastewater treatment feature advantages compared to conventional activated sludge plants in terms of effluent quality, reflected in lower values for organics, nutrients and micro-organisms. Semmens *et al.* (2003) used a bioreactor to treat a synthetic wastewater containing ammonium acetate and trace nutrients for about 190 days. The Chemical Oxygen Demand (COD) removals in excess of 95% were achieved in a 6 h nominal detention time. This study demonstrated that the membrane aeration can provide simultaneous BOD and N removal in the same reactor. Mohammed *et al.* (2008) investigated the efficiency of Membrane bioreactors (MBRs) for high reduction of Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD) and ammonia nitrogen (NH3-N). The results showed that removal efficiencies for the MBR varied from 97.8 to 99.9% for COD, 98.9 to 99.9% for BOD and 91.0 to 99.9% for NH3-N. Lew *et al.* (2009) used the microfiltration anaerobic membrane bioreactor (An MBR) for the treatment of domestic wastewater at 25EC. They observed a constant COD removal of 88% in the reactor.

Al-Jlil (2009) studied the COD and BOD reduction from domestic wastewater using sedimentation, aeration, activated sludge, sand filter and activated carbon in a sewage treatment process. He found that the mean maximum COD and BOD reduction was 92.17 and 97.66%, respectively. The sewage treatment system using different materials (sand filters, activated sludge) showed excellent potential for COD and BOD removal from domestic wastewater.

This study was conducted to evaluate the use of Membrane Bio-Reactor (MBR) in combination with activated sludge for the reduction of COD and BOD from domestic sewage water for use in landscape irrigation around King Abdulaziz City for Science and Technology (KACST) facility using a pilot scale plant.

MATERIALS AND METHODS

The study was carried at the Wastewater Treatment Plant (WTP), King Abdulaziz City for Science and Technology (KACST), Riyadh Saudi Arabia during 2009 and 2010. The WTP setup is shown in Fig. 1.

Membrane Bio-Reactor (MBR) is a Hollow Fiber Microfiltration Membranes made of PVC with a working volume of 12.5 L and containing two hollow-fiber polyethylene membranes (UMF 0234L1. Mitsubishi Rayon) each having a surface area and pore size of 0.2 m^2 and 0.4 μm, respectively.

Chemical Oxygen Demand (COD) is defined as the quantity of a specified oxidant that reacts with a sample under controlled conditions. The quantity of oxidant consumed is expressed in terms of its oxygen equivalence. The COD is expressed in mg L^{-1} O_2.

Biochemical Oxygen Demand (BOD) is an empirical test that determines the relative oxygen requirements of wastewater, effluent and polluted waters. BOD tests measure the molecular oxygen utilized during a specified incubation duration for the biochemical degradation of organic material (carbonaceous demand) and the oxygen used to oxidize inorganic material such as ferrous iron and sulfides. The BOD is expressed in mg L^{-1} O_2.

