Membrane Bioreactor: Solution to Decentralized Wastewater Reclamation

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Increasing Water Demands

With the increasing trends in population and per capita consumption patterns, the demand for potable water has been rising continuously. Rapid industrialization on the other hand, in the developed as well as developing countries has also led to significant 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 water resources, it is evident that soon the total water demand of the world will overshoot the available water resources. Nowadays, the course of the available usable water resources is also decreasing continuously due to excessive water usage and surface and groundwater pollution. Another factor contributing to this imbalance is the decline of the available water resources due to the manmade pollution and other induced problems from soil erosion, salt water intrusion, and constructions of dams. In many Indian urban centers the domestic and industrial water requirements are estimated to increase much higher rate than the agricultural water demand from the rural sectors. This excessive urban water demand, has led to the significant reduction in portion of annually renewable water which is considered as the country's buffer or safety factor against water scarcity. With this increasing trend in many Indian urban centers, this buffer is expected to reduce to half of its present size by 2010. Therefore, the water utilization must be planned, monitored and managed carefully. In this modern urban water cycle management approach, "Water Reuse" or "Wastewater Reclamation" plays an important management role.

Wastewater reclamation is the treatment or processing of wastewater to make it reusable for a direct beneficial use or a controlled use that would not have otherwise occurred. It is of particular importance to water starved cities as it can:

- Help the water intensive industries in such areas to operate continuously, in spite of water shortages, protecting production and employment.
- make available an equal amount of water for domestic supply to the city residents.
- provide a strong motivation for keeping the waste treatment plants in operation all the times and thus controlling the environmental pollution.
- help the municipalities to generate revenue by "selling " their sewage.
- provide opportunities for 'Privatisation" in water and wastewater management.

Among the many factors to be considered when designing such facilities are the use of the final effluent and the related requirements for effluent quality, the nature of the material to be removed to achieve the required quality, the problems associated with handling of the solids generated in the treatment processes, the potential for recovery and reuse of materials used in the process of treating wastewater, the demand for energy and other consumable resources and overall economic feasibility. Recent technological innovations in membrane filtration processes have made possible the reclamation of wastewater for direct and indirect reuse within the community, in a safe and cost-effective affair.

Decentralized Wastewater Reclamations

Adding to the great water demands, urbanization and industrialization have also increased the pollution load of bodies of water, calling for implementation of efficient municipal and industrial wastewater treatment processes. There are three broad schools of thought generally in the field of water reuse.

- Emphasizing on the need for more advanced technologies to turn wastewater into potable water to serve the rapidly growing countries
- Using 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.
- Exploring the possibilities of a more proactive approach such as better housekeeping, living patterns as regards the domestic water supply and cleaner production in the industry, and promote in-plant reuse.

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 1 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.

Traditionally in order to handle urban wastewater problems, large scale collection sewer net work and wastewater treatment plants were constructed. However, until recently, due to economy of the scale, these wastewater treatment facilities were built in centralized large-scale approach. However, during the past decade, this conventional approach of centralized wastewater treatment were found to be resource inefficient and increasingly expensive. These systems are associated with high construction and operationa and maintenance costs, which makes less attractive for developing countries. Specially, these systems become very un-attractive, if wastewater reclamation component has to be incorporated, as part of the urban water cycle management.

In terms of wastewater reuse the first generation of treatment train consists of coupling conventional wastewater treatment with water treatment (refer to figure 2). Here, the specific interest was given to removal of dissolved organic carbon with adsorption and ion exchange systems, based on the desirable end use. Where the second generation of treatment system further focused on elimination of some additional unit operation, by developing contact flocculation process and direct filtration. The current trend is the development Membrane bioreactor, where both water and wastewater treatment could be combined together. This is one the major technological development in urban wastewater treatment.

