Research Journal of

Environmental Sciences

ISSN 1819-3412

Academic
Journals Inc.

www.academicjournals.com

Research Journal of Environmental Sciences 3 (2): 267-277, 2009
ISSN 1819-3412

Membrane Bioreactor for Wastewater Reclamation-Pilot Plant Study in Jeddah, Saudi Arabia

Turki M. Alaboud
Department of Civil Engineering, Faculty of Engineering,
King Abdulaziz University, P.O. Box 5561, Makkah, Saudi Arabia

Abstract: This study conducted investigations at a pilot scale MBR plant, located in Al Khomra, Jeddah for a period of three months. The plant received wastewater from a residential area and adjoining workshops. Irrespective of the applied Mixed Liquor Suspended Solids (MLSS) concentrations (10, 15 and 20 g L^{-1}) and hydraulic retention times, HRT (8, 6 and 3 h), the MBR units realized excellent organics, nutrients and pathogen removal performances. In the course of the investigation, the influent Biochemical Oxygen Demand (BOD) (198-253 mg L^{-1}), Chemical Oxygen Demand (COD) (445-575 mg L^{-1}), Total Kjeldhal Nitrogen (TKN) (18-26 mg L^{-1}) and Total Phosphorous (TP) (8.6-13.6 mg L^{-1}) were removed with efficiencies varying within the ranges of 95-98, 90-95, 98.64-100 and 40-50%, respectively. A 2.1-3.1 log removal of fecal coliforms and a 5-6 log removal of total Coliforms were also accomplished. The best quality effluent achieved during this investigation convincingly satisfied the quality requirements for reuse for irrigation purpose in the country. Furthermore, severe membrane fouling, requiring chemical cleaning, was not encountered during the operation period.

Key words: Membrane bioreactor, nutrient removal, organics removal, pilot plant, wastewater reclamation

INTRODUCTION

The worldwide increasing demands for the exhaustible resource-water have resulted in a critical evaluation of water reuse as means of supplementing municipal and industrial water supplies (Howell, 2002). Water is a scarce and extremely valuable resource in Saudi Arabia. The renewable water resources are only 111 m^3/capita/year (Haddadin, 2002; US EPA, 2004). Being a desert country with a large agricultural and industrial base and a growing population makes the supply of fresh water essential to Saudi Arabia. The country's water demand has been increasing steadily at a rate of 2.6% per year over the past two decades, reaching around 20 billion m^3/year in 2000 (Abderrahman, 2000; Earth Trends, 2001). In general, fragmented legislation and institutional arrangements and low water charges (Bremere *et al*., 2001) have indirectly resulted in over-usage of domestic water, production of excessive quantities of wastewater and significant leakage. Quenching of the growing water demand entails, besides the conservation efforts, retrofitting of the existing desalination plants and setting up of the newer ones along with development and support of renewable water resources and the increased application of appropriate wastewater treatment plants realizing wastewater reclamation. To date water reuse has been practiced to a limited extent throughout the country, mainly in the big cities. An estimate shows that the wastewater generation in the country amounts to 700 Mm^3 $year^{-1}$, of which 620 Mm^3 $year^{-1}$ is covered by the collection system (US EPA, 2004). Ninety four percent of the collected wastewater is treated mainly by means of conventional biological wastewater treatment processes. The dwindling performance of the existing treatment plants along with the recent stringent disposal standards necessitate introduction of more effective treatment processes.

In this context, it is interesting to note that Membrane Bioreactor (MBR) process is a hybrid system amalgamating membrane separation with biological treatment (Visvanathan *et al*., 2000). Operating as an MBR allows conventional activated sludge plants to become single step processes, which produce high quality effluent potentially suitable for reuse (Stephenson *et al*., 2000). The membrane filtration process introduced into bioreactors not only replaces the settling unit for solid-liquid separation but also serves as an advanced treatment unit for bacteria and suspended solids, which cannot be removed completely by conventional processes. The quality of the effluent in this system is independent of settleability of the mixed liquor. This allows operation of the bioreactor at high biomass levels of 10,000 to 15,000 mg L^{-1} and high sludge retention time (SRT 20-50 days). Operating at high biomass levels, in turn, means that the bioreactor tank can be 2 to 5 times smaller than a conventional bioreactor (Visvanathan *et al*., 2000). Accordingly, over the past decade, submerged MBR processes have experienced unprecedented growth in domestic and municipal wastewater treatment/reuse (Yang *et al*., 2006).