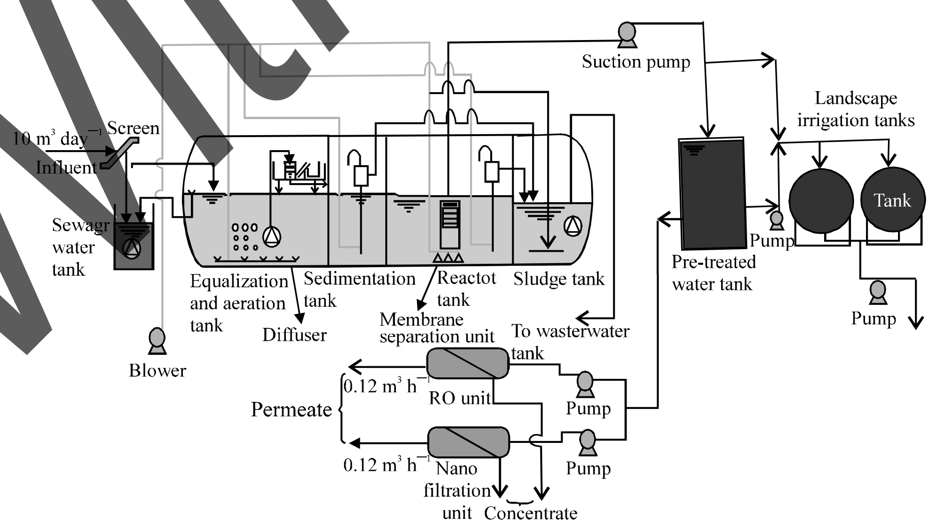

Fig. 1: Schematic diagram of wastewater treatment plant, KACST

Components of WTP and their functions: The total clean water production capacity of Wastewater Treatment Plant is 10 M^3 per day. The schematic diagram of WTP is presented in Fig. 1; the functions of different components of wastewater treatment plant are summarized below.

Sewage Water Tank (SWT): The wastewater from KACST facility is stored in this tank. A screen is placed in front of the water delivery pipe for the removal of waste materials such plastic sacs or other floating things to avoid blocking of the water pump at the time of pumping raw water to the Equalization and Aeration tank. Its total water holding capacity is 15 m^3.

Equalization and Aeration Tank (EAT): A flow adjustment pump is placed in the middle of the tank for the delivery of water to the Equalization and Aeration Tank. Its operation is automatic. Because whenever the water level in the Equalization and Aeration Tank is below the specified level, the pump stars working automatically and pump the raw water to EAT Tank. The air diffusers are installed at the bottom end of the tank for equalization purpose. Its total water capacity is 11 m^3.

Sedimentation tank (activated sludge): It holds the sediments from the wastewater before its delivery to the membrane bioreactor (MBR) tank. The activated sludge (source of different microorganisms) is added to promote the growth of bacteria. These organisms multiply very quickly in the presence of organic matter in the sewage water. The micro-organisms dissolve carbonaceous material, utilize protein as their food and produce nitrite and nitrate. The aeration of the tank oxidizes the organic compounds and the volatile compounds escape from the wastewater. Its total water capacity is 4.7 m^3. One half (½) cubic meter of activated sludge was added in this tank.

The overall goal of the activated-sludge process is to remove substances that have a demand for oxygen from the system. This is accomplished by the metabolic reactions (synthesis-respiration and nitrification) of the microorganisms, the separation and settling of activated-sludge solids to create an acceptable quality of secondary wastewater effluent and the collection and recycling of microorganisms back into the system or removal of excess microorganisms from the system.

Membrane Bio-Reactor (MBR) tank: It consists off two components (a. Membrane Separation Unit; b. Sludge Tank). A set of 8-membrane bioreactors are placed in the Membrane Separation Unit for the treatment of wastewater. The membrane bioreactors are Hollow Fiber Porous Tubes embedded in a plastic pipe on both sides. There are a total of 4-sets of membrane separation unit and each unit contains a set of 2-bioreactor membranes. The wastewater present outside the tubes is filtered rapidly through the walls of the Fiber Porous Tubes. The product water (also called as pre-treated clean water) from the membranes is sucked with a suction pump for two purposes, (1) irrigation of landscape area and (2) for further treatment in RO Unit and Nano-Filtration Unit to produce good quality water. Its total water holding capacity is 8.0 m^3.

Sludge tank: The sludge tank is a part of the membrane Bio-Reactor (MBR) tank where sludge is collected during MBR process. When the sludge reaches to a certain level, then it is pumped to the main ground storage tank by a submersible pump located in the sludge tank. It operation is automatic.

Air blower: One small air blower is installed along one side for supplying air to different parts of the plant. The blower is attached to a set of air diffusers in WTP placed at the bottom of different sections for aeration. The supply of air helps in the oxidation of certain organic compounds in the wastewater.

Collection of sewage water samples: The sewage water samples were collected on weekly basis from four portions of WTP namely Sewage Water Tank (SWT), Equalization and Aeration Tank (EAT), Sedimentation tank (activated sludge), Bio-Reactor Tank and the final treated water in a sterile plastic bottle of one liter capacity. The water samples were immediately transferred to analytical laboratory of National Center for Water Research (NCWR), KACST for analysis. The water pH, EC, temperature, Dissolved Oxygen (DO), Suspended Solids (SS) and turbidity were measured instantly.

