Feasibility of the membrane bioreactor process for water reclamation

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Abstract The feasibility of the membrane bioreactor (MBR) process for water reclamation was studied. Process evaluation was based on the following: literature review of MBRs, worldwide survey of MBRs, and preliminary costs estimates. The literature review and the survey have shown that the MBR process offers several benefits over the conventional activated sludge process, including: smaller space and reactor requirements, better effluent water quality, disinfection, increased volumetric loading, and less sludge production. The MBR process can exist in two different configurations, one with the low-pressure membrane modules replacing the clarifier downstream the bioreactor (in series), and the second with the membranes submerged within the bioreactor. Four major companies are currently marketing MBRs while many other companies are also in the process of developing new MBRs. The MBR process operates in a considerably different range of parameters than the conventional activated sludge process. The preliminary cost evaluation has shown that the MBR process is cost competitive with other conventional wastewater treatment processes.

Keywords Membrane bioreactors; membranes; reclamation; water reuse

Background

The City of San Diego is currently evaluating various water reclamation projects at their Aqua 2000 Research Center. Desalting membranes play an important role in many of these water reclamation projects since these membranes are the best available technology for removal of inorganic salts, trace metals and organic compounds; in addition they have the potential for removal of all classes of microorganisms. As part of the Aqua 2000 research program, the City is also interested in evaluating the new and emerging technologies currently on the market for municipal wastewater treatment which might provide a cost advantage for future water recycling projects. Prominent among these technologies is the Membrane Bioreactor (MBR) process, in which membrane filters (such as microfiltration or ultrafiltration membranes) are substituted for the sedimentation and filtration in conventional suspended growth biological treatment.

Membrane filters typically cost more than secondary clarifiers of comparable hydraulic capacity. As a result, up until the present time, MBRs have been most successful in the treatment of concentrated wastes where the biological reactor is large but the hydraulic capacity (i.e. the size of the membrane system) is small. As membrane technology is being more developed and reclamation projects requiring desalting membranes, the negative economic impact of MBRs is being reduced. That is because studies at both Aqua 2000 Research Center and the Water Factory 21 in California have confirmed that membrane filtration is the most cost-effective and reliable treatment process for preparing treated wastewater for the desalting process. Since membrane filtration is now required as pretreatment to desalting membranes, the economics shift to make the MBR process attractive for treatment of domestic sewage. That is because the MBR technology can replace multiple processes with a single membrane process as presented in Figure 1.

This paper evaluates the feasibility of the MBR process for water reclamation. Process

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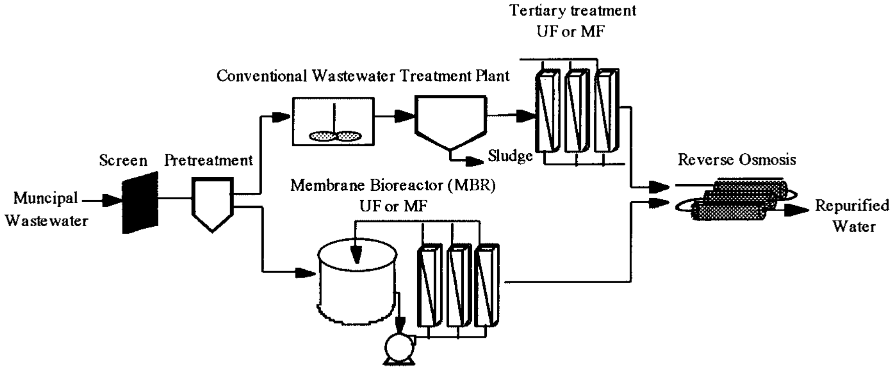

Figure 1 MBR versus conventional treatment process

evaluation is based on the following: literature review of MBRs, worldwide survey of MBRs, and preliminary costs estimates.

Literature search of MBRS application for wastewater treatment

A literature search was conducted to evaluate the performance of MBRs for municipal wastewater treatment. The details of the literature search can be found elsewhere (Adham and Gagliardo, 1998). Below are selected main points from the review.