Although the suitability of the MBR technology in producing reuse standard effluent has already been demonstrated in different parts of the world, this technology is rather new in Saudi Arabia. Only a handful of investigations, if any, regarding MBR from this region of the world may be pointed out.

The objective of this study was, therefore, to assess the suitability of the MBR technology for wastewater reclamation in Saudi Arabia. Investigations were conducted at a pilot scale MBR plant. This paper reports the technical feasibility of the process under the local conditions. This study on one hand casts light on wastewater reclamation potential by MBR in an arid country and on the other hand adds valuable information to the knowledge base of MBR technology.

MATERIALS AND METHODS

Pilot Plant Description

This study conducted investigations at a pilot plant MBR system located in Al Khomra, Jeddah for a period of three months. The pilot plant was constructed in a compound receiving wastewater from a residential area and adjoining workshops. Three parallel MBR units (Fig. 1) were employed. The units received wastewater from the same storage tank, so the values and concentrations of the different quality parameters in the influent were the same for all the three units.

Ultrafiltration hollow fiber membranes (Zenon) with pore size of 0.04 micron and nominal surface area of 0.93 m^2 were utilized in this study. In each MBR, a membrane was placed within a 204 L polyethylene tank, the water level of which was controlled by a float valve. Air was supplied to the fine bubble diffusers located at the bottom of each of the process tanks as well as to the coarse bubble diffusers built-in at the bottom of the membrane. The membranes were backpulsed periodically (permeation: 9.75 min, backpulse: 0.25 min) with permeate stored in backpulse tanks. During the whole course of the investigation the pH, temperature and dissolved oxygen values within the reactor varied within the range of 7.35±0.85, 24±5°C and 3.35±0.85 mg L^{-1}, respectively.

Plan and Schedule of Operation

To study the performance of membrane bioreactor under different operating conditions, three parallel MBRs each containing different mixed liquor suspended solids (MLSS) concentration were operated under progressively shorter hydraulic retention times (HRT). Table 1 summarizes the plan of operation.

The operation of the pilot plant was initiated on July 15, 2004. The startup phase continued until Aug 15, in order to build up the mixed liquor suspended solids of each unit to the predetermined value of 10,000, 15,000 and 20,000 mg L^{-1} for MBR1, MBR2 and MBR3, respectively. During Phase 1, all units were operated at a hydraulic retention time (HRT) of 8 h for one month.

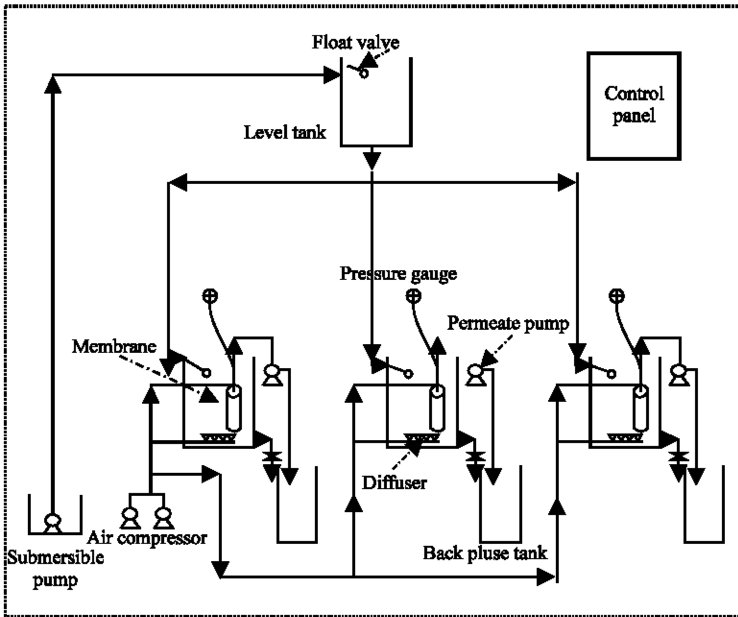

Fig. 1: Schematic of the pilot plant (three MBR units in parallel)

Table 1: Plan of operation (2004)

Unit	July	August	September	October	November
MBR 1 $(10{,}000\ mg\ L^{-1})^a$	Start up	HRT = 8 h	HRT = 6 h	HRT =3 h	
MBR 2 $(15{,}000\ mg\ L^{-1})^a$					
MBR 3 $(10{,}000\ mg\ L^{-1})^a$					

During Phase 2 and 3, all units were operated at a HRT of 6 and 3 h, respectively. Different levels of MLSS in different MBR units were maintained by varying sludge withdrawal rate (SRT of 40, 60 and 80 days) in each unit, while HRTs were varied by varying the flow rate of the permeate pumps (0.375, 0.5 and 1.0 L min^{-1}, respectively), hence, varying the quantity of permeate.

