POTENTIAL OF MEMBRANE TECHNOLOGY IN WATER AND WASTEWATER REUSE APPLICATIONS

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ABSTRACT

In the 1990s, increased interest in wastewater reuse in many parts of the world is occurring in response to growing pressures for high quality, dependable water supplies for agriculture, industry and domestic. Today, technically proven water and wastewater treatment and management schemes exist and can successfully achieve considerable reuse potential. However, the conventional technologies face certain difficulties like cost, area requirement, operational problems etc. which sometimes discourage the use of these technologies.

Membrane technologies provide an attractive alternative to extend the range of water and wastewater reuse application. They could be effective to a considerable extent in reuse because they offer considerable advantages such as better effluent quality, reduced area requirement, compact units, no odour problem, reduced chemical requirements etc.

INTRODUCTION

Need for Water Reuse

The evolution of wastewater reclamation, recycling and reuse has its roots in the early water and wastewater systems characteristic of the Minoan civilisation in Ancient Greece.

With increasing trends in population and per capita consumption patterns the demand for potable water has been continuously on the rise. Rapid industrialisation on the other hand, in the developed as well as developing countries has also led to massive increase in the demands for industrial and commercial water requirements. In addition to these direct influencing factors, rise in the standard of living of the people also affects the water demand adversely.

Comparing these rising trends in the water demand with the limited or constant water resources, it is evident that soon the total water demand of the world will overshoot the available water resources. Figure 1 presented below depicts the advantage of starting on a water reuse program early in time. The trend of the water demand can be pulled down by a substantial amount if water and wastewater reuse is effected and the available water resources could be sustainable over a longer period of time. It can be seen from the figure that the trend of the available usable water resources is also being pulled down continuously due to surface water and groundwater pollution, excessive usage and only a proactive corrective measure could possibly better the situation.

Considering the case of the Bangkok Metropolitan Region, the domestic and industrial water requirements are estimated to increase eightfold by 2010 and agricultural water demand, four fold, resulting in a decrease (78% in 1990 to 16% in 2010) in the remaining portion of the annually renewable water. The remaining portion of the renewable water can be withdrawn for further use, but the withdrawals would be made with increasing difficulty and higher costs or at the expense of other tangible benefits such as aesthetic values, recreation and other environmental benefits. This remaining supply of annually renewable water reflects the country's buffer or safety factor against water scarcity and environmental degradation such as saline water intrusion, desertification etc. This buffer would be reduced to half its present size by 2010. With less buffer to rely on, the water will become a scarcity source, its utilisation must be planned, monitored and carefully managed. Recycling and reuse of water should become the rule wherever the resource is limited, with drinking water taking the priority followed by industry and finally irrigation where the water is used up.

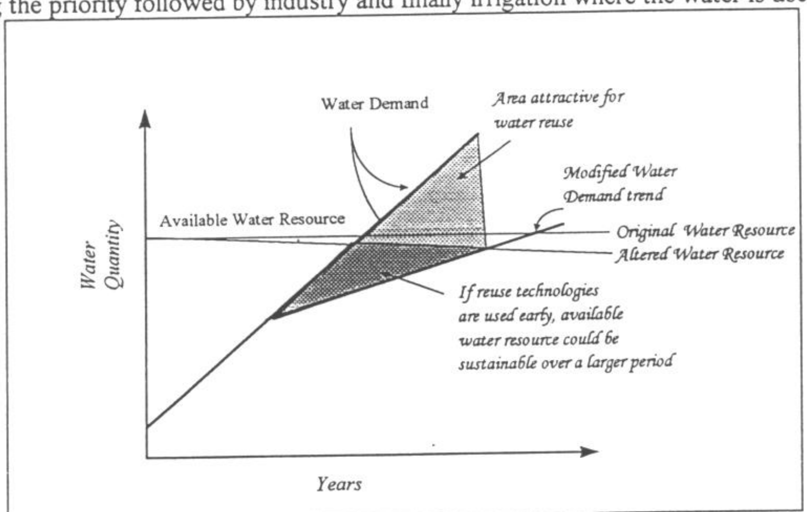


Figure 1 Sustainable Water Resources through early Water Reuse Practices

Another factor contributing to this imbalance is the degradation of the available water resources due to manmade pollution and other induced problems from soil erosion, salt water intrusion, construction of dams / reservoirs etc. Due to such problems less and less clean water resources are available for use.

