Treatment of Water by Membrane BIO Reactor

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Abstract— The membrane biological reactor (MBR) configuration has proven to be optimal for treatment of any industrial wastewaters when treatment efficiency is an important consideration. Industrial applications have ranged from nitrogen removal from food processing Wastewaters to use of the technology to deal with complex organics in wastewaters originating from the production of pharmaceuticals and the manufacture of polymeric membrane materials. Historically, low membrane flux, low permeability, limited membrane life and high membrane costs hindered broad application of the MBR technology. The membrane industry, including independent research and development organizations and system suppliers, invested considerable effort to overcome these limitations over the past decade. The result has been a dramatic increase in the number of new commercial system embodiments of the MBR configuration.

Key words: BOD, COD, Membrane bioreactor, Reverse Osmosis

I. Introduction

The ideal bioreactor configuration for treatment of organic (e.g., measured as COD) or inorganic (e.g., ammonia, nitrate) contaminants present in industrial wastewaters will operate efficiently (i.e., at a high contaminant volumetric removal rate) while achieving the design performance objective (i.e., contaminant percent removal or effluent quality requirement). Bioreactor systems such as the conventional activated sludge system, sequencing batch reactor system and trickling filters although typically designed for operation at a lower volumetric removal rate, are often selected for applications under site conditions where space constraints are not a factor and/or other conditions which render the systems acceptable. The membrane biological reactor (MBR) configuration has proven to be optimal for treatment of many industrial wastewaters when treatment efficiency is an important consideration.[1]

The MBR systems are available in two different configurations: “external” or “submerged”. In the “external” configuration, sludge is recirculated from the aeration basin to a pressure-driven membrane system outside of the bioreactor where the suspended solids are retained and recycled back into the bioreactor while the effluent passes through the membrane. But due to the recent advances, the external MBR systems are now operated with air-lift-assisted cross flow pumping, in which scouring air is introduced along with the sludge recirculation at the bottom of the vertically mounted membrane module to reduce the recirculation flow requirement. In this configuration, the membranes are regularly backwashed to remove suspended solids buildup and are chemically cleaned when operating pressures become too high.[1-2]

II. Membrane Bioreactor

Membrane bioreactor (MBR) is becoming one of such flourishing technology in water and wastewater treatment field. The MBR combines two proven technologies, i.e., enhanced biological treatment using activated sludge, and membrane filtration.

A membrane bioreactor (MBR) can be defined as a process that integrates the biological degradation of wastewater when coupled with membrane filtration [2]. .Membrane bioreactor (MBR) technology is a modification of conventional activated sludge systems, in which the secondary settler is replaced by membrane filtration units. This makes feasible a good control of solids retention time (SRT) and hydraulic retention time (HRT) in the system. Depending on how the membrane is integrated with the bioreactor, two MBR process configurations can be identified side-stream and submerged. Inside-streams MBRs, membrane modules replaced outside the reactor, and the reactor mixed liquor circulates over a recirculation loop that contains the membrane. In submerged MBRs, the membranes are placed inside the reactor, submerged in the mixed liquor. The side-stream MBR are more energy intensive compared to submerged MBRs due to higher operational trans-membrane pressures (TMP) and the elevated volumetric flow required to achieve the desired cross flow velocity. However, submerged MBRs use more membrane area and operate at lower flux levels [4].

III. Material Balance of RO System

The RO system includes a set of RO membrane elements, housed in pressure vessels that are arranged in a design manner. A high-pressure pump is used to feed the pressure vessels. The RO system is operated in cross flow filtration mode, not in dead end mode, because of the osmotic pressure of rejected solute. Figure 1 illustrates the material balance of a typical RO system. The feed flow is divided to permeate and concentrate flow.[3]

An RO membrane system consists of RO elements arranged in pressure vessels. The arrangement of the RO system can be single or double Pass with the specific geometry of the pressure vessel arrangement described in Stages, and with pressure vessels inside a Stage arranged in what is called an Array. Inside the pressure vessel, the elements are connected sequentially in series format with up to eight elements per pressure vessel.[4-5]