- Recent interest in the MBR technology for domestic wastewater treatment has occurred due to an increasing number of water repurification/reclamation projects and continuing advancement in membrane technology.
- The MBR process can exist in two different configurations, one with the low-pressure membrane modules replacing the clarifier downstream the bioreactor (in series), and the second with the membranes submerged within the bioreactor. No direct comparison between the two configurations was found in the literature.
- The MBR process operates in a considerably different range of parameters than the conventional activated sludge process. While solid retention time (SRT) falls in the range of 5–30 days for a conventional system, SRT values frequently exceed 30 days for the MBR. The loading rate or Food/Microorganisms (F/M) ratio falls in the range of 0.05–1.5d^{-1} for a conventional system, but is usually < 0.1 d^{-1} for an MBR. The low F/M ratio occurs due to the high mixed liquor suspended solids (MLSS) in the bioreactor, which typically range from 5,000 to 20,000 mg/L for MBRs as compared to 2000 mg/L in conventional processes.
- Low temperatures (below 13°C) impact the overall removal of contaminants by the MBR process.
- The MBR process offers several benefits over the conventional activated sludge process, including: smaller space and reactor requirements, better solids removal, disinfection, increased volumetric loading, reduced sludge production, system reliability throughout hydraulic and solids load variations, a higher and more consistent quality effluent, potential reduction in capital expenditures, and potential reduction in energy requirements.
- The MBR has been shown to produce less sludge with poorer settling characteristics, which might increase the difficulty of sludge disposal.
- With submerged MBRs, optimization of the packing density of the hollow fiber membrane elements, the type of air aerators used, and the specific placement of the aerators over the floor area of the bioreactor floor may be critical design elements.
- To adequately demonstrate the effectiveness of this technology, a parallel comparison

of a conventional suspended growth reactor, a MBR with in-series configuration, and a MBR with submerged configuration needs to be performed at pilot-scale.

Active manufacturers of membrane bioreactors, their applications and their installations

Four major companies are currently active in marketing the MBR system and are shown in Table 1. The active companies are: Zenon Municipal Systems (Canada), Mitsubishi Rayon Corporation (Japan), Suez-Lyonnaise-des-Eaux/Infilco-Degremont (USA), and Kubota Corporation (Japan). While many installations can be found for small capacity industrial waste plants, there are only a few operating municipal installations. Municipal installations in the 1.0 to 2.0 MGD ranges are currently under construction in Canada, Egypt and the United States.

Zenon Municipal Systems (ZMS), Mitsubishi Rayon and Kubota Corporation market submerged MBRs with polymeric hollow fiber membranes while Suez-Lyonnaise-des-Eaux/Infilco-Degremont (Suez-LDE/IDI) market in-series MBRs with tubular ceramic membranes.

Worldwide full-scale survey of existing MBRS

A Membrane Bioreactor plant survey questionnaire was developed to collect global full-scale design, operational and cost data. The survey questionnaire covers several issues, including: (i) MBR general information such as location, capacities, wastewater type, configuration (submerged or in-series), and start-up date; (ii) membrane characteristics and operational data, including pore size, surface area, flux rate, backwash and chemical cleaning parameters; (iii) bioreactor configuration, hydraulics and operational parameters, sludge production, and aeration rate; (iv) MBR performance for the removal of organic contaminants, ammonia-nitrogen, and microbiological contaminants (coliform bacteria); (v) and cost performance, including capital costs of membranes and the plant, O&M costs of labor, energy, sludge disposal and other.

Forty-five questionnaires were distributed among the four major manufacturers, and twenty completed survey forms were received. Eleven completed survey forms were received from ZMS, seven from Mitsubishi Rayon, one from Suez-LDE/IDI, and one from Kubota Corporation. The following is a summary of the main conclusions drawn from the analysis of the survey data received from twenty full-scale operating MBR plants.

Figure 2 illustrates the number of MBR plants versus capacity and year on-line. While the data is limited, it shows increasing implementation of the MBR process and expansion into higher capacity applications. Presently, the majority of the MBR plants are in the capacity range of less than or equal to 100,000 gpd, but the number of plants ranging between 1 and 5 MGD are increasing.