There could be three broad schools of thought generally in the field of water reuse (Alaerts, 1996).

Greater emphasis on the need for more advanced technologies to turn wastewater into potable water to serve the cities of a rapidly growing world. Adding more large water reservoirs and long distance water transfers just may become too expensive.

Better usage of the existing technologies to reuse wastewater for less critical purposes such as irrigation, air conditioning or environmental enhancement. The technologies are proven, cheaper and such applications do not carry large risks in implementation.

The third dimension, is to explore the possibilities for better housekeeping, living patterns as regards the domestic water supply and cleaner production in the industry, and promote in-plant reuse. That is, to have a proactive approach rather than a reactive one. It is possible in this case to consider relocation of high water consuming industries to less sensitive watersheds, or abolish the industries permanently from those areas.

Thus it is evident from the above discussion that to optimise on the consumption of the available water resources to meet the demands of the future and for sustainable development, it is necessary to promote and implement maximum water and wastewater reuse.

Conventional Technologies

Appropriate technologies for the management of wastewater will vary depending on whether centralised or decentralised wastewater systems are used. Also, it will depend on the location of the water reclamation facility with respect to the central wastewater plant. Figure 2 presents three general configuration alternatives for water reuse systems.

In the alternative A, the water reclamation facility is a stand-alone facility constructed in series with the collection. This option could be employed when the degree of treatment required for the reclamation is not very complex, and that a central WWTP could be avoided.

In B, a part of the collected wastewater will be reclaimed and the return sludge will be passed to the central wastewater plant. The reclaimed water will then be distributed to intended users. Another possibility to option B, could be having industry specific water reclamation services based on the characteristics of the water desired for that particular reuse. This would save on the distribution costs, which otherwise would be very high for centralised water treatment schemes. This innovative scheme termed as "Water Mining" literally involves tapping of wastewater from public discharge lines and treatment. Degree of treatment depends on the desired end reuse in the industry, e.g. washing, cooling water, boiler, gardening etc.

C, presents the water reclamation facility as a unit following the treatment plant.
D incorporates the concept of 'cleaner production' and reduction of at-source water requirements by internal recycling technologies, within the industry.

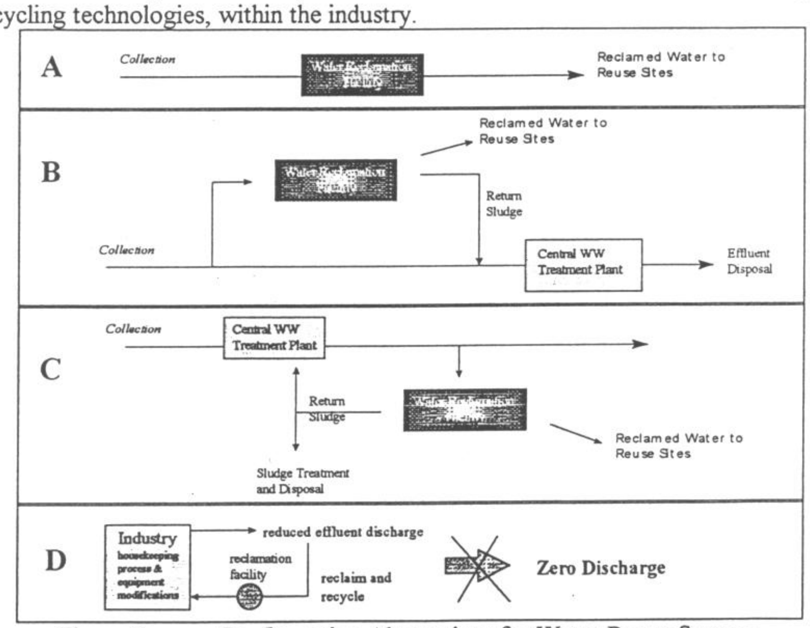


Figure 2 Configuration Alternatives for Water Reuse Systems
A - Central Treatment near Reuse Site, B - Reclamation of portion of WW, C - Reclamation of portion of effluent, D - Zero Discharge with Cleaner Production

Figure 3 presents the possible multi use configuration of a water reuse system. The treated water from the reclamation facility can be distributed among urban, agricultural and special industrial use. Under urban the customers could be commercial complexes, individual housing schemes. Agricultural use involves irrigation demands met by open channel conveyance, sprinkler systems etc. Special requirements could be small scale and large scale industries requiring a particular quality of water for the non process activities.

