Minor Research Project
(Closure Report)

Waste Water Treatment using Membrane Bio-Reactor (MBR)

By

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Prof. Karishma Hingnekar (Co-PI)

DEPARTMENT OF CIVIL ENGINEERING
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Hasan Rangwala
Karishma Hingnekar

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1. INTRODUCTION

Membrane Bioreactor (MBR) process includes membranes for biological treatment of activated sludge process. Sludge retention time is important parameter of MBR for efficient biological treatment. This process can handle various shock loads in very well manner. Sewage treatment it shows positive results with higher efficiency and can also be used or industrial wastewater.

This process of treatment using membrane bioreactor will be helpful for treatment of any kind of waste water be it sewage waste water or industrial waste water or any other kind. The equipment is further advancing with passing days and growing technology and is now in a very compact form requiring less space and could be installed for treating water before disposing it.

Disposing waste water without treatment causes harms to the environment and also couldn't be further reused. Looking at the present-day environment issues and lack of availability of clean water this treatment system has proved to be extremely beneficial, satisfying the environmental and human needs.

Using this MBR system in industries is the need of present day because of the current environmental norms and degrading nature and environment as it treats industrial waste water thereby decreasing pollution and increasing the amount of comparative clean water which could be used for various other purposes except for drinking.

1.1 Membrane Bioreactor (MBR)

The concept of Membrane bio reactor treatment was used in year 1969 by Dorr-Oliver Inc. In the recent years, there has been an exponential growth of MBR application in industrial and municipal years due to a lot of research and development in MBR systems. MBR can compete with the conventional systems when there is a need to get a higher quality of effluent.

1.2 Difference between Conventional Activated Sludge Process (CASP) & MBR Process

The CASP only retains the microorganisms that would have a better settlement in the sedimentation tank, but the MBR will retain microorganisms that would even have poor settling properties. Therefore, the microbial environment would be completely different in an MBR compared to that of CASP system.

Need of change felt was due to some of the following reasons in CASPs

- The lower the F/M = (QS0/VX) ratio, the higher the removal efficiency of BOD by the microorganisms that consume BOD as food. Here for a given Q and S0, the two ways to achieve lower F/M are
  i. To increase V, which is not always economical
  ii. To increase Z, which is only possible if the MLSS could be concentrated in the biological reactor as per (Ben Aim and semmens, 2002).
- The parameter which affects the performance of a bioreactor is the SRT = (VX/qXe). In CASP process, the value of X and Xe would be around 3000 to 10000 mg/L respectively, but in MBR it would be a lot more than that i.e., the average values would be around 15000 to 20000 mg/L. Thus, SRT of MBR can be computed by V/q. Thus, SRT of MBR could be three to four times than that of CASP making it 30 to 60 days. Due to longer SRT< the MBR will retain even slow growing microorganisms e.g. nitrifies. The microorganisms can grow in synthetic wastewater treatment also, which could be washed in 15 days in ordinary CASP system. Thus, MBR is suitable for performing the nitrification as well as treating industrial wastewater that contains synthetic chemical.
- The reason for lesser sludge production is that Longer SRT and higher MLSS will make a stress to the microorganisms in an MBR which requires more energy and cell maintenance, thus they leave less energy for cell production. This leads to lesser sludge production.
- The advantages of an MBR compared to CASPs for treating wastewater are as follows:
  i. Production of higher quality of treated effluent
  ii. Higher biomass concentration thus lower F/M ratio
  iii. Reduced cost of sludge handling due to the application of longer SRT and following to it a lower sludge growth and production
  iv. Low investment cost due to smaller footprint
- The disadvantages of the MBR system are:
  i. Disintegration of microorganisms
  ii. Excretion of soluble Microbial products like SMP that lead to fouling of membrane
  iii. Low microbial activity in industrial wastewater

Table 1.1 Difference Between CASP and MBR Systems

	CASP	MBR process
Fine screen	Not required	Required (1-3 mm)
Reactor volume	Larger than MBR for a given SRT	Smaller than CASP for a given SRT
Typical MLSS	1500 to 3000 mg/L	4000 – 15000 mg/L
RAS flow (% of influent flow)	50 to 100	300 to 500
Wastage location	Secondary clarifiers	MBR tanks
Area requirement	More	Less comparatively

[source: WEF 2012]

The MLSS concentration can be directly increased by extracting the treated effluent through a membrane, the retained water in the biological reactor will automatically having MLSS in concentrated form. MBR utilizes this concept.

1.3 Configurations of MBR:

Many variants exist in today's market but most of them are originally variants of two membrane configurations: Submerged/immersed MBR and sidestream MBR. In view of the market-dominance of the submerged MBRs, submerged MBR are bifurcated into two MBR namely, internal submerged MBR and external Submerged MBR. An external submerged MBR system allows improved chemical cleaning and lowers fouling conditions. Whereas external submerged MBR are better in terms of control over clogging and foaming. Biological reactors are optimized independently with no fluctuations, dead zones and short circuits resulting in better effluent quality. The major challenge is that the system have a larger footprint and higher operational cost in comparison to internal submerged MBR

A. Internal submerged MBR:

Internal submerged MBR are very common due to its compatibility with the activated sludge process, as the membrane module can be directly immersed in the reactor vessel. Using negative pressure, permeate is sucked using a vacuum pump retaining all the biomass in the vessel itself due to the size of the membrane.

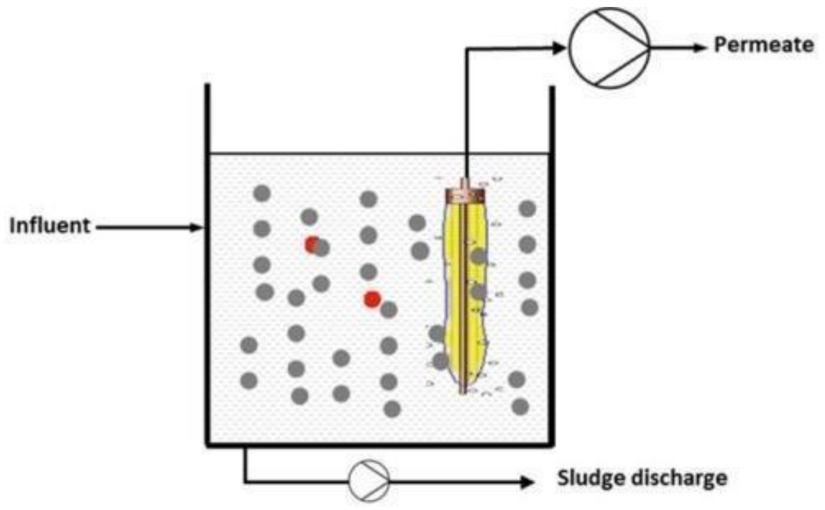

Figure 1. 1 Schematic Diagram of Internal Submerged MBR

Due to their compactness, low energy requirements and ease of sludge wasting directly from the reactor, they do not require a recirculation loop, making internal submerged MBRs a popular amongst others. These type of MBRs are suitable for wastewater with good filterability and require a more membrane area for effective treatment.