Decentralized wastewater reclamation is the treatment or processing of wastewater to make it reusable for a direct beneficial use or a controlled use that would not have otherwise occurred. This is particularly practiced in individual homes, clusters of houses, or isolated industry. These systems maintain both solid and liquid fraction of the wastewater near the point of original, thus excessive cost associated with transportation to towards the central wastewater treatment unit can be reduced.

Potential of Membrane Technology for Water Reuse

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 (Figure 3)

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 Bioreactors (MBR) combine conventional biological treatment processes with membrane separation. In a conventional activated sludge plant, biodegradation occurs in a bioreactor, followed by a secondary settling tank to separate water from the solids. However, due to economic and physical constraints, the effectiveness of such options is often limited and an alternative method for better solid/liquid separation becomes attractive. One of the considered better options is using membrane bioreactors (Figure 4).

The major advantages of the membrane bioreactors are:

- Since suspended solid are totally eliminated through membrane separation, the settleability of the sludge, which is a problem in conventional activated sludge, has absolutely no effect on the quality of the treated effluent.
- Sludge retention time (SRT) is independent of hydraulic retention time (HRT). Therefore a very long SRT can be maintained resulting in complete retention of slowly growing microorganisms, such as nitrifying bacteria, in the system.
- The overall activity level can be raised since it is possible to maintain high concentrations in bioreactors while keeping the microorganisms dispersed as long as desired and as a result, reactor volume will be reduced. In addition, the system requires neither sedimentation nor any post-treatment equipment to achieve reusable quality water, so the space saving is enormous.
- Treatment efficiency is also improved by preventing leakage of undecomposed polymer substances. If these polymer substances are biodegradable, there will be no endless accumulation of substances within the treatment process. On the other hand, dissolved organic substance with low molecular weights which cannot be eliminated by membrane separation alone can be taken up, broken down and gasified by microorganisms or converted into polymers as constituents of bacterial cells, thereby raising the quality of treated water.

- Removal of bacteria and viruses can be expected, so the disinfection process is ecologically sound.
- Compared to conventional activated sludge processes, maintaining low F/M (food/microorganisms) ratio will produce less excess sludge to be handled and treated.
- The fluctuations on volumetric loading have no effect on the system hence a high sludge capacity can be maintained.
- Since all the process equipments can be tightly closed no odor dispersion can occur.

While centralized wastewater treatment systems are an economically attractive solution for a large scale wastewater treatment plant, membrane based systems, become an attractive for small to medium size decentralized wastewater treatment units. Thus, currently MBR systems are considered the most attractive alternative decentralized wastewater treatment and reuse system.

Configuration of Membrane Systems

Membrane bioreactor consists of two parts, the biological unit responsible for the degradation of the wastewater, and the membrane module for the physical separation of the treated water from the mixed liquor.There are two types of membrane bioreactors (Figure 5) .

- membrane unit located outside the biological reactor (external loop); and
- membrane unit located inside the biological reactor (internal loop).

The membrane filtration occurs either within the bioreactor (submerged configuration), or externally through recirculation , subject to a pressure drop across the membrane driven by either the hydraulic head or a pump. The UF or MF membranes utilized by MBRs have pore sizes such that water and most solute species pass through the membrane whilst other larger species, such as solids and microorganisms, are retained. The choice between operating options is dependent upon the application, as both systems have advantages and disadvantages (Table 1). Aeration within the bioreactor provides the required oxygen transfer for growth of the biomass and mixing of the reactor. In the submerged configuration a coarse bubble diffuser is generally used. This system does not offer very efficient oxygen transfer but the rising bubbles provide a turbulent crossflow velocity over the surface of the membrane. This helps to maintain the flux through the membrane, by reducing the build up of material at the membrane surface, and thereby increases the operational cycle of the system.