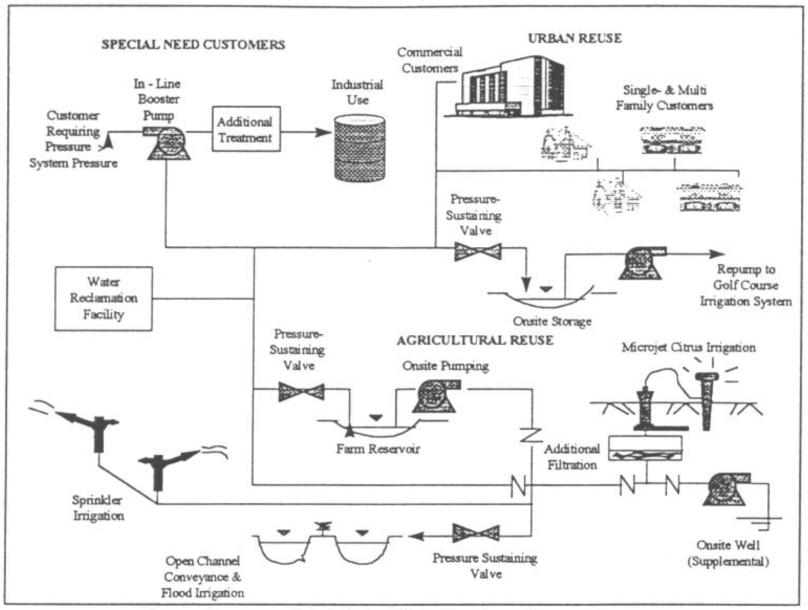


Figure 3 Multiple Distribution Reuse System

Table 1 provides some common categories for reuse of municipal wastewater.

Table 1 Categories of Wastewater Reuse

Agricultural Irrigation	Crop irrigation Commercial nurseries
Landscape Irrigation	Parks School yards Golf courses Cemeteries Residential
Industrial Recycling and Reuse	Cooling Water Boiler Feed Process Water
Groundwater Recharge	Groundwater replenishment Salt water intrusion control subsidence control
Recreational / Environmental uses	Lakes and ponds Marsh Fisheries
Non-potable urban uses	Fire protection Air-conditioning Toilet flushing
Potable reuse	Blending in water supply Pipe to pipe water supply

POTENTIAL OF MEMBRANE TECHNOLOGY FOR WATER REUSE

Advantage over Conventional Technologies

Figure 4 presents the comparison between the performance of conventional and membrane technologies. Conventional technologies use physico-chemical or biological methods involving addition of chemicals, complicates manual process control, high unit cost, large area requirements.

Membrane techniques avoid a few of these problems due to these merits :

Compactness - the membrane technologies employed are very space efficient. A typical water mining plant could occupy as little as 400 m^2 area for a capacity of 2.4 ML/d.

Odour elimination - Enclosed systems prevent breakthrough of odours and obnoxious smells.

Automation of system - The operation of both the MF and RO being automated, the process control is much better.

- Intermittent Operation - since no biological systems are involved, system can be shut down readily and restarted when required without loss in treated water quality.