B. External Submerged MBR:

In this type of MBRs the membrane modules are located outside the reactor basin. In this system, the mixed liquor from the reactor is pumped to this external MBR module. These type of MBR are commercially used in industries as these require very less area as compared to submerged MBRs and work better for high strength wastewater with poor filterability. The only disadvantage of these type of systems is that they consume more energy as more pumps are required and energy required for pumping and recirculating the sludge. They also need additional space and manifolds for active treatment

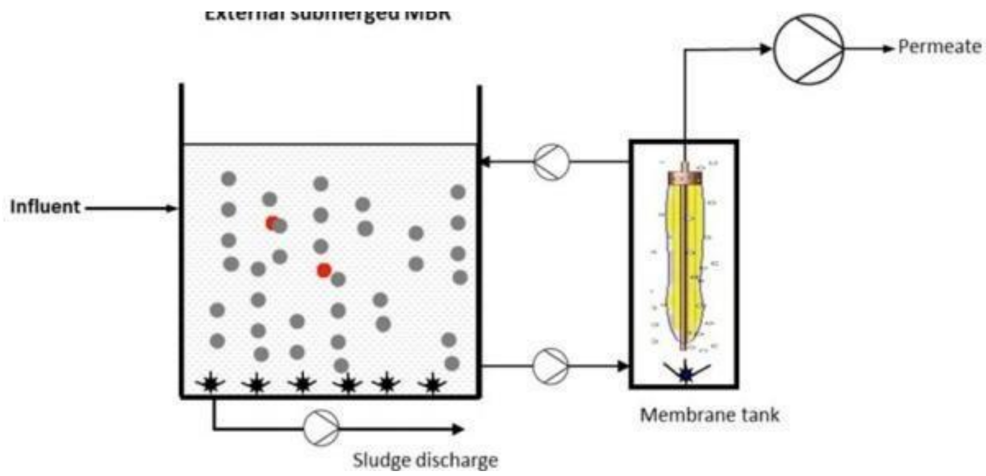

Figure 1.2 Schematic Diagram of External MBR

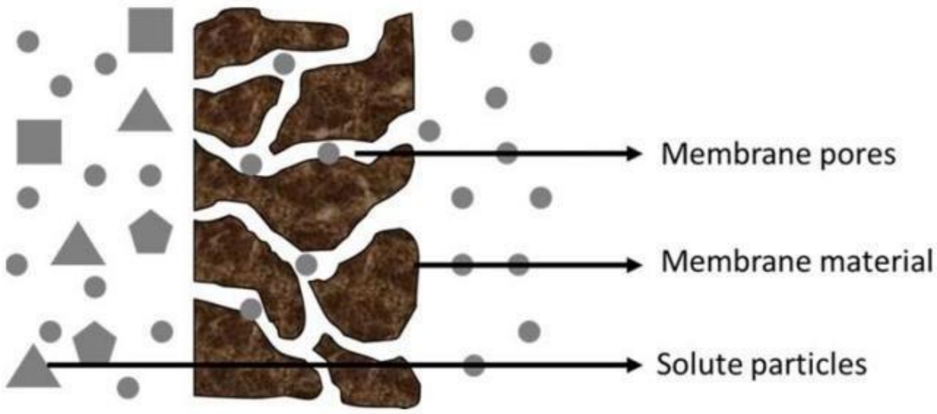

Figure 1.3 Pores In Membrane Structure

Membrane classifications: Membrane are classified depending on the criterias like porosity, driving force, material used (organic/inorganic), texture, characteristics of membrane (hydrophobic/hydrphilic), etc. The major variance is amongst the pore size. According to pore size, membranes can be classified into following four types:

1. Microfiltration
2. Ultrafiltration
3. Nanofiltration
4. Reverse osmosis

Another classification is whether the membrane can remove dissolved particles or those which can remove suspended or colloidal particulates.

Large pore sizes reduce the external surface fouling potential, which is a trade-off between selection of UF or MF. UF membranes are used for MBRs as these membranes strike a balance among effluent quality, energy requirements, and reduced internal membrane clogging. Pathogen removal is an added advantage as MF and UF systems. Removal of all bacteria and few viruses leads to reduced downstream disinfection and brings down the cost of plant construction, operation and maintenance.

The widely used membranes to date for a submerged type are either hollow fibres or flat membranes. The key to the success of internal membrane filtration is the direct application of air for membrane cleaning at the base of the membrane modules.

For flat membranes, the air bubbles and air-lifted liquid move upward along the membrane surface. Because the membrane elements are very close together in the membrane module, this uprising motion causes a wiping or rubbing action between the flat membranes that provides surface cleaning. In addition to the riser section sparged with air, this kind of airlift reactor also has a downcomer section with liquid moving downward between the membrane module and the wall of the bioreactor. For the successful control of the membrane fouling problem, this circulation velocity of air-induced two-phase flow of bubbling air and sludge should generate an appropriate turbulence for the cleaning of the membrane.

Figure 1.4 shows a schematic diagram of the Submerged Membrane BioReactor, for this research submerged type of Membrane Bioreactor is designed and manufactured as discussed in upcoming chapters.

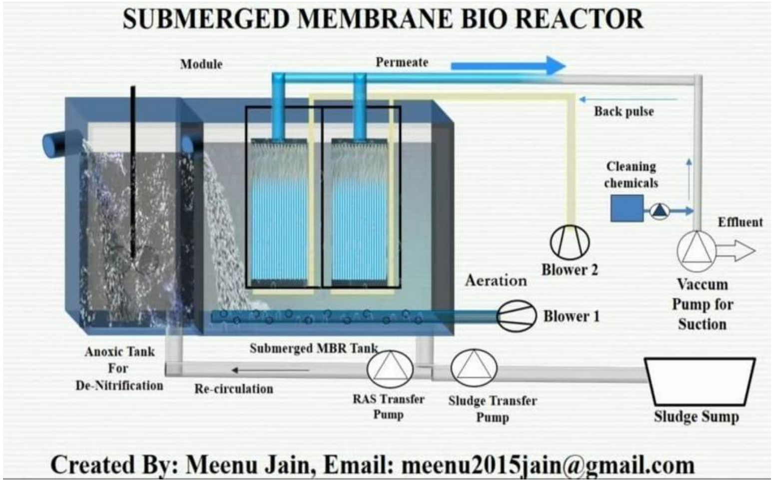

Figure 1.4 Schematic Diagram of Submerged Membrane BioReactor

2. LITERATURE REVIEW

In this chapter, various literature papers have been studied. The following is the summary of literature papers:

2.1 Methodology of MBR Treatment

MBR research is generally divided based on the purpose of membrane usage as follows:

i. Water filtration
ii. Aeration Membrane
iii. Extractive Membrane (Including Ion Exchange)

Along with these three purposes the operational parameters are also considered for research purpose as mentioned below:

i. Membrane fouling
ii. Operating and design parameters
iii. Sludge properties
iv. Microbiological characteristics
v. Costs and modelling

In Europe and Asia region, the majority of research studies focused on municipal wastewater treatment and in North America region the focus was on Industrial wastewater.

The different techniques useful for membrane fouling control are as follows:

- Optimization of Packing density of hollow fibers and flat sheets
- Optimizing locations of Aeration devices
- Orientation of fibers
- Fixing the diameters of fibers

As per research the hollow fibers in MBR, it is considered that modules with thin fibers, lower packing density and vertical orientation of fibers are better in terms of membrane fouling reduction of cake formation by controlling filtration below critical flux, by air-sparging in the vicinity of membrane, by operating in intermittent mode.

From literature, it is observed that use of external membrane treatment is more suitable for high temperature, high organic strength, extreme pH and high toxicity. Also, the research on external MBR treatment process is more than that of submerged MBR in

North America region only.

Literature review suggests that MBR treatment is successfully implemented for municipal wastewater treatment plant efficiently in different countries.

Then benefits and problems identified from literature review are as follows:

i. High quality effluent, ideal for post membrane treatments (e.g. Nanofiltration, ultrafiltration)
ii. Space savings enables upgrading of plant without land expansion
iii. Shorter start-up time compared to conventional treatment systems
iv. Low operating and maintenance manpower requirement

The problems for External and Internal Membrane treatment process is shown in Table 2.1.

Table 2. 1 Problems in External and Internal MBR

Both External and internal MBR	External MBR	Internal MBR
Bioreactor foaming	Bioreactor temperature impacting performance	Need of rigorous membrane cleaning
Membrane fouling	Entrained Air impacting suction	Membrane fouling during permeate back pulsing
Low Oxygen transfer efficiency	Pump operation	Lower membrane permeability than anticipated
Impact of raw wastewater solids	High costs	Membrane fouling due to build-up of oil and grease in the bioreactor
Operator mistakes		

2.2 Application of MBR for Industrial Wastewater

N. S. A. Mutamim, Z. Z. Noor, M. A. A. Hassan, And G. Olsson, "Application of Membrane Bioreactor Technology in Treating High Strength Industrial Wastewater: A Performance Review," Desalination, Vol. 305, pp. 1–11, 2012, doi: 10.1016/J.Desal.2012.07.033.