IV. Pressure Driven Membranes

Pressure-driven technologies include, in order of decreasing permeability, microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO). MF and UF often serve to remove large organic molecules, large colloidal particles, and many microorganisms. MF performs as a porous barrier to reduce turbidity and colloidal suspensions. UF offers higher removals than MF, but operates at higher pressures. In wastewater reclamation, MF or UF might provide a suitable level of treatment. The most commonly used process for the production of drinking water is RO, to remove coarser material so that fouling is minimized, but NF is now emerging as a viable alternative to conventional water treatment because it can operate at lower pressures and higher recovery rates than RO systems. NF is also cost-effective in many groundwater softening applications where the incoming turbidity is low.[4]

A. Classes of Pressure Driven Membranes:

Pressure driven membranes have been classified into four categories based on the membrane rejection properties as follows.

1) Microfiltration (MF) membranes:

Have the largest pore size (0.1 to 3 micron), require low transmembrane pressure (1 to 30 psi), and are used for turbidity reduction, removal of suspended solids.

2) Ultrafiltration (UF) membranes:

Have a smaller range of pore sizes than MF membranes (0.01 to 0.1 micron) require low transmembrane pressure (1 to 30 psi), and are capable of removing viruses as well as some colour, odour, and organics removal, along with everything that the MF process can remove.

3) Nanofiltration (NF) membranes:

Aare relatively new porous membranes that have a pore size less than 0.002 micron require moderate transmembrane pressure (75- 150 psi), and are primarily used for natural organic matter removal for controlling disinfection by product precursor, water softening and sulphate removal.

4) Reverse Osmosis (RO) membranes:

Reverse Osmosis (RO) membranes are effectively non-porous membranes that require high transmembrane pressure (150-500 psi) and are used for monovalent salt removal like Na+, K+. [6]

V. EXPERIMENTAL SETUP

The experimental setup consists of a feed tank, reactor, heater, membrane cap and an air blower followed by RO pump. Each part of the setup can be explained as follows.

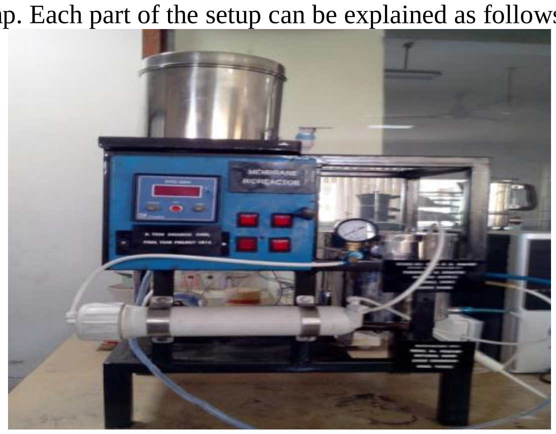

Fig. 1: Experimental Setup

A. Feed Tank:

The feed tank is usually used to store the feed i.e. sludge and then supplied it to the reactor. The feed tank is made up of stainless steel (SS) having capacity of 7 liters and working capacity of around 4 liters. The tank is having a valve attach which can control the flow of feed wastewater. Tank is placed on the top of reactor as stainless steel does not readily rustor stain with water as ordinary steel does, but despite the name it is not fully stain-proof, most notably under low-oxygen, high-salinity, or poor-circulation environments.

Fig. 2: Feed Tank

B. Reactor:

The reactor consists of a plain vessel provided with aeration at the bottom. The aeration provided at the bottom helps in agitation of the solution, due to the movement of bubbles. Thus, there is no need to provide the reactor with agitation. Heating takes place in the reactor. A thermocouple is placed in the reactor for temperature measurement. The reactor is closed from the top. The capacity of the reactor is 5 lit. A level measurement is maintained in the reactor so that the sludge should not come out of the reactor. The remaining sludge can be removed from the bottom. The inlet and outlet diameters of the reactor are same i.e., 1.5 inches which are placed at the opposite directions.

C. RO Pump:

RO (reverse osmosis) pump is used for the flow of fluid through the membranes. The pump is having constant flow rate during whole process and it has a 26V capacity of power supply. It cannot directly attached to power supply because it has dc voltage it required adapter to control the flow current during the process.