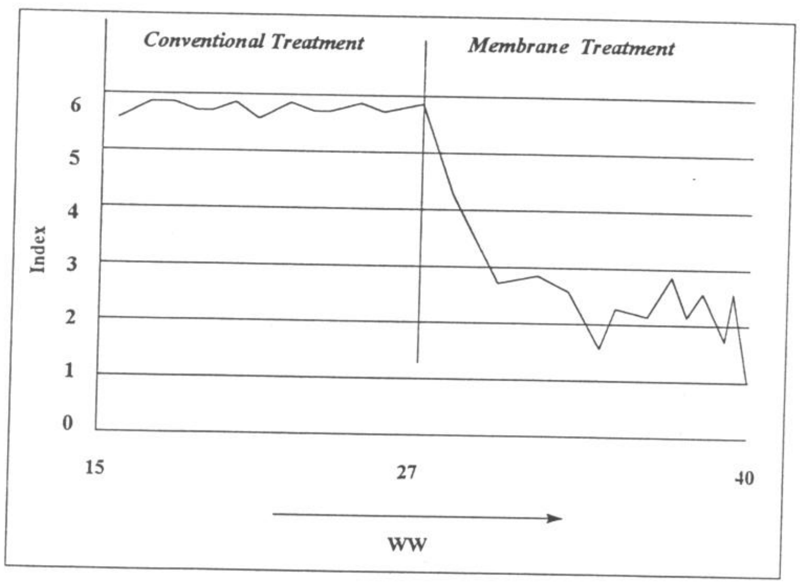


Figure 4 Conventional Vs Membrane Technologies

TECHNOLOGY DESCRIPTION

The basic underlying principle in membrane technology is forced selective passage of solute or solvents through special membranes, resulting in separation of individual constituents in the influent. Based on the membrane type, operating conditions, degree of separation desired, type of pollutants, various techniques such as reverse osmosis, ultrafiltration, microfiltration etc. have been developed.

Reverse Osmosis

RO is a high pressure, energy efficient separation process. RO membranes are designed to concentrate low molecular weight organic materials and salts while allowing water and solvents to pass. Typical operating pressures for a process RO system range from 200 to 800 psi. For example, a seawater RO system could operate at as high as 1200 psi. Thus production of industrial washwater or potable water from saline waters could be achieved by reverse osmosis. That is, seawater which was not considered as a direct water resource, could be utilised in some amounts to produce usable water. Reverse osmosis has also been successfully used in series for high purity water production. The major advantage being no chemical regenerants necessary (as compared to ion exchange).

Nanofiltration

NF is similar to RO except that mono-valent ions and very low molecular weight organics will pass, divalent cations will be rejected. NF technology is being applied to large streams never before considered economically feasible because the capacity of NF membranes is inherently higher than RO. Applications include de-mineralization, color removal, removal of natural organics and de-salting.

Ultrafiltration

UF is simply a low pressure selective fractionation of molecules by size. Depending on the molecular cutoff selected, the UF membrane will concentrate high molecular weight species while allowing dissolved salts and lower molecular weight materials to pass. UF membranes are commercially used in numerous market areas for concentration, clarification and diafiltration of large process streams.

Microfiltration

MF is the most open of all the cross-flow filtration devices with pore sizes in the range of 0.01 to 10 microns. Typical applications include the concentration and/or clarification of high molecular weight species such as bacteria, yeast, and moulds. MF has been used as pretreatment in water supply treatment schemes. Major advantages of using MF against Rapid Sand Filter are less sludge production and less disposal costs, no chemical inputs and a better filtrate (effluent) quality.

Membrane Science and Technology (MST) is a new and fast growing area of chemical engineering research. The physicochemical nature of MST offers unlimited engineering opportunities for energy efficient chemical separation, purification, concentration and fractionation in industry. MST can contribute significantly to the economic development in the areas of industrial wastewater treatment for water recycling and reuse, production of ultrapure water, environmental protection, food processing, petroleum engineering, biotechnology, and pharmaceutical and biomedical applications.

APPLICATIONS OF WATER REUSE WITH MEMBRANE TECHNOLOGY

- obtaining drinking water from sea and brackish water
- processing systems for the production of ultrapure water
- treating industrial and municipal wastewater to produce water fit for recycle and reuse in industry
- water pollution control and waste recovery
- conserving energy in the concentration and fractionation processes involved in food processing and pharmaceutical industries
- treatment of gas-gas and gas-vapour mixtures in the separation applications involved in the petroleum and petrochemical industries
- developing hybrid chemical separation systems in process industries for better operational efficiency and economy
- developing bioreactor and downstream processing systems in biotechnology applications
- developing analysis and other biomedical devices

CASE STUDIES

1. Water Mining (type B, Fig. 2)

Aim : To study the performance of Screening, Microfiltration and Reverse Osmosis for raw sewage treatment to enable water reuse. Figure 5, below shows the schematic of the overall process.