Figure 3 provides the probability plot for membrane operational flux for the MBR systems. The 50th percentile of the membrane flux values is 15 gfd. As expected, this values is

Table 1 MBR vendors

Trade Name	Company	Country	Wastewater	Current Status
BIOREM	Kubota	Japan	Domestic	**Still active**
STERAPORE	Mitsubishi Rayon	Japan	Industrial, Domestic	**Still active**
ZENOGEM	Zenon Env. Inc.	Canada	Oil	**Still active**
BRM	Suez-LDE/IDI**	France	Domestic, Industrial	**Still active**

*C.G.E: Compagnie Générale des Eaux
**Suez-LDE/IDI: Group Suez-Lyonnaise des Eaux/Infilco Degremont Inc.

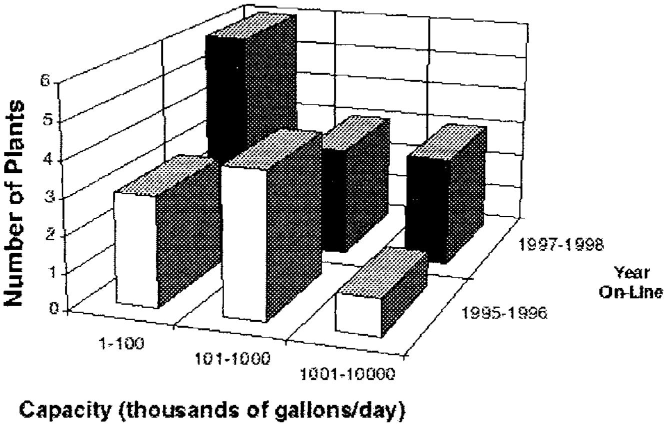

Figure 2 Number of MBR plants versus capacity and year on-line

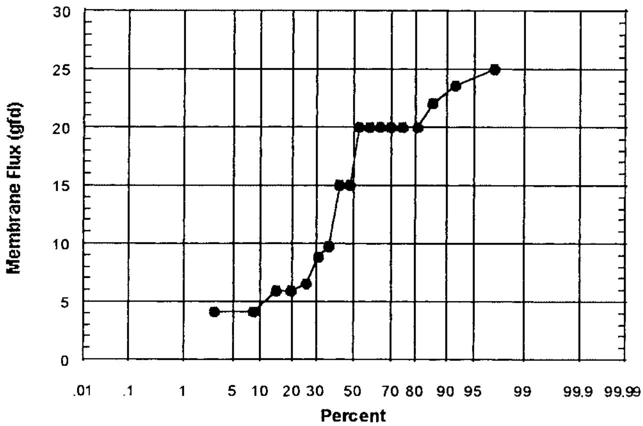

Figure 3 Membrane flux probability plot

lower than the nominal membrane flux in drinking water and reclaimed water applications which are 60 gfd and 40 gfd, respectively.

The probability plots for the mixed liquor volatile suspended solids (MLVSS) in the bioreactor is illustrated in Figure 4. As far as bioreactor operation is concerned, the 50th percentiles for MLVSS content were observed at 10,000 mg/L, respectively. Compared to a conventional wastewater treatment facility, which operates at a MLVSS of 2,000 mg/L, the MBR incorporates five times the MLVSS concentration.

The effluent water quality obtained from the MBR process is illustrated in Figures 5 to 7. The 50th percentile removals of biochemical oxygen demand (BOD), total suspended solids (TSS), and ammonia-nitrogen were all observed to be in the order of 2 logs or 99%. BOD concentration in the effluent varied from non-detect to 4 mg/L. The effluent TSS concentration was in all cases less than or equal to 2 mg/L (below detection limit). Finally, the median for total coliform removal was observed at 5 to 6 logs. Only one plant provided their influent total coliform concentration, but a 10^6 to 10^7 cfu/100 mL was assumed as the typical total coliform concentration in a primary treated municipal wastewater.