In the initial discussion it is given that there are some constraints of concern (limitations) in pH, temperature, pressure and also some corrosive chemicals that would lead to not only contaminate the microbes in reactor but also destroy the membrane

High strength wastewater means the wastewater that contains fats, oil and grease or other organic or inorganic compounds in the great amount according to types of sources that take part. It is called High strength because the components in the wastewater are in huge amount, e.g. High amount of COD, ammonia, suspended solids, heavy metals, etc. with shock loading happening sometimes. High ratio of BOD5/COD is shown as readily biodegradable and low BOD5/COD indicates as slowly biodegraded or contains a part of non-biodegradable or toxic elements. Strength of wastewater can be based on the biodegradable and non-biodegradable elements contained in the wastewater. Thus, to treat wastewater with low BOD5/COD ratio, the slow biomass acclimatization is required for stabilization. Following points are noticeable:

- Ratio of 0.5 BOD5/COD is considered as readily biodegradable or easily treatable.
- If ratio value is less than 0.5, the wastewater needs to have physical and chemical treatment before a biological treatment takes place.
- High strength wastewater can cause clogging, corrosion, scaling, biological growth and foaming in any systems.
- If this high strength wastewater is discharges directly into the environment it clogs the soil.

As per Authors and discussion carried out, It was difficult from industrial wastewater which generally required higher HRT due to complex pollutants degradation and gives longer biomass adaption period.

Extractive MBR (EMBR) is operated for **high concentration of inorganic compounds** e.g. high salinity and extremely pH value that can inhibit the biodegradation process. Also, EMBR selectively extracts specific organic pollutants (phenol, hydrogen sulphide and some inorganic) that can be degraded in separate Bioreactor.

Table 2.2 Membrane Size and Contaminants Treated

Sr. no	Size	Contaminants treated
1	100–1000 nm (Microfiltration)	Suspended solids
2	5-100 nm (Ultrafiltration)	Instance bacteria and viruses
3	1-5 nm (nanofiltration)	Dissolved particles

2.3 Performance evaluation of MBR Treatment

S. J. Khan, G. Hasnain, H. Fareed, and R. Ben Aim, "Evaluation of treatment performance of a full-scale membrane bioreactor (MBR) plant from unsteady to steady state condition," J. Water Process Eng., vol. 30, pp. 1–9, 2019, doi: 10.1016/j.jwpe.2017.03.004.

In this study, performance evaluation of a full scale MBR plant at startup and optimization from unsteady to steady state was carried out. Plant was fed with real domestic low strength wastewater of a university campus. This study was done to fill the gap and help in understanding the startup situation of a newly established MBR plant and optimizing SRT and flux under real conditions.

After pretreatment, the water enters biotank where mixing takes place and from that tank, the water enters membrane tank where water is sucked with the help of a pump from a submerged MBR (Hollow fibre unit). The following observations and justifications were interpreted:

- The excess sludge returns the drain while the rejected water enters the biotank through recirculation line provided.
- The measurement of EPS was also conducted by extracting from MBR sludge by cation exchange resin method.
- For 80 days, sludge was not taken out, so as to increase the MLSS concentration necessary for biodegradation of organic compounds and then SRT of 80, 60, 50, 40, 30, 20, and 15 days was kept and the plant was operated accordingly.
- HRT of 4.5 to 3 hours was set and operated the tank accordingly.
- During the starting of system, even on lower MLSS concentration of 2000mg/L, the COD removal rate was achieved to be 85 % with the effluent of less than 20 mg/L Average. This high COD removal rate was justified by the reason that most of the organic matter in domestic wastewater was mostly biodegradable even without applying fully biomass. Later on 90% removal was seen.
- In case of phosphate removal efficiency, was initially less than 50% at startup, but after the acclimatization period of 4 to 5 days. It became stable to more than 80% throughout the run.
- Removal of NH_4^+ -N was mostly by biological nitrification in the reactor prior to the membrane filtration process.
- Membrane acts as a strong barrier to keep the nitrifying microorganisms in the

reactor, and thus proliferates the autotrophic nitrifiers without any loss, indirectly facilitating the nitrification process.

- TSS removal was 99/9% and effluent turbidity was 0.4 to 0.6NTU. This good value of turbidity in the effluent is the proof that ultrafiltration membrane was very efficient in removal of suspended solids and can be considered as a complete physical barrier for suspended and colloidal solids. It was observed that the membrane tank had more biomass as compared to that of biotank, because of complete SS rejection by membrane fibre unit.
- MLVSS/MLSS ratio was found to be better in case of lower SRT. Due to shorter SRT, relativity more old sludge in endogenous phase is wasted and replaced by newly active growing sludge and thus MLVSS/MLSS ratio improves.
- Reason of high TMP for shorter SRT could be the reduction in size of bioparticles. These small particles causes pore blockage on the surface of fibres of Membrane.

Irreversible fouling was seen at the end of 174 days run. Concluding the paper, following points are observed:

- Higher SRT favored superior treatment performance resulting in higher concentration of biomass but demonstrated poor sludge settling characteristics. The treatment efficiency suffered a bit in terms of lower SRT.
- High flux and shorter SRT leads to rapid membrane fouling.
- EPS production increases with shorter SRT.
- The overall of 20 days SRT with 20 LMH proved to be optimal combination for full scale MBR plant keeping in view filtration rate, treatment performance and sludge characteristics.
- The study infers that the MBR start-up, flux and SRT are very important parameters of MBR operation from steady to unsteady condition which needs to be selected carefully for optimization and long-term sustainable performance of the MBR plan.

N. Atanasova, M. Dalmau, J. Comas, M. Poch, I. Rodriguez-Roda, and G. Buttiglieri, "Optimized MBR for greywater reuse systems in hotel facilities," J. Environ. Manage., vol. 193, pp. 503–511, 2017, doi: 10.1016/j.jenvman.2017.02.041.

In the beginning of the paper, sustainable urban water system is discussed which helps in saving water and at the same time reduce the load on wastewater disposal system.

Advantages of greywater separation and its disadvantages are discussed. They are as follows:

According to the literature reports from some authors, the ratio of COD:N:P are 100:20:1, 250:7:1, 100:2.25:0.06, etc., for bath showers and hand basins respectively which indicates that the grey water is deficient in nitrogen and phosphorus, which could cause problem for biological treatment.

Advantages of sustainable urban water system are they support the cities' green infrastructure, have a cleaner air, urban agriculture, and it the water is used for heat recovery, then they also contribute to energy demand reduction. The selection depends on the source and amount of greywater to be treated, standards that need to be achieved related to the type of its reuse which includes toilet flushing, irrigation, service water, etc. and available space to install the technology. The objective of this paper was to show the technical and economic feasibility of optimized MBR based GW reuse system. TO accomplish that, a pilot scale MBR for GW treatment was implemented to a hotel with separate greywater from showers so as to monitor its operation and optimize its energy consumption by using advanced scour control system. The MBR was in operation for six months.

As discussed in the paper, the most important feature of grey water with regard to biodegradation is its nutrient imbalance as the nitrate and phosphate levels are way lesser than the COD present. Thus for an effective organic removal, nitrate and phosphorus should be there in wastewater so as to accomplish biological treatment process.

The aeration rate according to the paper are 0.63 m3/m3/hr for full scale MBR whereas it can be reduced to an optimum of about 0.37 m3/m3/hr

Coarse bubble for nitrification was used to achieve nitrification by maintaining DO at 0.5 mg O2/l. The removal efficiency for COD ranged from 80 to 95% with the discharge of 30 mg/L. In terms of energy saving, upto 66.7 % of air savings were achieved, without affecting the standard parameter removal.

In terms of cost analysis, the system of sized 3 to 7 m3/day found to be economical. The return in the investment for system of 7 m3/day is less than 5 years. Hotel like this when treating 30 m3/day of wastewater gave a 3 year return of investment.

Concluding the paper, MBR can show a great removal efficiency while treating hotel grey water by providing a stable effluent quality. The author recommends the cities with densely population, are particularly appropriate for MBR based GW system because of the economic feasibility and good quality of the water reused. This minimized the risk of water borne infections that could be fatal for the tourist industry as well. The treated water has a very low organic content and thus can be stored in tanks for a longer period and further can be used in non-potable purposes.

W. Song, B. Xie, S. Huang, F. Zhao, And X. Shi, Aerobic Membrane Bioreactors for Industrial Wastewater Treatment. Elsevier B.V., 2020.