Table 1 Comparison of Submerged and Side Stream MBRs

Parameter	**Submerged MBR**	**Side-Stream MBR**
Aeration Cost	High (90%)	Low (20%)
Pumping Cost	Low	High (60-80%)
Flux	Low	High
Foot Print	Large	Smaller
Cleaning Requirements	Less Frequent	More frequent
Operating Cost	Lower	Higher
Capital Cost	High	Low

COMMERCIAL MBR SYSTEMS

The two main suppliers of MBR systems for wastewater treatment are Kubota (Japan) and Zenon (USA). Other suppliers are Degremont (France), Membratek (S. Africa), Orelis/Mitsui (Japan),US Filter (USA) and Wehrle Werk (Germany). Kubota uses a flat sheet membrane made of polyolefin with a non-woven cloth base giving a nominal pore size of 0.4microns. It operates with membrane treatment units submerged in the reactor in which the MLSS is maintained within the range of 15,000 to 20,000mg/L. Kubota has a reference list of over 400 plants treating domestic and industrial wastewater, with most of the sites located in Japan.

Zenon markets the ZenoGem system, based on the ZeeWeed membrane, which is a hollow fibre with an external diameter of 1.9mm and a nominal pore size of 0.4microns (Figure 6). The filtration capacity is in the range of 40-70L/m^2h under a driving transmembrane pressure of 10- 50kPa. Zenon has a reference list of over 150 plants treating domestic and industrial wastewater.

Table 2, presents the overall performance of immersed type MBR systems in terms of influent and effluent concentrations. Considering the guidelines and criteria for reclaimed water use for various purpose in Japan, the effluent of MBR comply with every aspect of the reported values. In this pilot scale unit, it was also noted that the reactor performance was not affected at various operating conditions. This indicates that the improvement in membrane flux can result in an undisturbed water quality even at a hydraulic retention time of 3 hours, thus reducing the size of the treatment unit. The effectiveness of the process was proven since both effluent turbidity and pathogen removal was detected below drinking water standards. If necessary, a small dosage of chlorine could be added to maintain a residual chlorine concentration in the distribution system of the main water supply.

Table 2 Comparison of reclaimed water quality of the MBR with reuses guidelines

Table 1 Comparison of reclaimed water quality of the MBR with reuse guidelines

Parameters	Concentration		Criteria/Guidelines [a]		
	Influent	Effluent	Toilet Flush Water	Landscape Irrigation	Environmental Water
Total coliform/(Count/mL)	> 10^7	ND	≤ 10	ND	ND
Fecal coliform/(Count/mL)	> 10^5	ND	-	-	-
Chlorine residual combined/(mg/L)	-	-	TA	≤ 0.4	-
Appearance	NP	NU	NU	NU	NU
Turbidity /(NTU)	> 1000	< 0.3	-	-	≤ 10
Biological Oxygen Demand	295-	< 4	-	-	≤ 10
(BOD)/(mg/L)	375	NU	NU	NU	NU
Odor	NP	7.3-8.4	5.8-8.6	5.8-8.6	5.8-8.6
pH	7.6-8.5	< 25	-	-	-
Chemical Oxygen Demand	530-	< 3	-	-	-
(COD)/(mg/L)	625	< 6	-	-	-
Total Kjedahl Nitrogen	26-165	0.2-4	-	-	-
(TKN)/(mg/L)	26-165	<30	-	-	-
Total Nitrogen (TN)/(mg/L)	2.2-9.0				
Total Phosphate (TP)/(mg/L)	> 5000				
Color/(Hazen color unit)					

NP - Not pleasant NU - Not Unpleasant ND - Not Detected TA - Trace amount

[a] adopted from Japan Sewage Work Association, 1993.

The Challenge Continues

Although systematic reuse of treated water has not been commonly adopted by the municipalities and industries in the recent years, there is still a significant interest from the government and industrial sector to explore its potential to avoid any future water scarcity problems. 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.

The review of the membrane bioreactors for the application of wastewater treatment has proven that this emerging technology has developed a niche in the wastewater treatment sector. While, research efforts of late have been directed towards application of membrane separation bioreactors to various wastewaters, the challenge continues for the researchers in its development of a membrane bioreactor process that is both robust and efficient for various wastewater applications in this ever-growing world.

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