COD and BOD analysis of wastewater samples: The BOD and SS analyses were carried out in accordance with Standard Methods for the Examination of Water and Wastewater (APHA, AWWA and WEF, 1995). The COD analysis was carried out in accordance with a US EPA approved method utilizing Hach Laboratory Method 8000 (Spectrophotometer Model DR/2010). NH3-N analysis was carried out using Hach Laboratory Method10031 (Spectrophotometer Model DR/2010). Turbidity was analyzed using a Turbidimeter Model 2100N (Hach Laboratory). Total coliforms were analyzed using the IDEXX Quanti-Tray 2000.

Data analysis: The data was analyzed by ANOVA and other statistical techniques described by Snedecor and Cochran (1973).

RESULTS AND DISCUSSION

Chemical composition of raw sewage water: The total water salinity showed some decreasing trend from raw sewage water to the treated water but the difference in the total water salinity does not seem to be significant. The NO_3 concentration increased significantly in the treated water which could be attributed to the nitrification of the organic nitrogen to nitrate form due to oxidation by excessive aeration and action of activated sludge. However, the SO_4 and HCO_3 concentration decreased significantly in the treated water than the raw sewage water. This decrease could be due to the oxidation of carbonaceous compounds by aeration and the action of different bacteria in the activated sludge for decomposition of organic compounds in the sewage water. Also, the Na contents increased while Mg contents decreased in the treated water due to activated sludge and the MBR. The DO also increased in the treated water resulting from aeration and the decomposition of different organic pollutants from the sewage water. The Ca and Cl did not show any significant changes during the whole process. The F contents decreased from 11 to 1.2 in the treated water and were within safe limits for agriculture use (Table 1).

Effect of MBR and activated sludge on COD: Mean COD ranged between 81-10.5 mg L^{-1} in various treatments (Table 2), the reduction in COD was significant among the various sewage water treatments ($LSD_{0.05}$ = 17.552). The reduction in COD was 48% (Equalization and Aeration Tank, EAT), 95% (MBR with aeration) and 98.5% in the final product water. The difference in COD reduction between the raw sewage and EAT was significant. This showed that simple aeration of sewage water can reduce the COD significantly by oxidation process. Although, there was a decreasing trend in the COD reduction from MBR stage to the final product water but the

Table 1: Mean chemical composition of sewage water in different components of Wastewater Treatment Plant (WTP)

Parameters	SWT	EAT	BFT	TW
pH	7.63	8.30	8.13	7.50
EC (dS m^{-1})	1.441	1.330	1.317	1.295
TDS (mg L^{-1})	971	877	869	782
DO (mg L^{-1})	1.08	5.41	6.42	4.2
Temperature (°C)	20	21	22	22
T. Alk. (mg L^{-1})	328	260	236	44
Ca (mg L^{-1})	98	109	117	78
Mg (mg L^{-1})	26	26	37	6.2
Na (mg L^{-1})	151	219	344	219
K (mg L^{-1})	6	3.2	33	3
F (mg L^{-1})	11	9	9.4	1.2
NO_3 (mg L^{-1})	36	70	88	103
SO^4 (mg L^{-1})	153	149	134	92
HCO_3 (mg L^{-1})	400	317	287	53
Cl (mg L^{-1})	134	165	153	160

SWT: Sewage water tank, EAT: Equalization and aeration tank, BFT: Membrane bio-filter tank, TW: Treated water, EC: Electrical conductivity, TDS: Total dissolved solids, T. Alk.: Total alkalinity

Table 2: Effect of Membrane Bioreactor (MBR) and activated sludge on COD and BOD contents (mg L^{-1}) of sewage water

Sample location	R-1	R-2	R-3	R-4	Mean	Overall reduction (%)
COD						
SWT	133	77	51	63	81a	100
EAT	66	30	32	42	42.5b	48
BFT	50	16	10	4.2	20c	95
TW	34	6.2	0.7	1.2	10.5c	98.5
Statistical analysis						
$LSD_{0.05}$ = 17.552						
R^2 = 0.942						
BOD						
SWT	109	84	198	93	121a	100
EAT	48	48	96	63	63.75b	48
BFT	22	14	50	6.3	23c	81
TW	11	2.2	4.0	1.9	4.78c	96
Statistical analysis						
$LSD_{0.05}$ = 36.058						
R^2 = 0.893						