In the beginning of paper, a brief introduction of various categories of industries and waste water from those industries is given. Industrial wastewater generated contains a high amount of both organic and inorganic substances, toxic compounds like phenol, toluene, sulphide, cyanides, etc. They have a large fluctuation in their pH and TDS levels.

Following to this, an overview of MBR technology for industrial wastewater treatment has been given. As per the Authors, it would be benefitting the acclimation (adapt, adjustment) of microbial community to extreme conditions of Industrial wastewaters as well as the enrichment of special microbes that can degrade specific industrial pollutants.

The main factors hindering the wider application of MBR in industrial wastewater treatment are (i) Low microbial activity, and (ii) Serious membrane fouling due to extreme wastewater conditions. This paper summarises the application of MBR in industrial wastewater treatment with latest research progress and future perspectives The summary of successful MBR performances has been given with type of wastewater, COD, HRT, SRT, removal parameters, etc. In chemical wastewater, COD inlet was 1898 ± 532 with HRT of 14 days, and SRT of 30 to 51 days. The removal efficiency was 80% observed.

2.4 Summary of Literature Review

MBR (Membrane bioreactor) technology is an excellent modern wastewater treatment technology, having the several advantages over conventional activated sludge processes. Membrane bioreactor technology is a membrane separation technology and bioorganic combination of new wastewater treatment technology. Operating as an MBR allows conventional activated sludge plants to become single step processes, which produce high quality effluent potentially suitable for reuse. This report discuss the design of such laboratory scale membrane bio reactor for study the efficiency for the different operational parameters for wastewater treatment

3. DESIGN OF MBR (Membrane bioreactor)

3.1 Design Process of MBR

The Membrane Bioreactor is designed in such a way that it can handle multiple processes together with the partitions provided which serves the purpose of an individual tank. These chambers not only allow multi-purpose operations, but also do not disturb the work of another chamber.

The important points for designing an MBR system are as follows:

- F/M = The Food to microorganism ratio gives the substrate removal rate per unit solids in the system.
- MCRT or SRT = The Solids Retention Time is the average time the activated sludge solids are in the system.
- HRT = The Hydraulic retention time is the measure of the average length of time that a soluable compound remains in the constructed bioreactor. The volume of the aeration tank is divided by the influent flow rate to find the HRT.
- Aerobic zone: Aerobic treatment of wastewater is a biological process that uses oxygen to break down organic contaminants and other pollutants like nitrogen and phosphorus. Here Oxygen is continuously mixed into the wastewater by means of mechanical aeration device, such as air blower or compressor and a sparger.
- Anoxic zone : Anoxic zone treatment is a treatment of wastewater which treats water in absence of oxygen. The microorganisms take nitrate from the wastewater thus the wastewater achieves the process of denitrification.

Following are the initial data assumed for the design of the Laboratory Scale Bio-reactor:

- F/M = 0.5
- $S_i = BOD_{in}$ = 39.5 mg/L
- $S_o = BOD_{out}$ = 5 mg/L
- Q_a = Flow = 0.36 m3/day
- X = MLSS = 3000 mg/L
- SRT = 10 days
- HRT = 6 hours = 0.25 day

Considering the initial data Design of the Reactor is as follows

Design Volume of Aeration Tank = $Q_a \times (S_i - S_o)/[(F/M) \times X]$

∴ Design volume = $[0.36\ m^3/day \times (39.5 - 5)\ mg/L]/[0.5/day \times 3000\ mg/L]$

$= 0.00828\ m^3$

Design volume of Anoxic tank = HRT × Q_a

$= 0.25\text{-}day \times 0.36\ m^3/day = 0.09\ m^3$

Design volume of Membrane tank = Based on similar shape and cost effectiveness, similar to Design volume of Aeration tank

Total volume of tank $= 0.00828 + 0.1499 + 0.00828\ m^3$

$= 0.10656\ m^3$

Let depth be 0.4 m, Therefore Area = $0.2664\ m^2$

Let length 0.6 m, thus the overall dimension will be = <u>**0.6m x 0.45m x 0.4 m**</u>

Fig. 3.1. Laboratory scale submerged membrane bioreactor

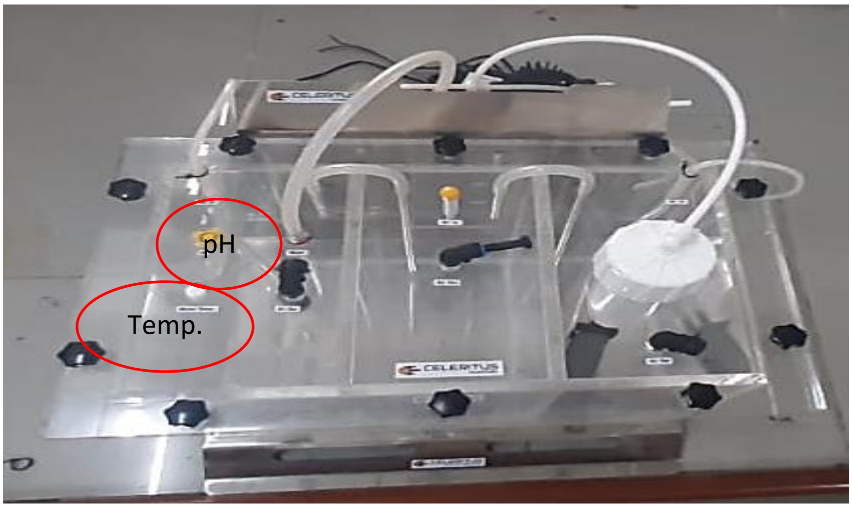

Fig. 3.2. Laboratory scale submerged membrane bioreactor with pH and temperature check point configuration

3.2 Working of MBR

The sample after the initial tests done, is introduced into the Chamber-1 of the Tank. If the value of COD comes out to be too high, then the sample is diluted to some proportion with distilled/tap water, then the water is introduced.

Chamber-1

This chamber is Aeration chamber. Oxygen in the form of air is provided with the help of Air pump. As per the design and pump rate, 2 hours of oxygen is provided in the Aeration tank, then the water is transferred to chamber-2 with the help of automatic siphon action, or by using a water pump. Oxygen is required in the Aeration zone of MBR for oxidation of part of influent organic matter, and also for endogenous respiration of the micro- organisms in the system. The oxygen requirement of the aeration tanks is calculated with the help of following equation:

O_2 required = {(Q(Y0-YE)/f) – (1.42 QW * XR)} gm/day

Where ; f = (BOD_5/BOD_u) = (5 Day BOD/Ultimate BOD) = 0.68

1.42 in the equation is the oxygen demand of biomass in gm/gm

The above formula represents the oxygen demand for carbonaceous BOD removal and does not account for nitrification. The extra requirement of oxygen for nitrification is theoretically found to be 4.56 Kg O_2/kg NH_3-N oxidized to NO_3-N.

The aeration facilities of the Membrane bioreactor are designed in order to provide the calculated oxygen demand of the wastewater against the specific level of D.O. in wastewater. The aeration devices, along with supplying the required oxygen demand, also shall provide adequate mixing or agitation, so that the entire MLSS present in the aeration tank will become available for the biological activity.

Chamber-2

This chamber is Anoxic zone chamber, where Anoxic reactions takes place in absence of oxygen. Anoxic processes and zone are used for the removal of nitrogen from wastewater. The process of biologically nitrogen removal is known as denitrification. Denitrification requires that nitrogen be first converted into nitrate, which typically occurs in an aerobic zone. The nitrified water is then exposed to an environment without free oxygen (Anoxic zone). Organisms in the anoxic zone uses the nitrate as an electron acceptor and release nitrogen in the form of nitrogen gas or nitrogen oxides.

Chamber-3

Chamber-3 consists of the main heart of the membrane bioreactor, i.e., Membrane. The function of membrane is to separate the solids from liquid. This process is achieved with the help of water pump which suck the water through the membrane and separates it out. The residual is the Solids which are recycled at the end of 15 days (i.e., the pre-decided SRT).

In this way the filtered (treated) water is achieved. Then this treated water is discarded into the streams, or further treated with the help of nano- filtration for reuse for industrial purposes, etc.