A typical reverse osmosis system utilizes an automatic shut-off valve (ASO) that stops the RO system from producing water when the holding tank reaches 50%-67% of the incoming water pressure. As the holding tank gets close to being full, the quality of the water produced by the system begins to diminish, as well as sending more water down the drain due to the increasing back pressure from the holding tank. The product is of Fillmax Company.

Fig. 3: RO Pump

D. Air Pump:

Air pump is provided for aeration at the bottom of the reactor. The aeration provided at the bottom helps in agitation of the solution, due to the movement of bubbles. An air pump is a device used to move air, possibly under pressure. Typical air pumps move air by using an electromagnet to rapidly vibrate a rubber diaphragm. Unfortunately, this has the side effect of creating noise as well as moving air. The pump is having two outlets for providing oxygen from into bioreactor it can be continuously give oxygen to the wastewater present in the bioreactor. The air pump is having a regulator which can operate speed of oxygen is provided into bioreactor. The diameter of pipe is 0.5 inches. The product is of Pentair Company.

Fig. 4: Air Pump

E. Heater:

Heater is provided to the bioreactor for heating the wastewater inside the tank. The heater is having capacity to heat water till 500 degree Celsius. But we need only 50 degree Celsius and its temperature is control with the help of thermocouple, which is depth inside water and it gives a reading on the screen. Heater is applied on the tank on 3 cm from the base of tank as heater should always kept deep in the water. It requires high voltage to heat the water. The product is of Hubbell Heaters Company.

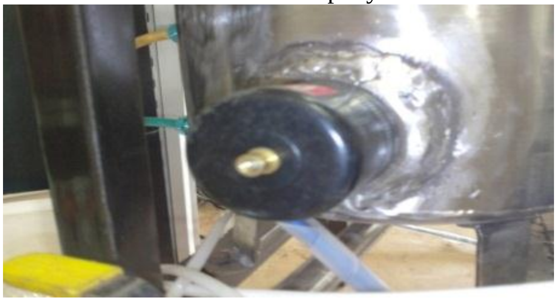

Fig. 5:.Heater

VI. DESIGN AND FABRICATION OF MBR

A. System Design Information and Feed Water:

The RO membrane system highly depends on the available feed water. Therefore, the system design information (customer/OEM, required product flow rate, expected recovery rate, annual water temperature, water source, application, pre-treatment, required product water quality, operating pressure limit, etc.) and the feed water analysis should be thoroughly studied and considered in selection of the RO system design. If the required permeate water quality is so high that the quality cannot be achieved by 1pass RO system, and then a 2 pass RO system should be considered. As an alternative to the 2 pass RO, an ion exchange resin system may also be a viable design option. [7].

B. Range of Element Operating Conditions:

The RO membrane system should be designed such that each element of the system operates within the recommended operating conditions to minimize the fouling possibility, and to exclude mechanical damage. The limiting conditions are the maximum recovery (system and element), the maximum average permeates flux, the minimum concentrate flow rate, the maximum feed flow rate, and the maximum lead element permeates flux, and so on. The higher the fouling tendency of the feed water, the limits of the parameters become stricter.[7-8]

VII. OPERATIONAL PERFORMANCE

A. Waste Water Analysis:

The major water types treated by RO membrane are roughly divided into seawater, brackish water; wastewater, municipal water and RO permeate. In addition, these water types are finely classified by the type of pre-treatment (natural or artificial). With respect to TDS concentration, 35,000 mg/l is considered to be the standard.[8]

B. Particulate Removal by MBR Systems:

– The MBR influent turbidity concentration ranged between 65–161 nephelometric turbidity units (NTU) with a median concentration of 112 NTU.
– MBR systems tested achieved excellent particulate removal with permeate turbidity concentration of less than 0.1 NTU under normal operating conditions.
– During few incidents, when membrane plates of Huber and Kruger MBR systems were compromised, permeate turbidity was recorded up to 0.3 NTU.