Preliminary cost analysis of MBRS

A cost analysis was conducted to compare three treatment processes: Zenon MBR (based

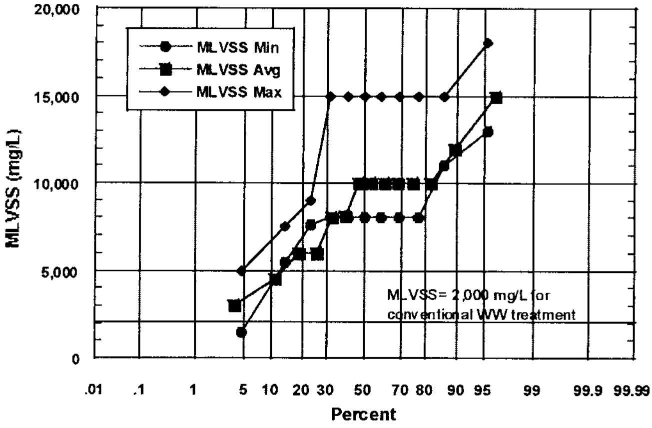

Figure 4 MLVSS probability plot

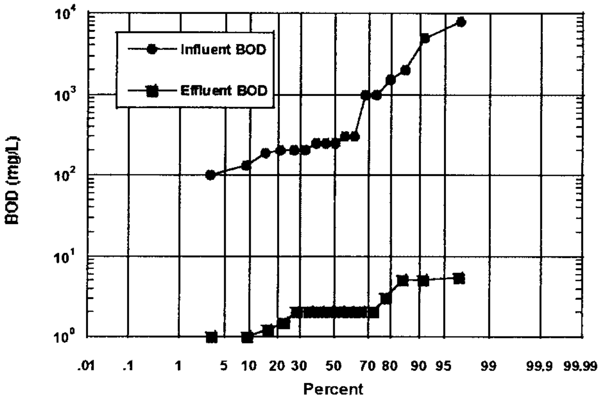

Figure 5 BOD probability plot

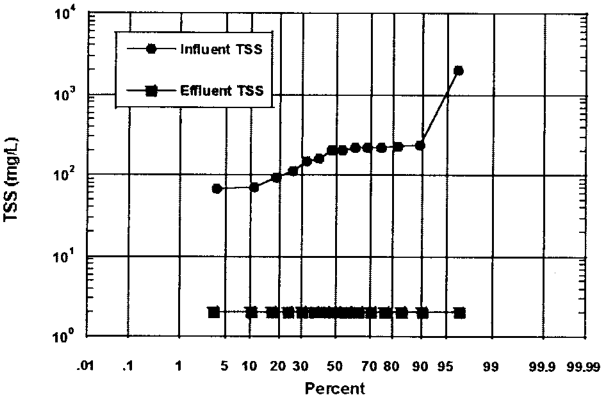

Figure 6 TSS probability plot

on full-scale costs provided by the manufacturer), oxidation ditch, and conventional activated sludge. Figure 8 presents the process train schematics for each alternative. Each of the above alternatives was compared as pre-treatment to RO. The design capacity selected for cost comparison was 1 MGD since no actual data are available on MBRs with larger capacities. Also, this capacity is considered, at this time, one of the most viable use of the MBR in the municipal services water reclamation market.

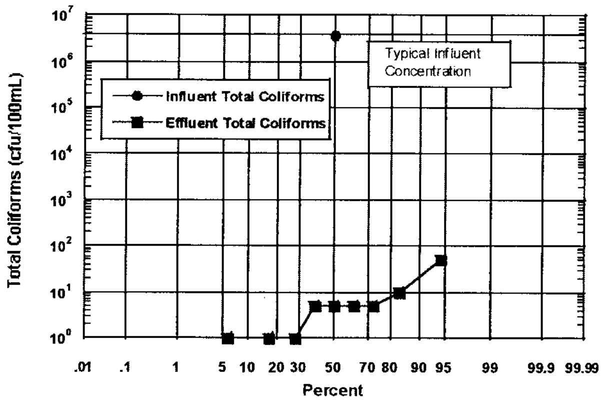

Figure 7 Total coliform probability plot

A summary of the cost comparison is presented in Table 2. Details of the cost estimates and assumptions can be found elsewhere (Adham and Gagliardo, 1998). It is important to remember that the costs presented are based on a conceptual design level and include amortized capital cost plant over a 20-year period at 8% interest rate. It appears that the total cost of the MBR alternative is more favorable than the other alternatives. However, due to the fact that the costs presented are approximate in nature based on a conceptual design level, it is prudent to conclude that costs for all three alternatives are comparable. Costs associated with land were not included, although the fact that MBRs do not take up as much space as either a conventional or an oxidation ditch treatment plant, could be an advantage. Finally,