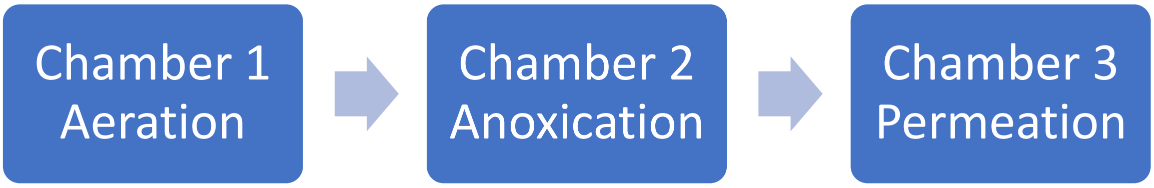

Figure 3.3 Process Flow through MBR

The membrane bioreactor treatment process follows these three chamber reactions for wastewater treatment as shown in figure 3.3.

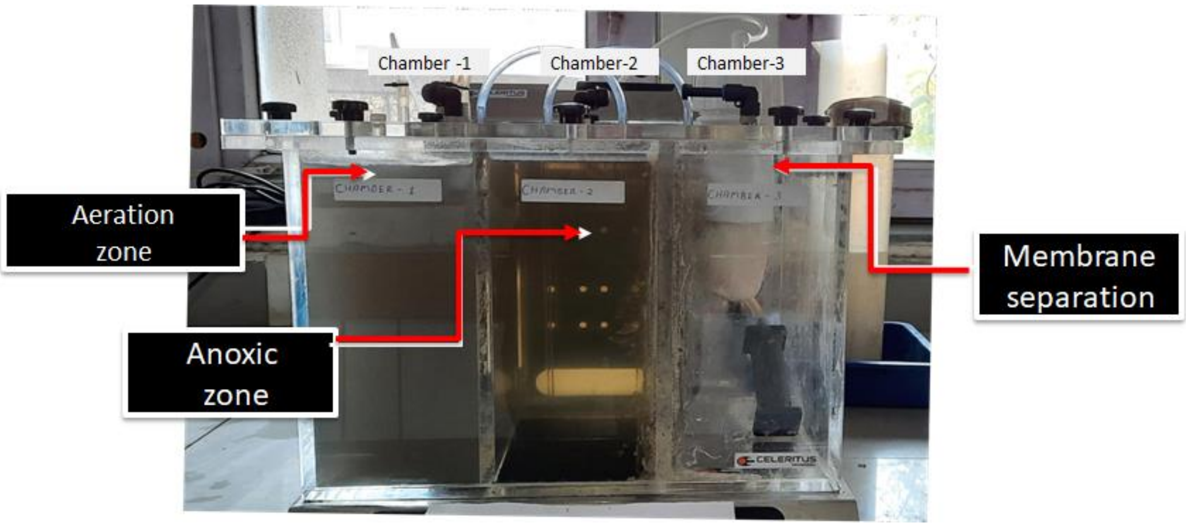

Figure 3.4 Process Flow through Laboratory Scale MBR

4. EXPERIMENTAL WORK

4.1 Methodology

Membrane bioreactor was designed and manufactured as per the laboratory experiment need. The prime objective of this study is to evaluate efficiency of membrane for industrial wastewater treatment using membrane bioreactor. To achieve this objective following methodology for the experimental work was used.as shown in Figure 4.1 below.

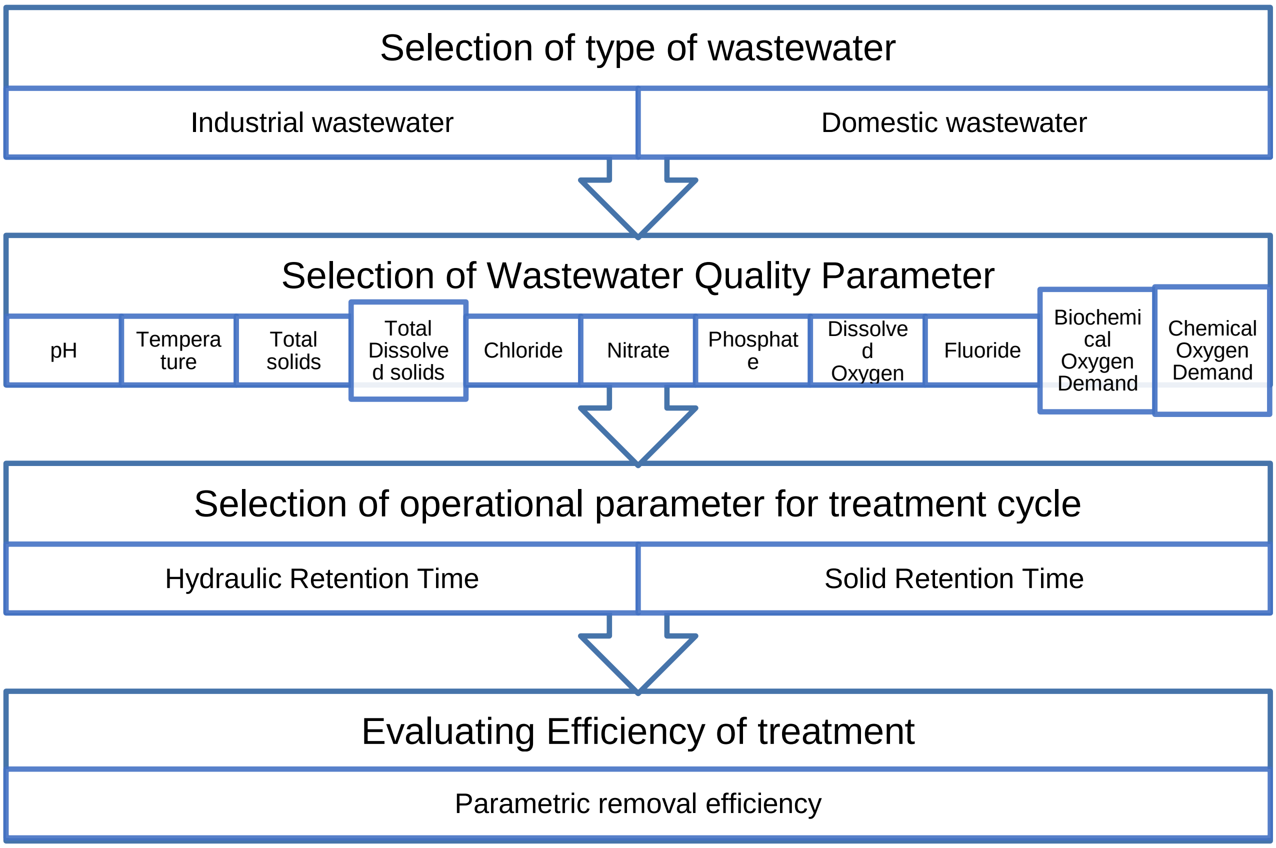

Figure 4.1 Methodology of Experimental work

Step 1: Selection of type of wastewater

The membrane bioreactor is combination of biological and filtration process. Initially one trial run was completed using domestic wastewater which helps in biological treatment. Then industrial wastewater treatment cycle was performed following domestic waste water and combination of both for this study.

Step 2: Selection of wastewater quality parameter

The quality parameters were chosen based on the literature review. Important parameters are TSS, Nitrate, chloride, Sulphate, ammonium, BOD for Domestic sewage and COD for industrial sewage as per the discharge standards set by CPCB. Also, the secondary treatment is governed to remove BOD, COD and Suspended solids in a greater amount and to meet up the discharge standards. The colorimetric methods were not reliable and they were considered as approximate method. The method of testing the parameters is as follows:

TABLE 4. 1 Parameters and its methods of testing

Parameters	Unit	Methods
pH	-	pH meter
Temperature	^{o} C	Digital temperature meter
Total solids	mg/L	Gravimetry method
Total Dissolved solids	mg/L	Gravimetry method
Chloride	mg/L	Argento-metric titration
Nitrate	mg/L	Colorimetry method
Phosphate	Mg/L	Colorimetry method
Dissolved Oxygen	mg/L	Modified Winkler's method
Fluoride	mg/L	Colorimetry method
Biochemical Oxygen Demand	mg/L	DO consumption in 5 Days @ 20 ^{o} C
Chemical Oxygen Demand	mg/L	Potassium Dichromate method

Step 3: Selection of Operational Parameter

It is observed from literature study that the as solid retention time and hydraulic retention time increases it reduced membrane fouling time. Different set of solid retention time and hydraulic retention time was selected for this experimental work as shown in Table 4.2.