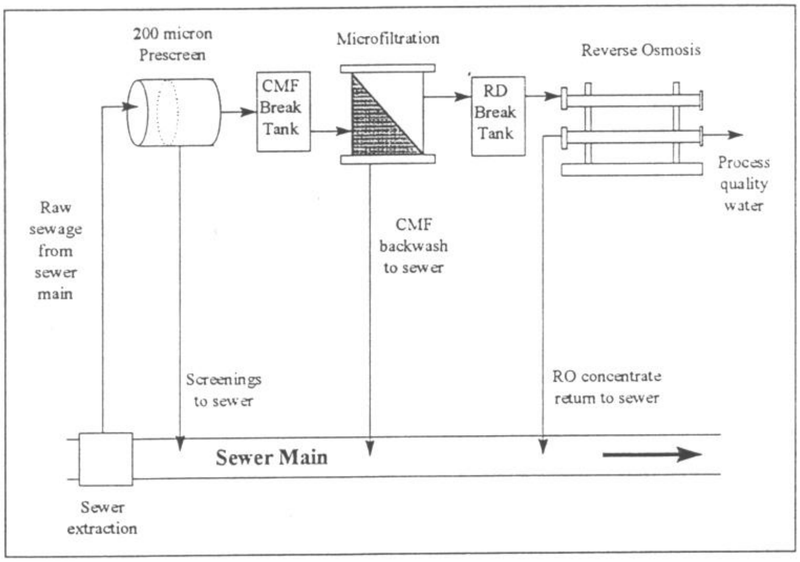


Figure 5 Schematic of the Screen/CMF/RO Water Mining Process

Set-up : A pilot plant with a capacity of 100 kL/d was constructed at a sewage treatment plant and operated for a continuous period of 12 months. Two experiments were carried out, one with a combination of screening and microfiltration and the other with a reverse osmosis unit attached to the former combination.

Results and Conclusions : The first combination yielded a BOD < 2 mg/L, Phosphorus < 0.1 mg/L and Nitrogen < 3 mg/L, but still contained dissolved nutrient and organics. Thus it was observed that this configuration removes only SS and Bacteria and the filtrate water is suitable only for low grade industrial applications or irrigation

The latter configuration with RO resulted in a further removal of dissolved salts.
This filtrate water is suitable for boiler feed, non potable reuse, cooling and process washwater.

The preliminary capital and operating costs for the Screen / CMF / RO were about $1,150 / kL/d and $0.57 /kL/d. Depending on the other allowances for civil works, storage, sewage extraction etc. the operating costs would be $0.8 to $1.05 / kL/d.

2. Exploring Zero Discharge Potentials for the sustainability of a Bottle Washing Plant (type D, Fig. 2)

Aim : To identify, and study technologies that can recover water for reuse, minimise raw water input and consequently lead to zero discharge.

The beverage industry which requires large amounts of good quality water in their processes is a major contributor to the problem of excessive pumping from existing aquifers in Thailand. In view of a government restriction on groundwater withdrawal, an overall water management plan was drawn for the sustainability of a softdrink plant in Bangkok which depends solely on deepwell source for its water needs. The schematic of the setup is presented in Figure 6.

Observations and Methodology : The overall water balance drawn for this plant revealed that 76% of the raw water consumed daily ends up in the biological wastewater treatment plant (WWTP). A large portion (40%) of this wastewater is generated from the bottle-washing units.

By employing microfiltration for polishing of the WWTP effluent, the plant can recover process water for reuse such that, groundwater input is reduced by 40% and liquid discharged to the receiving water by 56%.