The mean values by the same letter(s) are not significantly different at 5% level of significance ($LSD_{0.05}$).SWT: Sewage water tank, EAT: Equalization and aeration tank, BFT: Membrane bio-filter tank, TW: Treated water

difference was not significant. This indicated that simple aeration with the addition of activated sludge significantly reduced the COD of sewage water which was within safe limits for irrigation to landscape areas. This significant reduction in COD could be attributed to the oxidation reactions due to continuous aeration in combination with activated sludge. Similar findings were reported by many researchers who used sedimentation, aeration, activated sludge, sand filter and activated carbon (Al-Jlil, 2009), activated carbon made up of Avacado Peels (Devi *et al.*, 2008), low-cost carbonaceous materials (Devi *et al.*, 2002; Devi and Dahiya, 2006) and discarded material based mixed adsorbents (mixed adsorbent carbon, MAC and commercial activated carbon, CAC (Devi and

Dahiya, 2008) for the reduction of COD from wastewaters. The reduction of COD ranging from 92.12-99.05% was reported at different places. The study results also agree with those of Mohammed *et al.* (2008), who showed that removal efficiencies for the MBR varied from 97.8 to 99.9% for COD and Lew *et al.* (2009), who observed a constant COD removal of 88% in the reactor.

In conclusion, the use of MBR and activated sludge is appropriate for the removal of COD from sewage water. In the present study, the COD concentration in the treated water was within the maximum permissible limits of 30-45 mg L^{-1} according to Ayers and Westcot (1985). This suggested that the treated water can safely be used for landscape irrigation without potential health and environmental hazards.

Effect of MBR and activated sludge on BOD: The reduction in BOD was significant among the various sewage water treatments ($LSD_{0.05}$ = 36.058) with mean values ranging from 121-4.78 mg L^{-1} (Table 2). The reduction in BOD was 48% (Equalization and Aeration Tank, EAT), 81% (MBR with aeration) and 96% in the final product water. The difference in BOD reduction was significant between EAT and MBR treatments. This indicated that simply aerating the sewage water alone can reduce the BOD significantly by oxidation of excess carbonaceous materials in the sewage water. Though, there was a decreasing trend in BOD reduction from MBR tank to the final product water but the difference was not significant. The results indicated that combined action of continuous aeration, activated sludge and MBR significantly reduced the BOD of sewage water which was within safe limits for irrigation to landscape areas. This significant reduction in BOD could be attributed to the biological reactions due to the addition of activated sludge (a source of different bacteria) which might have utilized all the organic pollutants in the sewage effluent along with continuous aeration in different stages of sewage water treatments. Similar results were reported by Devi *et al.* (2002, 2008), Semmens *et al.* (2003), Devi and Dahiya (2006, 2008) and Al-Jlil (2009) who used different materials in the wastewater treatment plants for the removal of BOD from wastewaters. The reduction in BOD ranged between 95-99.18%. The study results were comparable with those of Mohammed *et al.* (2008), who showed that removal efficiencies for the MBR varied from 98.9 to 99.9% for BOD in the treated wastewater.

Overall, the BOD concentration in the treated water was within the maximum permissible limits of 3-4 mg L^{-1} according to Ayers and Westcot (1985) for its safe use in industrial cooling and landscape irrigation. The study results also resemble with those of Melin *et al.* (2006) who concluded that membrane bioreactors (MBRs) are a promising process combination of activated sludge treatment and membrane filtration for biomass retention. They also highlighted that the Membrane Bio-Reactors (MBRs) for municipal wastewater treatment feature advantages compared to conventional activated sludge plants in terms of effluent quality, reflected in lower values for organics, nutrients and micro-organisms.

CONCLUSION

The combined use of MBR and activated sludge along with continuous aeration of different chambers of WTP reduced both the COD (98.5%) and BOD (96%) which was within the maximum permissible limits for landscape irrigation and industrial cooling. This method proved to be safe and feasible sewage water treatment which can be applied in small community places where the sewage water production is limited and can easily be handled at least for landscape development for community service with minimal health and environmental hazards.

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