Sampling and Analytical Methods

Samples-collected on every third day through out the whole period of continuous operation- were analyzed for organics, nutrients and pathogen removal following the standard methods (APHA/AWWA/WEF, 1998) as outlined in Table 2. pH was determined using a portable pH meter. Organics removal efficiency was assessed by monitoring and comparing the Biochemical oxygen demand (BOD) and Chemical oxygen demand (COD) in the influent municipal wastewater and the MBR permeate. In order to ascertain the Nitrogen and Phosphorus removal performance by the pilot plant MBRs following parameters were monitored: Ammonia Nitrogen (NH_3-N), Nitrate Nitrogen (NO_3-N), Total Kjeldhal Nitrogen (TKN), Total P (TP). Observation of the Total and Fecal Coliform content provided insight into the extent of disinfection of wastewater achieved by MBR. In this study membrane fouling was indirectly assessed by monitoring the transmembrane pressure (TMP) throughout the whole period of observation of three months.

Table 2: Analytical methods for the on-site laboratory

Parameters	Units	Method No.
Ammonia-N	mg L^{-1}	SM 4500 C*
Nitrate-N	mg L^{-1}	SM 4500 C*
Total Kjeldahl Nitrogen (TKN)	mg L^{-1}	SM 4500 B*
Biological Oxygen Demand (BOD_5)	mg L^{-1}	SM 5210 D*
Chemical Oxygen Demand (COD)	mg L^{-1}	SM 5220 D*
Total phosphorus-P	mg L^{-1}	SM 4500 E*
Total/volatile suspended solids	mg L^{-1}	SM 2540 D and E
Total coliform	cfu 100 m L^{-1}	9222 B
Fecal Coliform	cfu 100 m L^{-1}	9222 D

SM: Standard Methods for the examinations of water and wastewater. *Modified Method used with Hach DR/4000 Spectrophotometer

RESULTS AND DISCUSSION

The pilot plant MBR units were operated under different operating conditions (HRT and MLSS conc.). In-depth evaluation of the results observed in the course of three months of operation was made. This enabled drawing of a preliminary inference as to the suitability of the MBR technology in Saudi Arabia.

Carbonaceous Organics Removal

Overall Removal

In the course of the operation of the MBRs (containing different MLSS concentrations) under different HRTs, the BOD in the influent wastewater ranged between 198 and 253 mg L^{-1}. The BOD in the membrane-permeate, on the other hand, varied in the range of 4 to 12 mg L^{-1}. Figure 2-4 show the variation of BOD in permeates of different MBRs in the course of investigations under different HRTs. The mean BOD removal efficiency never dropped below 95% and the best average BOD removal approached 98%.

Conversely, the COD in the influent municipal wastewater fluctuated between 445 and 575 mg L^{-1}; while that in the membrane-permeate, as a function of influent COD, MLSS concentration and applied HRT, ranged from 23-56 mg L^{-1}. Figure 5 and 6 sketch the variation of COD in permeates of different MBRs in the course of investigations under different HRTs. The mean COD removal efficiency seldom dropped below 90% and the best average COD removal approached 95%.

Effect of HRT and MLSS Concentration

A clear influence of HRT and MLSS concentration on organics removal by MBR was observed throughout the whole period of investigation. Operation of the MBRs (each containing a specific stable MLSS concentration of 10, 15 and 20 g L^{-1}, respectively) under successively shortened HRT revealed a general trend of higher removal performance being associated with high MLSS concentration and longer HRT. However, the differences in removal performances under different operational conditions were not substantially high and it should be emphasized here that even with a HRT as short as 3 h the MBR realized fairly well removal performance comparable to that achieved under longer HRT. The results are in conformation with other available reports (Enegess *et al*., 2003).