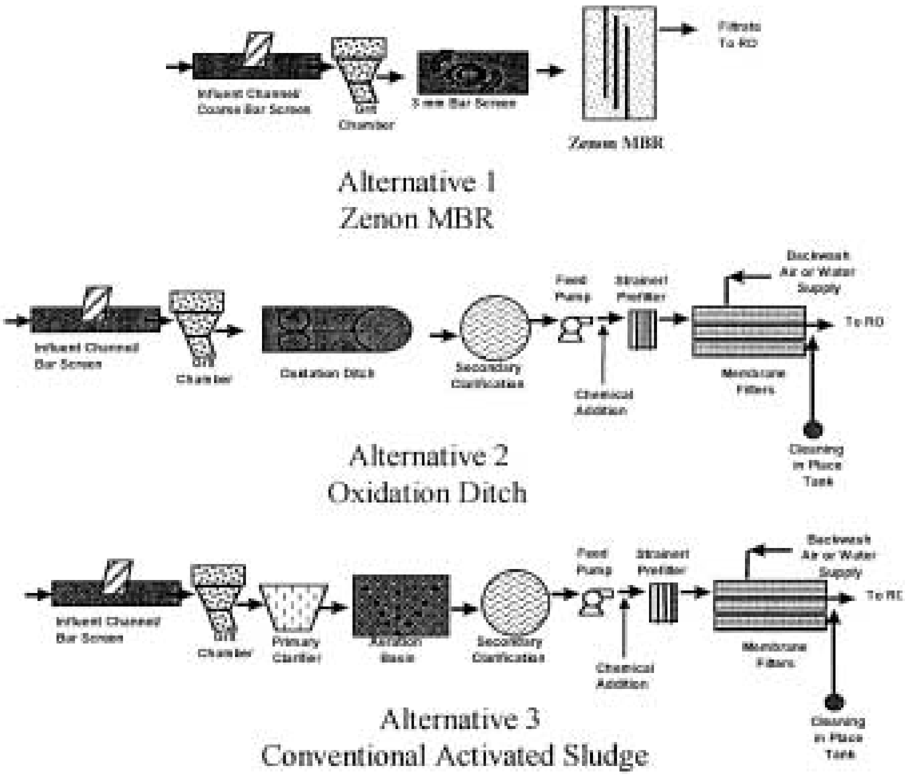

Figure 8 Process train schematics

Table 2 Summary of capital and O&M costs

Alternative	Capital Costs	Amor. Cap cost, $/yr	O&M Costs, /yr	Total Cost, $/yr	Total Cost, $/1000 gal
Zenon	$5,068,627	$516,000	$267,000	$783,000	$2.15
Oxidation ditch	$5,587,800	$569,000	$307,000	$876,000	$2.40
Conventional activated sludge	$5,933,520	$605,000	$262,000	$867,000	$2.38

it should be noted that the O&M costs associated with MF could be greater due to the fact that it is treating secondary effluent and not tertiary effluent. What this exercise does illustrate is that the MBR is a viable alternative and should be seriously considered for specific projects. There is a serious market potential for such technology in many projects. Pretreatment to RO for water reclamation is one of those projects.

Summary

The feasibility of the MBR process for water reclamation was evaluated. Feasibility evaluation was based on the following: literature review of MBRs, worldwide survey of MBRs, and preliminary costs estimates. The literature review and the survey have shown that the MBR process offers several benefits over the conventional activated sludge process, including: smaller space and reactor requirements, better effluent water quality, disinfection, increased volumetric loading, and less sludge production. The MBR process can exist in two different configurations, one with the low-pressure membrane modules replacing the clarifier downstream the bioreactor (in series), and the second with the membranes submerged within the bioreactor. Four major companies are currently marketing MBRs while many other companies are also in the process of development of new MBRs. The MBR process operates in a considerably different range of parameters than the conventional activated sludge process. The preliminary cost evaluation has shown that the MBR process is cost competitive with other conventional wastewater treatment processes.

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Reference

Adham, S. and Gagliardo, P. (1998). *Membrane Bioreactors for Water Repurification- Phase I. Final Technical Report. Desalination Research and Development Program Report No. 34*. Bureau of Reclamation. Denver, CO. (Nov. 1998).