C. Organics Removal by MBR Systems:

– The MBR influent BOD_5 concentration ranged between 97–277 mg/L with a median concentration of 161 mg/L.
– MBR systems tested achieved excellent organics removal with permeate BOD_5concentration of less than the detection limit of 2 mg/L for all the samples collected during the study period.
– Even when the membranes were compromised for MBR systems, permeate BOD_5 concentration was still less than the detection limit of 2 mg/L.

D. Rejection by RO System:

– The median influent conductivity concentrations for the RO system was measured at 1,720 micro Siemens (µS) and ranged between 1,466– 2,025 µS.
– The membrane achieved greater than 98% of conductivity rejection with median permeate conductivity concentration measured at 32 µS.[10]

VIII. Membrane Performance

A. *RO Membrane:*

Reverse osmosis a technique employing a membrane which is “semi permeable” that is; under the influence of pressure a larger proportion of water (the solvent) passes through the membrane than do the dissolved salts or organic molecules (the solutes).

Such semi permeable membranes are common in nature; the skin is a good example and this phenomenon, osmosis, two materials make up the bulk of commercial RO membranes, cellulose acetate and an aromatic polyamide.

Reverse osmosis membranes do not have definable pores in the way that the films used in ultra-filtration. There are only spaces between the fibres making up the film which can take up water because of the acetyl or similar groupings which form the surface. The dense layer of active surface is about 0.25 microns thick supported by a thicker porous layer.[6]

The water in the spaces between the fibres has a short range order with each water molecule placed so that the oxygen atom occupies the vertex of a tetrahedron and the hydrogen bond connects each pair of molecules. This is an ice-like structure. In ice it is of course continuous, in liquid water at room temperature about half of the molecules are, at any one time, in such clusters. When pressure is applied to the membrane, molecules on the high pressure side are incorporated into the ice-like structure replacing molecules which “melt” away on the other side.[11]

Fig. 6: Reverse Osmosis Membrane

B. *How The Reverse Osmosis System Works?*

Reverse Osmosis is a process in which dissolved inorganic solids (such as salts) are removed from a solution (such as water). This is accomplished by household water pressure pushing the tap water through a semi permeable membrane. The membrane (which is about as thick as cellophane) allows only the water to pass through, not the impurities or contaminates [12]. These impurities and contaminates are flushed down the drain. Ultimately, the factors that affect the performance of a Reverse Osmosis System are:

- Incoming water pressure
- Water Temperature
- Type and number of total dissolved solids (TDS) in the tap water
- The quality of the filters and membranes used in the RO System (see operating specs)

IX. Procedure of MBR

A RO membrane showing the feed water supply line for MBR, The wastewater is feed in the feed tank. The feed tank is having capacity of 7 liters and its working capacity is 6 liters. The tank is having plastic valve which is connected at the bottom side of tank. The feed waste water is supplying to the bioreactor with help of pipe which is connected to the top of bioreactor. The bioreactor tank is also having various outlets. The first outlet is supplying the waste water to the pump which sucks by the pump and second outlet is at the bottom of the bioreactor it is used for removal of sludge. There is a oxygen supply to the bioreactor at the bottom of the tank. The microorganism present in waste water in cannot be die due to continuous flow of oxygen.

The bioreactor is having capacity of 5 liters and working capacity is 4 liters. There is overflow after 4 liters is fill in reactor. Then starts pump and water goes to presses gauge and then it goes to the membrane chamber. The RO membrane cap is having 1 inlet and 2 outlets. The wastewater goes in the membrane and it gets process inside membrane cap with help og RO membrane and finally its gets out. One outlet for purify water and another outlet for non-treatment water. The non-treated waste water is recycled into bioreactor. The finally treated pure water is collected separately.

The Membrane Bioreactor is a simple, but very effective combination of the activated sludge treatment process and the membrane filtration process. Imagine an activated sludge aeration basin, with sets of RO or ultra-filtration membrane filtration modules submerged in the aeration basins, and having MBR.