Nutrients (N,P) Removal Performance

Nitrification

One of the inherent advantages of MBR is total retention of sludge (Muller *et al*., 1995). This provides congenial atmosphere for proliferation of slow growing nitrifiers within MBR and hence usually high nitrification is achieved in MBRs (Stephenson *et al*., 2000). Excellent nitrification was

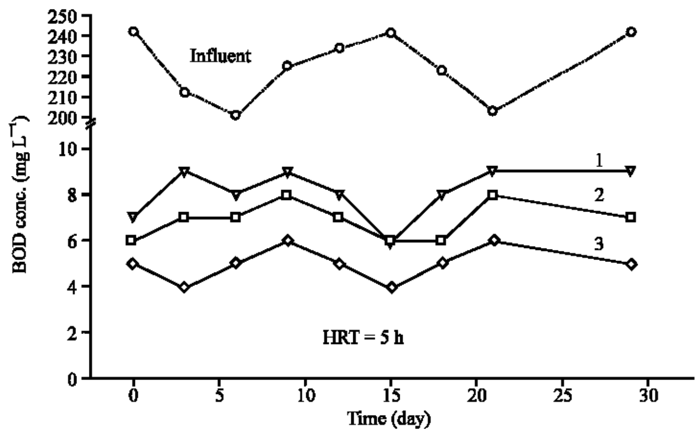

Fig. 2: Variation of BOD in permeates of different MBRs under HRT of 8 h (1, 2, 3: MLSS concentration of 10, 15 and 20 g L^{-1}, respectively)

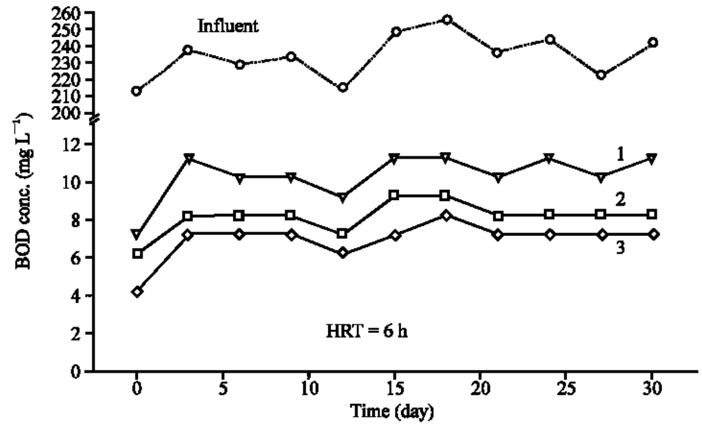

Fig. 3: Variation of BOD in permeates of different MBRs under HRT of 6 h (1, 2, 3: MLSS concentration of 10, 15 and 20 g L^{-1}, respectively)

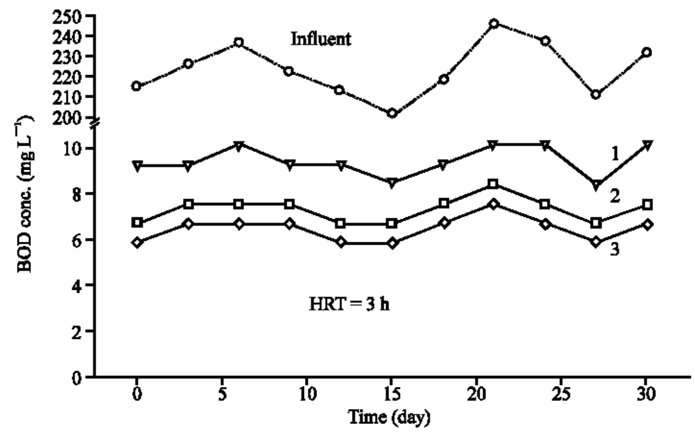

Fig. 4: Variation of BOD in permeates of different MBRs under HRT of 3 h (1, 2, 3: MLSS concentration of 10, 15 and 20 g L^{-1}, respectively)

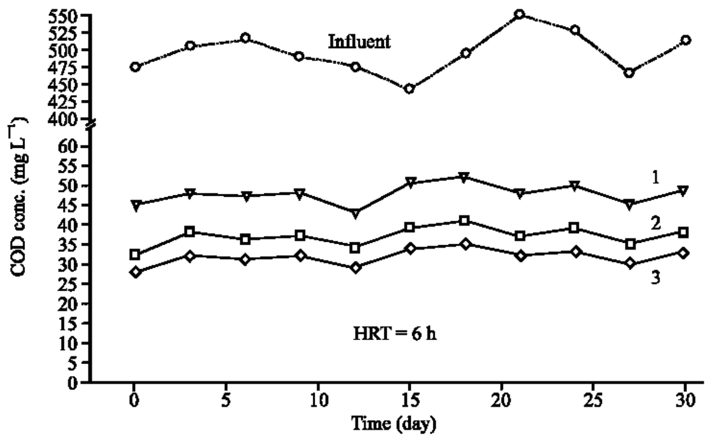

Fig. 5: Variation of COD in permeates of different MBRs under HRT of 6 h (1, 2, 3: MLSS concentration of 10, 15 and 20 g L^{-1}, respectively)