Table 4.2 Operational Parameters to be considered for Experimental Work

Sr. No	Parameter/Ratio	Range
1.	Solid Retention Time (SRT)	10 days & 15 days
2.	Hydraulic Retention Time (HRT)	6 hours & 8 hours

Step 4: Evaluating Efficiency of Membrane bioreactor treatment

The efficiency of treatment is evaluated by considering important parameter removal efficiency from inlet and outlet. The parameters which are considered are Biochemical Oxygen Demand, Chemical Oxygen Demand mainly.

4.2 Components of Membrane Bio-Reactor and Its Characteristics:

1) Aerobic zone Air pump and diffuser:

An Air pump is a pump to push the air. This air can be in the form of pre- compressed air or the atmospheric air. The uses of Air pump are to power pneumatic tools, air horn, to aerate the aquarium or pond via a sparger.

2) Membrane:

A membrane is a device which separates solids and liquids. A number of hollow strands of fibre are used in the Lab-scale membrane. The retention of solids which remains in the chamber thus further increasing the MLSS concentration of the wastewater. Permeate is taken off from the system with the help of vacuum pump which is attached to the top of membrane.

3) Membrane Pump

Membrane pump is a vacuum pump which take off water from the tank with the help of centrifugal acceleration of the motor.

Characteristics:

- 24 V
- 1.18 A
- 4LPM
- Pressure = 30 PSI

4) Water pump

The water pump is used for transferring of water from chamber 1 to chamber 2 in case of malfunctioning of syphonage action. This pump also helps in cleaning of water from the chambers and also in sludge recirculation.

The Water pump used here in Lab-scale MBR is Rolly Gold 12 V RO-4949

Characteristics:

- 12 V Normal, 9-14 Fluctuating
- 3-4 Amps
- Flow = 6 LPM
- Pressure = 130 PSI

Cleaning Mechanism:

Cleaning of tank is required after every cycle or dealing with different types of wastewater.

The cleaning is done manually where the lid is taken out and using water and a cloth cleaning is done.

FIGURE 4.2 LAB-SCALE MBR AT THE TIME OF CLEANING

4.3 Details of Different Trial Cycles considered for Membrane Bioreactor Treatment

Trial Cycle 1 – Industrial Wastewater Combination Batch 1:

Membrane bioreactor is generally used for sewage water treatment of domestic wastewater. As industrial wastewater comprises heavy metals, high COD, toxic chemicals, phenols which may or may not hamper the biological activity in the reactor. It depends on the level of toxicity or level of inhibitors inside it.

To know the removal efficiency of various parameters, wastewater from the chemical industry was selected.

The chemical industry consists of the following material: Intermediates are petroleum downstream products processed for various applications. The product delivered by Industry is vinyl sulfone and vinyl sulfone.

The main objective in this cycle was to check the efficiency of COD, as it being one of the main parameters. The COD test was done and the results were found. The COD of chemical industry wastewater being 1368 mg/L, was very high for lab scale Membrane Bioreactor treatment so it was diluted as per requirement. The dilution of the wastewater sample is mentioned in Table 4.3 below:

Table 4. 3 COD of wastewater with dilution ratio

Sr. No	Dilution Ratio	COD (mg/L)
1	Undiluted	1368
2	3:4	1110
3	1:1	580

4	1:4	360

Trial Cycle 2 – Industrial Wastewater Combination Batch 2:

Trial 2 was carried out considering Chemical Industry wastewater from different batches. This wastewater sample has different characteristics than the previous cycle.

Technical Parameters to be considered for this trial

Aeration HRT 4 hours

HRT (chamber - 3) = 48 hours

Trial Cycle-3 Wastewater of STP Nirma University:

This trial cycle was only run for the addition of the microbes in the bioreactor, thus the two main parameters were checked. i.e., BOD and COD.

Technical Parameters to be considered for this trial

Aeration HRT 4 hours

HRT (chamber - 3) = 48 hours

Trial Cycle-4 Treatment of Mix water (STP + Industrial Wastewater):

The dilution Mix ratio of industrial wastewater with the Domestic sewage wastewater was kept to be 1:4. The reason of decrease of industrial wastewater is with the increase of industrial wastewater, higher the chances of toxic elements which harm the removal efficiency by harming the microorganisms and their activities. While doing initial tests of mix, it was found COD:N ratio is very less i.e., 100:0.1. Nitrate being the very important parameter is important. SO it was decided to increase the nitrate content additionally by adding nitrate before treatment. The best way to do so was to add cow dung or any fertilizer in a decided proportion after appropriate testing of various proportions. As the cow was not available, it was decided to go with the fertilizer. Appropriate mixes were prepared by adding some grams of nitrate in water so as to check the nitrate condition of the water.

TABLE 4. 4 NITRATE PROPORTIONING AND MIXING

Sr. No	% of fertilizer of total volume	Result of Nitrate (mg/L)
1	5 %	4 mg/L
2	10%	7 mg/L

With the increase in percentage of mixing, there is a direct increase of solids concentration being a constraint, it was decided to go with 5% of fertilizer. Which adds up to 350 grams of Fertilizer.

Technical Parameters to be considered for this trial

Aeration HRT 6 hours

HRT (chamber - 3) = 48 hours

Trial 5: Ahmedabad Municipal Corporation Sewage Treatment Plant, Pirana:

As by mixing the sewage water to industrial wastewater, removal efficiency seemed to be higher as found in literature study also. The removal efficiency can reach up to 99% if the raw sewage treatment is introduced.

The STP is based on the Activated Sludge process with a fine bubble diffused aeration system. This plant reduces the deterioration of River

Sabarmati by treating much of the industrial + domestic sewage being mixed in the sewer lines. The system is made such that the effluent water can be used for irrigation. It is India’s first STP with PLC SCADA system with auto operation. This plant runs under gravity from inlet point. In addition to this, the STP is capable of generating about 1.2 MW electricity by providing an additional Biogas engine system, which is self-sufficient to make the STP energy free.

Technical Parameters to be considered for this trial:

Aeration HRT 6 hours

HRT (chamber - 3) = 48 hours

5. RESULT & DISCUSSION

5.1 Results

Trial Cycle 1 – Industrial Wastewater Combination Batch 1:

The trial cycle 1 consists of chemical industry wastewater as discussed in chapter 4, the final result obtained for different parameters are shown in Table 5.1.

Table 5.1 Results and Preliminary Observations of Parametric Removal Efficiency of Trial Cycle-1

Sr. No.	Parameters	Before treatment (mg/L)	After Treatment (mg/L)	Parametric removal efficiency	HRT	Observation
1	Zinc	-	0.1	-	1st	-
2	Fluoride	-	1.3	-	1st	-
3	Phosphate	-	7.5	-	1st	-
4	Nitrate	10	0	100%	1st	Denitrification fully achieved
5	TS	1963.1	1071	45.44	2nd	As expected in Mircro-filtration
6	TDS	1824	991.5	45.64	2nd	As expected in Mircro-filtration
7	TSS	139.1	79.5	42.80	2nd	As expected in Mircro-filtration
8	COD	360	240	33.33%	3rd	Sign of Removal of organic impurities
9	Chloride	526	661.733	-25%	3rd	Negative

As shown in Table 5.1, Zinc, Phosphate and sulphate presence was checked at the outlet only. However, the important treatment parameters Solids, Chemical Oxygen Demand

(COD), Nitrate and chloride were obtained for both inlet and outlet.

Trial Cycle 2 – Industrial Wastewater Combination Batch 2:

The trial cycle 2 consists of chemical industry wastewater as discussed in chapter 4, the final result obtained for different parameters are shown in Table 5.2 below.