There are two proposed strategies for recovering rinse water from the bottle-washing units. A microfiltration-reverse osmosis system will purify the rinse water for reuse in the bottle washing process, thereby reducing raw water consumption further to 58% and the liquid discharge by 81.5%. On the other hand, a dual filter media-ion exchange system can reduce raw water input to 57% and the liquid discharge by 80.5%.

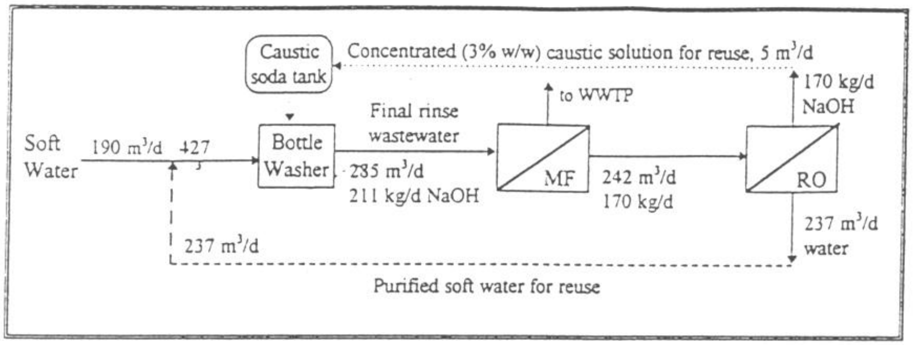


Figure 6 Schematic of the MF/RO system for caustic and water recovery.

3. Membrane Technology in a Sugar producing factory (type **, Fig. 2)

Aim : To develop a membrane technology to recover salts and reuse water, from the process effluents of a sugar manufacturing plant..

Background and Methodology : The plant studied is a sugar producing industry situated in Northeast of Thailand and handles 22 x 10^3 tons of sugarcane per day. Decolorisation of the raw sugar is achieved by ion exchange i.e. the brown sugar liquor (after carbonation and filtration) is passed through an ion exchange resin column, producing a fine liquor which can be evaporated and crystallised as refined sugar product.

The regenerant used in the ion exchange is 10% Sodium Chloride brine solution. Here, industrial grade salt is used, which has to be remelted and filtered before use. A sand filter was used for the purpose and the filtrate solution is pumped to the Ion Exchange column. The waste brine produced in the ion exchange regeneration is discharged to two holding ponds of capacity, 40,000 m^3 each.

This waste brine contains colloids, colour material and large amounts of NaCl. Biological degradation of this waste is impossible due to the high salts content. Secondly, the stored brine waste can leach into the ground water table and contaminate it. During rainy season, it was often observed that the ponds overflow, resulting in damage to adjoining areas.

4 tons of NaCl are required daily for regeneration. Cost of NaCl is about 0.12 US $ per Kg. That is, about US $ 480 per day were spent on NaCl. Daily, about 150 m^3 of waste brine is generated from the ion exchange unit.

The spent NaCl during regeneration was not recovered and was discharged into the ponds. Thus, fresh stock of the salt and pure water was required daily.

PROCESS MODIFICATION USING MEMBRANE TECHNOLOGY

It was envisaged that use of membrane filtration could be an effective solution to these problems. A series of Memcor membrane systems were installed using Microfiltration (MF), Nanofiltration(NF) and Reverse Osmosis (RO) in the same order.

The plant uses a unique three stage membrane process to fully treat and recycle the effluent. The process involves three distinct stages of treatment. The first stage microfiltration, removes all contaminants and particles from the raw brine solution. The second stage, Nanofiltration, removes the sugar colour from the effluent. The final stage, Reverse Osmosis, concentrates the brine for recycle to the manufacturing process. The product from the final stage is the equivalent of drinking water quality and can be used as a coolant or safely discharged to the local water system.