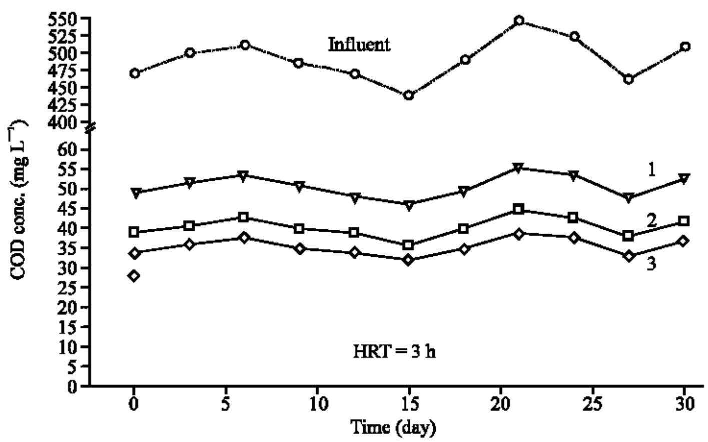

Fig. 6: Variation of COD in permeates of different MBRs under HRT of 3 h (1, 2, 3: MLSS concentration of 10, 15 and 20 g L^{-1}, respectively)

realized throughout the whole period of observation in this study. In the course of the operation (under different HRTs) of the MBRs each of which contained different MLSS concentrations, the TKN in the influent municipal wastewater ranged between 18 and 26 mg L^{-1}. The TKN in the membrane-permeate, on the other hand, varied in the range of 0-0.3 mg L^{-1} depending on the influent TKN and also the reactor MLSS concentration. The nitrification efficiency, hence, never dropped below 98.64% and during the best performance a complete nitrification was observed. The effect of HRT on the performance of the MBRs with different MLSS concentrations was rather negligible. Figure 7 shows the variation of TKN and NO_3^- in permeate under an HRT of 8 h.

Denitrification

Denitrification, necessitates creation of anoxic environment within the same reactor (e.g., by employing intermittent aeration) or requires an additional anoxic tank with periodic sludge-recycling from the aerobic tank (Li *et al*., 2008). In this study, in absence of such anoxic environment, high rate of denitrification could not be expected. In fact, denitrification only ranged in between 18.94 and 32.21% (data not shown).

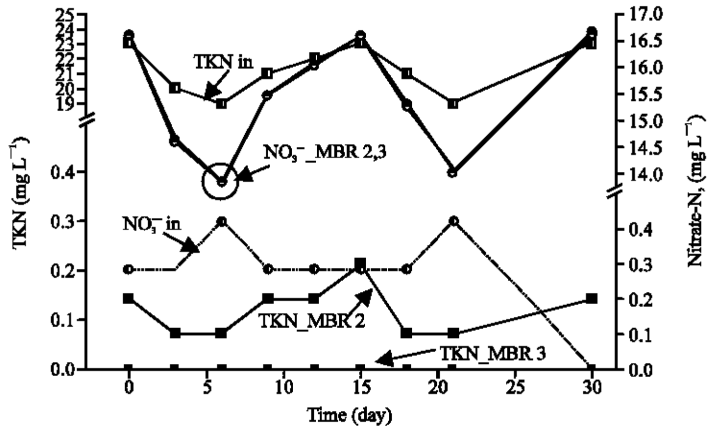

Fig. 7: Variation of TKN and NO_3^- N in permeates under different MLSS conc. HRT = 8 h (1, 2 ,3: MLSS concentration of 10, 15 and 20 g L^{-1}, respectively)