X. Calculation of Operating Parameters

A. *Basic Equations for RO Calculations:*

Water transport through the membrane is expressed as a permeate flux. The flux is generally defined as the volumetric flow rate of water through a given membrane area. In the case of RO, the unit of flux is expressed as liters of water per square meter of membrane area per hour (lmh) or gallons per square foot per day (gfd). The permeate flux is proportional to the net driving pressure (NDP).

$$Jv = A^{*}\ NDP \qquad (1.1)$$

$$NDP = \Delta P - \Delta\pi - 0.5\times dp \ (1.2)$$

In which: $\Delta P = P_f - P_p$, pressure differential $\Delta\pi=\pi(C_{fave}) - \pi(C_p)$, average osmotic pressure differential J_V, permeate flux, A, water permeability (specific flux), NDP, net driving pressure P_f, feed pressure, P_p, permeate pressure, P_c, concentrate pressure, dp, pressure dropm, (C_{ave}), average feed osmotic pressure, (C_p), permeate osmotic pressure Cf, feed concentration, Cp, permeate concentration, Cc, concentrate concentration $C_{fave} = (C_f + C_c) / 2$, Average feed concentration

NDP is calculated by pressure difference, osmotic pressure difference and pressure drop. The average feed concentration (feed and concentrate) is used to calculate osmotic pressure.

The product flow rate can be obtained by multiplying the permeate flux by total membrane area.

$$Q_p = M_A \times J_V \qquad (1.3)$$

In which: Qp, product flow rate, M_A, total membrane area

The pressure drop is calculated by the average flow rate (feed and concentrate) as follows:

$$dp = a \times \{(Q f + Q c/ 2\}^b \quad (1.4)$$

In which a and b are coefficients, specific for element and feed spacer configuration. The values for these coefficients are obtained experimentally.

B. Solute Transport:

Solute transport through an RO membrane is expressed as a solute flux. This solute flux is proportional to the concentration difference across the membrane. The average feed concentration (feed and concentrate) is used in the feed side to calculate solute transport. And the rate of solute transport is defined by rejection or salt passage as follows:

$$J_S = B \times (C_{fave} - C_p) \quad (1.5)$$

$$R = 1 - (C_p / C_{fave}) \quad (1.6)$$

$$SP = 1 - R = C_p / C_{fave} \quad (1.7)$$

In which: J_S, solute flux, B, solute permeability, rejection, SP, salt passage rejection and salt passage are usually expressed as percent.[13-15]

XI. RTD (Residence Time Distribution) of MBR

The residence time distribution (RTD) of a chemical reactor is a probability distribution function that describes the amount of time a fluid element could spend inside the reactor. Chemical engineers use the RTD to characterize the mixing and flow within reactors and to compare the behaviour of real reactors to their ideal models. This is useful, not only for troubleshooting existing reactors, but in estimating the yield of a given reaction and designing future reactors.

	Bench scale MBR	
	At Inlet	**At Outlet**
Hydraulic residence Time in min	45	42
Mean Residence In (Min)	5.30	4.12
Actual reactor volume in liters	4	4
Effective in liters	4.72	4.26

Table 1: Bench scale MBR

The theory of residence time distributions generally begins with three assumptions:-

1) The reactor is at steady-state,
2) Transports at the inlet and the outlet takes place only by advection, and
3) The fluid is incompressible.

The incompressibility assumption is not required, but compressible flows are more difficult to work with and less common in chemical processes. A further level of complexity is required for multi-phase reactors, where a separate RTD will describe the flow of each phase, for example bubbling air through a liquid. Residence time not only relates to hydraulic residence time but bacterial residence time as well. It has a symbol (tow). It is the inverse of the Eigen value derived from the mass balance method.

A. Quantitative RTD Properties of RO Membrane:

The tracer response was observed at 1 min for the lead membrane and 3-minute for the tail membrane (sharp early peaks) indicating the short circuiting from inlet to outlet [4]. The 2-min delay of the tracer response of the tail element suggests that the tracer may need longer time to reach the tail membrane and there is a different performance between the lead and tail membrane in the same MBR tank. It can be seen that after 10 min, the RTD of both membranes has coincided with each other. Therefore, the different performance of the membranes might occur during the beginning of the operation and would be roughly similar along with time.

XII. Cost Analysis

The purpose of this cost analysis was to perform budgetary cost estimates of the newly developed MBR systems tested during this design. Each system offers unique design features, which may reduce capital and/or O & M costs. It was also intended to compare the current MBR cost estimates to historical cost estimates to gain some insight on the overall trend of MBR costs in the municipal wastewater treatment market. Due to the increasing number and size of MBR facilities, it is important for industry to have current cost estimates to allow for proper planning.