Table 5.2 Results and Preliminary Observations of Parametric Removal Efficiency of Trial Cycle-2

Sr. No	Parameters	Before treatment (mg/L)	After Treatment (mg/L)	Parametric removal efficiency	HRT	Observation
1	Nitrate	2.5	0	100%	1st	Denitrification and sign of Microorganism m Activity
2	TS	2906.2	2816.2	3.09%	2nd	Almost Nil removal
3	TDS	2774.6	2752.9	0.78%	2nd	Almost Nil removal
4	TSS	131.6	63.3	51.89%	2nd	Moderate removal
5	COD	470	660	Negative	2nd	Possibility of refractory organics, and less MLSS concentration
6	Zinc	0.1-0.25	0.25	Negative	3rd	Presence of Refractory Organics
7	Fluoride	1.1	3.1	Negative	3rd	Presence of refractory organics
8	Phosphate	35	25	28.57%	3rd	Sign of MO activity
9	Chloride	1772.5	1276.2	28%	3rd	Less removal

As discussed in chapter 4, trial 2 consists of wastewater from different batches which have different chemical configurations. For this trial, different parameters shown in table 5.2 parametric removal efficiency are evaluated.

Trial Cycle-3 Wastewater of STP Nirma University:

As discussed in chapter 4, this cycle was run for improving efficiency of biological activity in membrane bioreactor. Only BOD and COD removal efficiency is considered for the same.

Trial Cycle-4 Treatment of Mix water (STP + Industrial Wastewater):

As discussed in chapter 4, trial 4 consists of wastewater from industry and sewage treatment plant. For this trial, different parameters shown in table 5.4 parametric removal efficiency are evaluated.

Trial 5: Ahmedabad Municipal Corporation Sewage Treatment Plant, Pirana:

As discussed in chapter 4, trial 5 consists of wastewater from industry and sewage treatment plant. For this trial, different parameters shown in table 5.5 parametric removal efficiency are evaluated.

Table 5.5 Results and Preliminary Observations of Parametric Removal Efficiency of Trial Cycle-5

Sr. No	Parameters	Before treatment	HRT1	
			Effluent quality	Efficiency
1	COD	360	30	91.66%
2	BOD	39.5	7	82.27%
3	Chloride	506	489	3%

Table 5.3 Results and Preliminary Observations of Parametric Removal Efficiency Of Trial Cycle-3

Sr. No	Parameters	Before treatment (mg/L)	After Treatment (mg/L)	Parametric removal efficiency	HRT	Observation
1	COD	150	210	Negative	1st	Possibility of refractory organics due to earlier sample
2	BOD	30	6.3	79%	1st	Insufficient parametric removal efficiency as compared to literature papers

Table 5.4 Results and Preliminary Observations of Parametric Removal Efficiency of Trial Cycle-4

Sr. No	Parameters	Before treatment	After Addition of nutrients	HRT1		HRT-2		HRT-3	
				Effluent quality (mg/ L)	Efficiency	Effluent quality (mg/ L)	Efficiency	Effluent quality (mg/L)	Efficienc y
1	COD	460	-	340	26.09 %	310	32.61 %	250	45.65 %
2	Total Solids	2904	4314.8	2471.4	42.72 %	-	-	-	-
3	Total Dissolved Solids	2737.6	2988.4	2251.6	24.66%	-	-	-	-
4	Total Suspended solids	166.9	1326.4	219.8	83.43%	-	-	-	-
5	Chlorides	1134.4	1198.21	886.25	26.04%	857.89	28.40%	-	-
6	Sulphates	130	60	50	61.53%	-	-	-	-

Observation for pH and temperature:

As membrane bioreactor treatment is pH and temperature sensitive, the observation of pH and temperature is shown in Table 5.6 and Figure 5.1. Similar observations were seen in rest other cycles too.

Table 5.6 pH & Temperature Monitoring at Regular Base

Sr. No	Date	pH		Temperature (° C)	
		Morning	Evening	Morning	Evening
1	19/01/2021	7.9	8.01	24.5	25.6
2	20/01/2021	8.07	8.32	27.9	27.5
3	21/01/2021	7.96	7.91	26.4	26.2
4	22/01/2021	7.47	7.48	26.5	26.2
5	25/01/2021	7.38	7.74	27	26.5
6	27/01/2021	8.02	8.11	26.5	26.9
7	28/01/2021	8.2	8.26	25.1	25.2
8	29/01/2021	7.54	8.13	26	26.7

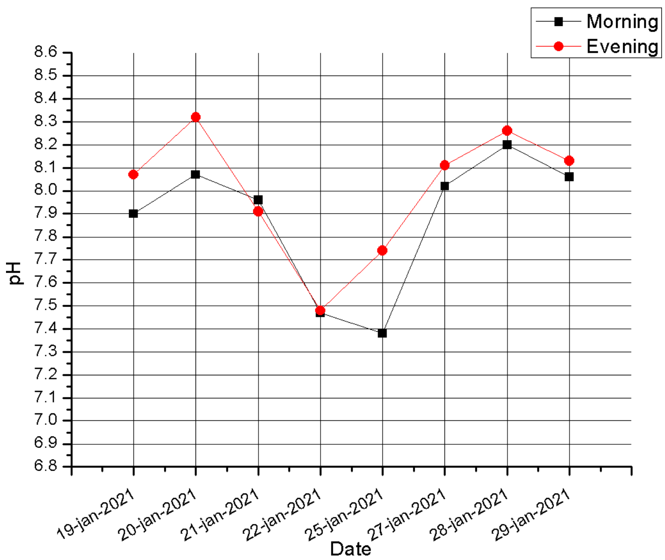

Figure 5. 1 pH Observation

During the initial days, the pH starts dropping from 8.32 to 7.38. This is due to addition of Oxygen in the aeration tank, ammonium ion gets oxidized, resulting into loss of alkalinity. This reduces the pH in Aeration Tank. pH and alkalinity begin to recover once the aeration is shut off after the optimum Oxygen is supplied. While the aeration is off, denitrification takes place, which allows the alkalinity to increase and the rise in pH. The nitrate breaks from NO3 and free nitrogen gas is released in the atmosphere in the anoxic tank in chamber 2, the half of the weight of ions of nitrate are dissolved in sample.

This is the main reason of rise in pH

$$NO_3 + BOD = N_2 + O_2 + Alkalinity$$

5.2 Discussion

Trial Cycle 1 – Industrial Wastewater Combination Batch 1:

From the results obtained from Trial cycle -2 it was observed that the MBR is working efficiently as the removal of COD of about 33% has been obtained. The removal is though less than the removal rate of literature studied, but the type of wastewater used here was toxic in nature

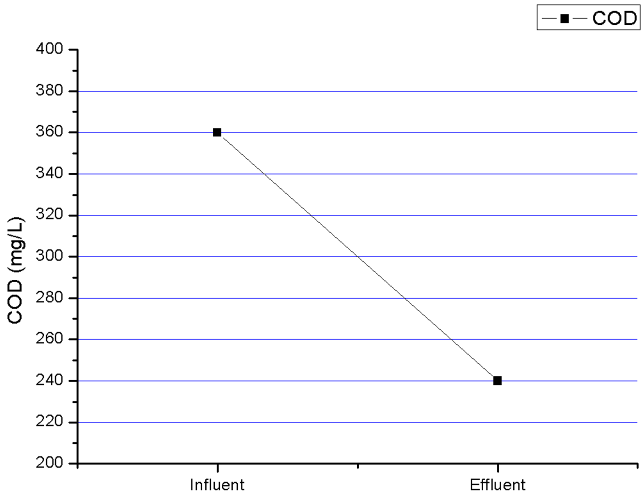

Figure 5. 2 COD Removal in Trial Cycle 1

The COD in effluent was 240 mg/L and is less than the CPCB standards of 250 mg/L for discharge in the surface water. Another reason of less removal of COD is due to very less MLSS concentration. Out of these MLSS, only 71% is MLVSS, which is mixed liquor volatile suspended solids. The toxic elements can be treated by giving a pretreatment before MBR process. Also the initial sample was in a limited amount thus the MLSS concentrations were not increased up to the mark and it resulted in a less removal of COD.

Removal efficiency of Nitrate was seen to be full, 100 percent achieved. This shows the process of Denitrification to be achievable in the anoxic zone. The nitrates serves as a food to microorganisms in their growth. The increase in removal efficiency is seen if the COD: N ratio is more i.e., 100:5 to 100:10 [Weilsong. Et. Al]. In our case the COD: N was not as sufficient as 360:10 = 2.77, thus this could be one of the possible reasons of lesser removal efficiency in our Lab-scale MBR.