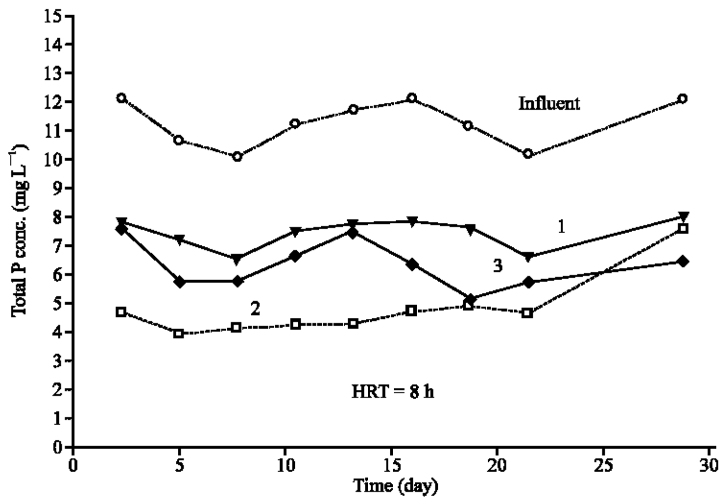

Fig. 8: Variation of Phosphorus concentration in permeates of different MBRs under HRT of 8 h (1, 2, 3: MLSS concentration of 10, 15 and 20 g L^{-1}, respectively)

Phosphorus (P) Removal

Unless some extra measures to enhance the Phosphorus removal is undertaken, usually a P-removal performance similar to that of a conventional biological process is exhibited by an MBR. Enhanced P-removal may be brought about by addition of an anaerobic zone prior to the aerobic zone and returning nitrate-free sludge from the aerobic zone or by using a metal coagulant dosing (Yeoman *et al*., 1988; Stephenson *et al*., 2000). In absence of any additional facilities to enhance P removal, the MBRs operated in this study achieved a reasonable average P removal rate of around 40-50%, while occasionally the removal exceeded 60%. Rare instances of P-removal below 20% were, however, also encountered. The influent P varied within the range of 8.6-13.6 mg L^{-1} and the best removal yielded a permeate P concentration of 3.9 mg L^{-1}. No distinct trend of effect of influent P concentration, HRT and MLSS concentration on the P-removal could be detected. Figure 8 shows the variation of phosphorus in permeates of different MBRs under an HRT of 8 h.

Pathogen Removal

One of the main features of MBR technology, which is particularly important when considering reuse of treated wastewater, is the ability of the membrane to remove pathogenic organisms, yielding disinfection of the effluent. Reductions in bacteria and viruses of 4-8 log have been reported (Kolega *et al*., 1991; Shang *et al*., 2005).

Mean Removal

Table 3 and 4 depicts the mean concentrations of Total and Fecal Coliforms in membrane-permeate. In this study, Fecal Coliform content in the permeate never exceeded 63 cfu/100 mL^{-1}. It usually varied around 40 cfu/100 mL^{-1} and was occasionally detected in amounts as low as 7 cfu/100 mL^{-1}, whereas that in the influent ranged from 7000 to 22000 cfu/100. The Fecal coliform removal efficiency, hence, at times was as high as 99.92% and never plummeted below 99.20% (corresponding to a log removal of 3.1 and 2.1, respectively). The total coliform in the influent, on the other hand, fluctuated in the range of 1×10^7 to 2.4×10^7 cfu/100 mL^{-1}, while that in the permeate remained below 90 cfu/100 mL^{-1} and occasionally as low as 10 cfu/100 mL^{-1}. Hence a maximum 99.99991% (6 log) removal and a minimum 99.9993% (5 log) removal of total coliform were achieved during continuous operation of the MBRs with different MLSS concentration under different HRTs.

Effect of HRT and MLSS Concentration

Although in general the pathogen removal efficiencies of the MBRs were up to the mark, an intriguing trend of higher removal being associated with the reactor with the lower MLSS concentration was noticed (Table 3, 4). For instance, under a HRT of 8 h. the mean total coliform removal for the MBRs with MLSS concentrations of 20, 15 and 10 g L^{-1} were 99.99968, 99.99977 and 99.99979%, respectively. The similar trend persisted during operations under the subsequent shorter HRTs. However, such nuances may not be of immense practical significance. On the other hand, in terms of the effect of HRT, all the MBRs, each with a specific stable MLSS concentration, were observed to realize the best removal performances under a HRT of 6 h, the next best performance being achieved under a HRT of 3 h. Detected differences in removal efficiencies were, however, only minor.