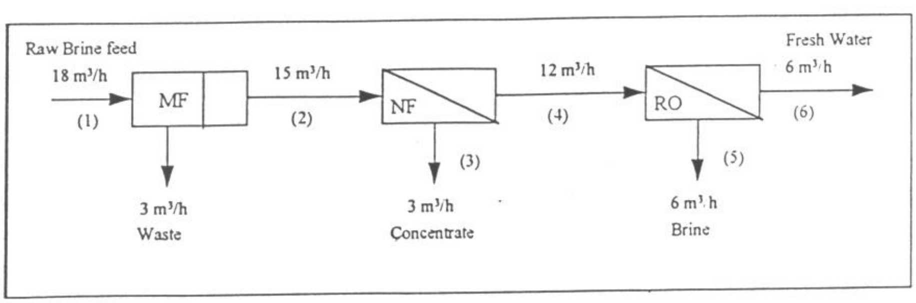
The entire process is non chemical and environmentally sound. Each process duplicated the processes evident in nature to physically reject or separate the solution. The driving force is pressure using membranes.

MEMBRANE FILTRATION INSTALLATION

The primary advantages achieved here, through such a combination of membrane systems are :

- segregation of various contaminants, resulting in ease of EOP treatment
- potential to recover and reuse the regenerate, NaCl
- obtain fresh water to reuse in the process, thereby decreasing daily fresh water purchase
- decrease wastewater load on ponds, thus avoiding the problems mentioned earlier

The concentrates from the MF and NF contain only colour and organic matter and a little amount of salts. These streams were combined and fed to the Waste Brine ponds as shown in the figure 7.



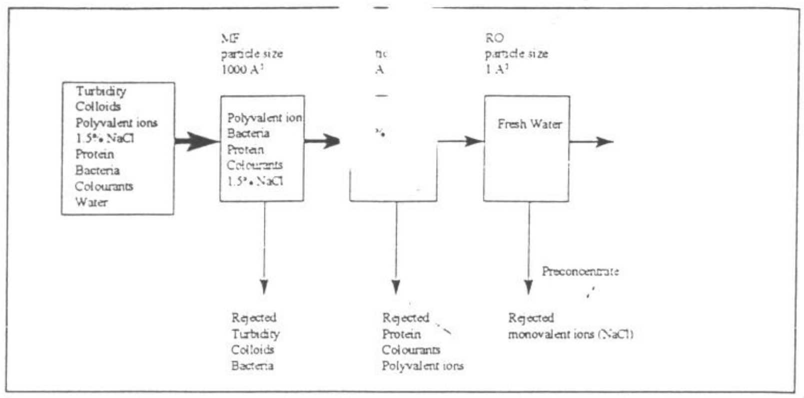


Figure 7 Flowcharts for Salt recovery and Water Reuse in a Sugar Producing Industry

A part from these particular applications the possibility of coupling a membrane unit to an activated sludge plant opens the way to a general process of biodegradable waste water recycling.
In place of conventional treatment activated sludge + clarifier and additional tertiary treatment necessary for getting the quality level required, the direct coupling of an activated sludge tank to a membrane module looks very promising due to the following advantages :

1) The quality of the treated water is very good
   - turbidity ≤ 0.1 NTU
   - efficient disinfection
2) Very compact process due to the concentration of biomass up to 20 g/l.

Presently two kinds of coupling are proposed :

- pumping the activated sludge to a tubular module outside the activated sludge tank (Membrane Bio Reactor MBR)
- Immesing hollow fibers (BIOSEP) or follow panels (KUBOTA) directly in the activated sludge tank : the water is pumped by succion through the membranes.

This configuration takes benefit of the bubbles (necessary for the aeration) for dellogging permanently the membrane.
Coupled with periodic backwash quite large fluxes are obtained in "soft" conditions.

For all of these processes the first industrial plants started recently and full scale technical and economical results are becoming available.

CONCLUSION

Several factors (technical and economical) are in favour of increasing use of membranes for waste water reuse.

1. The membrane cost is decreasing : the investment needed for membrane equipment is becoming more and more competitive with conventional processes.
2. Due to a better knowledge of fouling phenomena and due to the progress in material science, the operating conditions of membrane processes are becoming "softer" (lower pressure, lower cross flow velocity) reducing the energy cost and enlarging the life of the membranes.

3. Due to existing range of membrane from RO to MF it is possible to find the best membrane process for the quality of the waste water to be treated and the level of quality required for the treated water.
4. The so called "hybrid" processes (combination of two membrane processes or combination of a membrane process with physicochemical or biological treatment) might appear as the optimal solution.

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