Costs	**Price (Rs.)**
Cost of Equipment’s	20750
Capital Cost	15000
Operation & Maintenance Cost	5000
Direct Cost	5000
Indirect Cost	2000

Table 2: Overall Cost Analysis

A. Total Expenditure:

Engineers designing cross flow membrane equipment into process flow-sheets must balance capital cost and operating expense just as they do for other process equipment. For membrane equipment, the capital contributions and typical fraction of the total are as in the below table.

Items	**Specification**	**Price (Rs.)**
Feed tank	Stainless steel	500
Water Heater	Heated water till 500 degree Celsius	500
Water Motor	Power= 26volts	2000
Pressure gauge	Measuring the flow of fluid	250
Reactor bin	Capacity 5 litres & Working capacity 4 litres	5000
Air pump	Continue flow of air in tank	500
RO membrane	Pores size 0.01µm	2000
Others	Designing and Fabrication	15000
TOTAL		25750

Table 3: Total Expenditure Sheet

1) Capacity:

Costs will be generated for 1.0 and 5.0 lit/day MBR systems. System will be for a sewer mining (scalping) plant. Residuals controlled through wasting to a downstream treatment facility.

2) Operating Flux:

Membrane costs shall be based on the net operating flux rate demonstrated (non-peak operation) during RO testing.

3) Operating TMP (transmembrane pressure):

Costs will be based on operating TMP of 2 psi, with arrange of 1 – 2 psi.

4) Screening:
Costs will include 0.8 mm perforated center feed rotary drum screens.

5) Cleaning Interval:
The frequency of maintenance cleaning will be per the manufacturer's recommendation.

6) Redundancy:
The MBR systems will be designed at average conditions to operate with one filter units out of service (OOS). One unit OOS to accommodate routine relaxing/backwashing and an additional membrane filter unit OOS for chemical cleaning. System must be designed to accommodate increased flow to remaining filter units due to OOS unit.[16]

B. Advantages:

- Compactness and small layout size of the plant.
- Simple management of the plant, as a result of high degree of automation (low dependence on human factor.)
- Small quantity of excess sludge produced.
- Constant effluent quality, regardless of the influent.
- Operation costs are lower than in classical biological plant.
- Complete bacteria rem1oval.
- Possibility of reuse of treated wastewater for irrigation purposes or as process water.
- No odour emission or noise.
- Fast construction, because of relatively small size of the plant.
- No risk of biomass loss.

C. Disadvantages:

- Higher capital cost, primarily resulting from the membrane unit cost.
- Operation at high SRTs may increase levels of inorganic chemicals that are harmful to the microbial populations.
- Fouling of membrane is the major disadvantage of the process.
- The process is time consuming and also consumes high power.
- Regular cleaning of membrane is a tedious process.
- The reactor also needs to be cleaned on a regular basis.

D. Precautions:

- Check all the connections of pipe which are attach to the parts.
- Always check the levels of water in the feed tank.
- Electrical insulation should be periodically tested.
- Use proper tools for testing and repairing.
- Always repaired the equipment after switching the power off.
- Sufficient lightening and ventilation should be provided, floors should be free from oiliness, and floor should keep kept clean.
- Stop the process if there is leakage happened.
- Machines and their parts should be fenced when is not possible to provide safeguards.
- Check temperature always performing process after every minute.
- All tools of MBR should put in proper place.

XIII. Conclusions

- The following conclusions can be made regarding the use of MBRs for treatment of industrial astewaters.
- The MBR technology has proven optimal for treatment of many industrial wastewaters.
- The external membrane MBR configuration is preferred versus the internal membrane configuration, for a number of technical reasons.
- Recent membrane and system design advances have resulted in comparable economics for external versus internal membrane MBRs over a much broader wastewater flow rate range.
- Future developments are likely to include the emergence of cost-effective anaerobic MBR systems and full scale application of alternative MBR configurations in which membranes are used for other purposes than simply biomass-effluent separation.

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