Suitability for Wastewater Reclamation

Excellent pollutant and pathogen removal performances irrespective of MLSS concentrations and applied HRTs were observed during the pilot plant investigation. The high performance of the MBRs under the environment locally prevailing in Saudi Arabia is, in general, in accordance with the available reports in literature (Galil and Levinsky, 2007). In this context it may stated that MBR technology

Table 3: Total Coliform concentrations in influent and permeate

		Permeate range (cfu/100 mL)		
HRT (h)	Influent range (cfu/100 mL)	MBR 1	MBR 2	MBR 3
8	1×10^7-2.4×10^7	45-70	50-75	45-85
6	1.2×10^7-2.4×10^7	10-90	20-85	25-90
3	1.2×10^7-2.4×10^7	15-70	30-75	45-85

Table 4: Fecal Coliform concentrations in influent and permeate

		Permeate range (cfu/100 mL)		
HRT (h)	Influent range (cfu/100 mL)	MBR 1	MBR 2	MBR 3
8	7×10^3-2.2×10^4	32-49	35-52	32-60
6	9×10^3-2×10^4	7-63	14-60	18-63
3	7×10^3-2×10^4	11-49	21-53	32-60

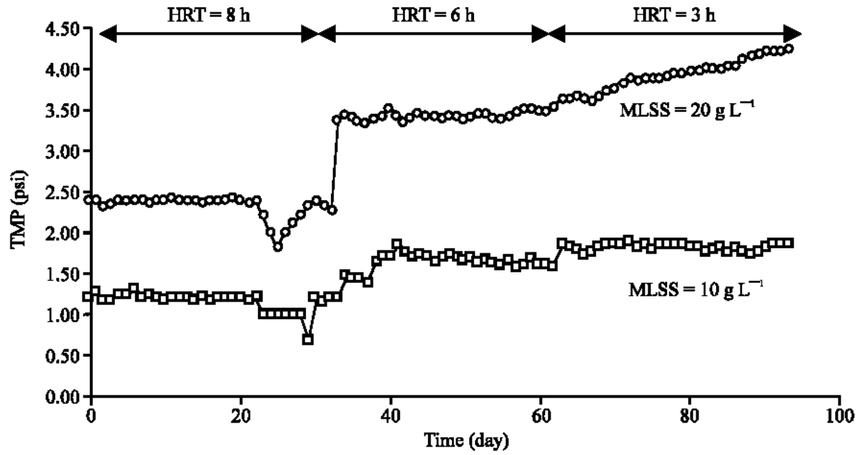

Fig. 9: Variation of transmembrane pressure (TMP) under different HRTs and MLSS concentrations

Table 5: Comparison of MBR permeate quality with reclaimed water standards in Saudi Arabia

	Parameters				
	BOD (mg L^{-1})	TSS (mg L^{-1})	Turbidity (NTU)	pH	Coliform (cfu/100 mL)
Standard[a]	10	10	1.0	6-8.4.0	2.2
MBR permeate[b]	4	5	0.3	6.5-8.2	10.0

[a]For Irrigation (Source:USEPA, 2004); [b]Best quality achieved during this study

is technically feasible in the Kingdom. Since another important aim of this study was to assess the suitability of this technology for accomplishing wastewater reclamation, a comparison of the quality of the permeate obtained during the experiment with the standards in Saudi Arabia was deemed essential. Table 5 furnishes such a comparison. It is interesting to note that the permeate quality, in terms of all the studied parameters except one, convincingly conformed the quality requirements for reuse in irrigation purpose in the Kingdom. Although the pathogen content in the permeate slightly surpassed the standard value, an appropriate removal may certainly be expected provided some extra measures are taken.

Hydraulic Performance of the Membrane

Despite excellent effluent quality, the membrane fouling problem impedes the widespread application of the MBR technology (Le-Clech *et al*., 2006). Severe membrane fouling may necessitate frequent chemical cleaning and/or costly membrane replacement. Hence assessment of the membrane fouling propensity is an indispensable part of the overall feasibility study of MBR application at a particular site.

In addition to the permeate-backpulsing (15 sec/10 min), the requirements as specified by the membrane supplier for routine operation included sodium hypochlorite (NaOCl) backpulsing of the membrane corresponding to the rise of TMP to a value of 9.0 psig (62 kpa) and occasional off-site cleaning by soaking into NaOCl and/ or HCl solution. However, in the course of this study, a stable flux could be maintained without any chemical cleaning.

As one would expect, higher TMP was usually observed to be associated with the higher MLSS concentration and lower HRT (Fig. 9), nevertheless, fatal membrane fouling, requiring frequent chemical cleaning, was not encountered and stable fluxes irrespective of the MLSS concentration and applied HRT were maintained during operation of the MBRs.

CONCLUSION

Being a desert country with a large agricultural and industrial base and a growing population makes a serious pursue of alternative water resources, such as wastewater reclamation, imperative for the development and growth of the economy of Saudi Arabia. MBR technology is a very attractive means for achieving tertiary effluent owing to its inherent compactness and single-step pollutant removal capability. Hence, this study aimed at the assessment of the suitability of the MBR technology in Saudi Arabia.

The pilot plant MBR units realized excellent organics, nutrients and pathogen removal performances irrespective of the applied MLSS concentrations (10, 15, 20 g L^{-1}) and HRTs (8, 6 and 3 h) without encountering severe membrane fouling. A stable pollutant removal performance concurrent with abatement of membrane fouling presents the proposed MBR system as a promising option for the treatment and reuse of the wastewater explored in this study.

REFERENCES

Abderrahman, W.A., 2000. Urban water management in developing arid countries. Int. J. Water Resour. D, 16: 7-20.

APHA/AWWA/WEF, 1998. Standard Methods for the Examination of Water and Wastewater. American Public Health Association/American Water Works Association/Water Environment Federation. 20th Edn., Washington DC, USA .

Bremere, I., M. Kennedy, A. Stikker and J. Schippers, 2001. How water scarcity will effect the growth in the desalination market in the coming 25 years. Desalination, 138: 7-15.

Earth Trends, 2001. The Environmental Information Portal, Water Resources and Freshwater Ecosystems, 1999-2000. World Resources Institute, http://earthtrends.wri.org/index.php.

Enegess, D., A.P. Togna and P.M. Sutton, 2003. Membrane separation applications to biosystems for wastewater treatment. Filtr. Separat, 40: 14-17.

Galil, N.I. and Y. Levinsky, 2007. Sustainable reclamation and reuse of industrial wastewater including membrane bioreactor technologies: Case studies. Desalination, 202: 411-417.

Haddadin, M.J., 2002. Water issues in the Middle East challenges and opportunities. Water Pollut., 4: 205-222.

Howell, J.A., 2002. Future research and developments in the membrane field. Desalination, 144: 127-131.

Kolega, M., G.S. Gorhmann, R.F. Chiew and A.W. Day, 1991. Disinfection and clarification of treated sewage by advanced microfiltration. Water Sci. Technol., 23: 1609-1618.

Le-Clech, P., V. Chen and A.G. Fane, 2006. Fouling in membrane bioreactors used in wastewater treatment. J. Membrane Sci., 284: 17-53.

Li, Y.Z., Y.L. He, D.G. Ohandja, J. Ji, J.F. Li and T. Zhou, 2008. Simultaneous nitrification-denitrification achieved by an innovative internal-loop airlift MBR: Comparative study. Bioresour. Technol., 99: 5867-5872.

Muller, E.B., A.H. Stouthamer, H.W. Van Verseveld and D.H. Eikelboom, 1995. Aerobic domestic wastewater treatment in a pilot plant with complete sludge retention by cross-flow filtration. Water Res., 29: 1179-1189.

Shang, C., H.M. Wong and G. Chen, 2005. Bacteriophage MS-2 removal by submerged membrane bioreactor. Water Res., 39: 4211-4219.

Stephenson, T., S. Judd, B. Jeferson and K. Brindle, 2000. Membrane Bioreactors for Wastewater Treatment. 1st Edn. ISBN: 1 900222 07 8. IWA Publishing, London.

US EPA, 2004. Office of Research and Development, NRMRL, Technology Transfer and Support Division, Guidelines for Water Reuse. http://www.epa.gov/nrmrl/pubs/625r04108/625r04108.pdf

Visvanathan, C., R. Ben Aim and K. Parameshwaran, 2000. Membrane separation bioreactors for wastewater treatment. Crit. Rev. Environ. Sci. Technol., 30: 1-48.

Yang, W., N. Cicek and J. Ilg, 2006. State-of-the-art of membrane bioreactors: Worldwide research and commercial applications in North America. J. Membrane Sci., 270: 201-211.

Yeoman, S., T. Stephenson, J.N. Lester and R. Perry, 1988. The removal of phosphorus during wastewater treatment: A review. Environ. Pollut. A, 49: 183-233.