Removal of Suspended solids was found to be nearly 50%. The membrane used in the Lab-scale MBR was Ultrafiltration having precision of 0.01 to 0.1 micrometer. According to Noor Sabrina et al., 2012, the MBRs with ultrafiltration can remove all the suspended solids and also the bacteria and viruses, thus providing the safe discharge biologically to environment. There would be some suspended solids which might be smaller than this or the efficiency of membrane would not be up to the mark as the membrane is bought from a local manufacturer.

The removal of Total solids was very less and it is because the membrane filtration only supports the filtration upto the size of 100 nanometers. The dissolved particles are already dissolved in effluent water as they can easily pass through the micro filter membrane. Thus, removal of dissolved particles is absent. For the removal of TDS, nanofiltration, Reverse Osmosis methods are required. Higher removal efficiency and colour removal is seen in post treatment with nano-filtration [wenbo yang, et al; 2006]. Fluoride, being 1.3 mg/L, is in the limit as described by CPCB standards. Phosphate removal is not seen up to the mark and has been supported by [khan; 2017] claiming the less removal of phosphate in the initial setup days of treatment.

Trial Cycle 2 – Industrial Wastewater Combination Batch 2:

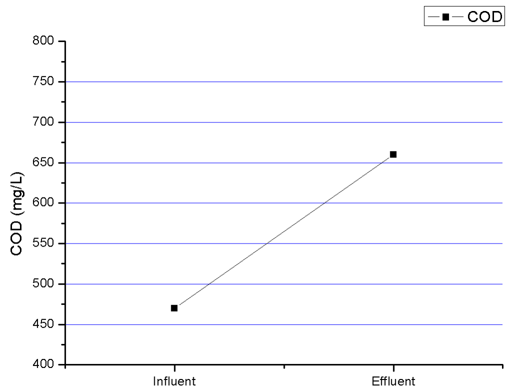

Figure 5. 3 COD Removal in Trial Cycle 2

From the results obtained from Trial cycle -2, it was observed that the MBR is working not efficiently as the removal of COD was found to be negative. This negative removal is due to the presence of **refractory organics** as the wastewater is of industrial type and that also highly toxic from chemical and synthetic industry. In wastewater, some compounds are classified to be refractory when they are poorly biodegraded or exhibit a low value of BOD: COD.

Figure 5. 4 Colour Comparison of Influent and Effluent

The denitrification was found to be 100%. The removal of other parameters is similarly seen in the previous trial cycle and the reasons are similar.

Trial Cycle-3 Wastewater of STP Nirma University:

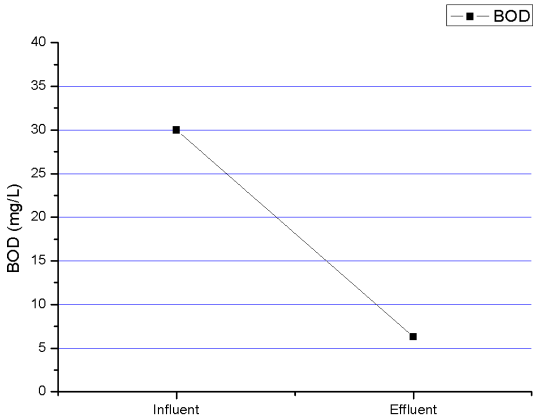

Figure 5.5 BOD Removal in Trial Cycle 3

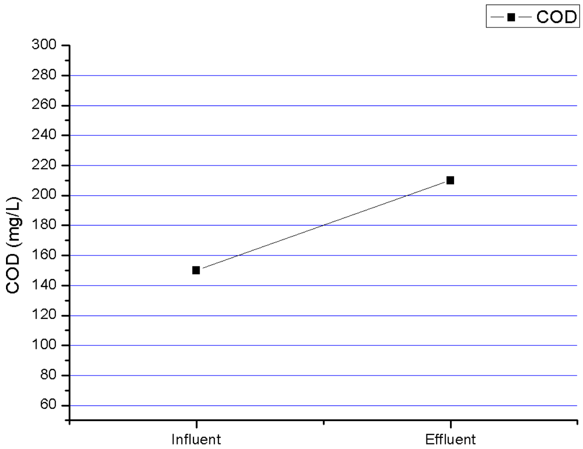

Figure 5.6 COD Removal in Trial Cycle 3

As the main reason of the addition of sewage wastewater was just to increase the microbial population so as to increase the removal efficiency of the MBR treating wastewater, not all parameters were checked. The removal COD in trial cycle 3 was also found negative. One of the reasons is due to trace remaining of earlier cycle can lead to negative removal of COD. The BOD removal is found out to be 79% with the effluent quality of 6.3 mg/L. The BOD removal was achieved to be sufficient enough, though not that much efficient as claimed by many inferred papers. Another reason could be as the STP-Nirma plant was not working, the sample was not having up to the mark value as most of the sludge was settled down for a long time.

Trial Cycle-4 Treatment of Mix water (STP + Industrial Wastewater):

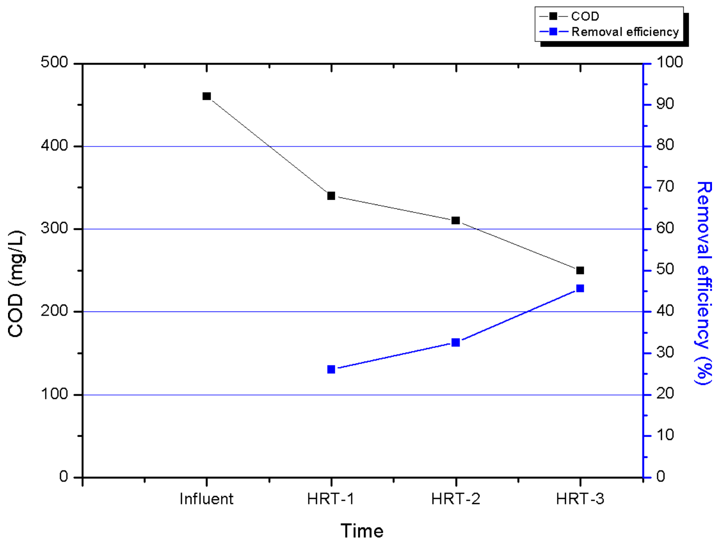

Figure 5. 7 COD Removal in Trial Cycle 4

By looking the results, and analysis of earlier results, it was decided to change the inlet water by mixing the industrial chemical wastewater to the sewage water so as to increase the micro-biological activity and disintegration of organic matters in Lab-scale MBR. The main focus of this mixing two different wastewaters was to look into some of the important parameters like COD, chlorides, sulphates, etc. and their removal efficiency. As per the results obtained, it can be clearly seen the importance of domestic sewage wastewater while treating the industrial wastewater addition in proportion. This addition of sewage wastewater is enhancing the biological activity and thus reducing the COD for up to 45.65% giving the effluent of 250 mg/L.

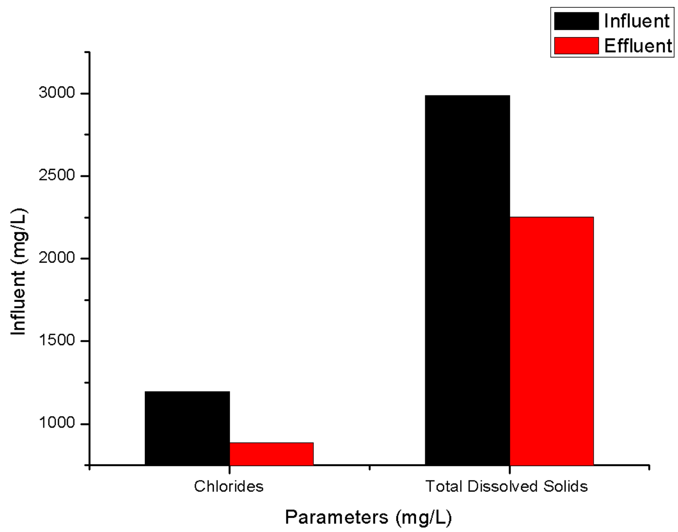

Figure 5. 8 COD Removal in Trial Cycle 4

Trial 5: Ahmedabad Municipal Corporation Sewage Treatment Plant, Pirana:

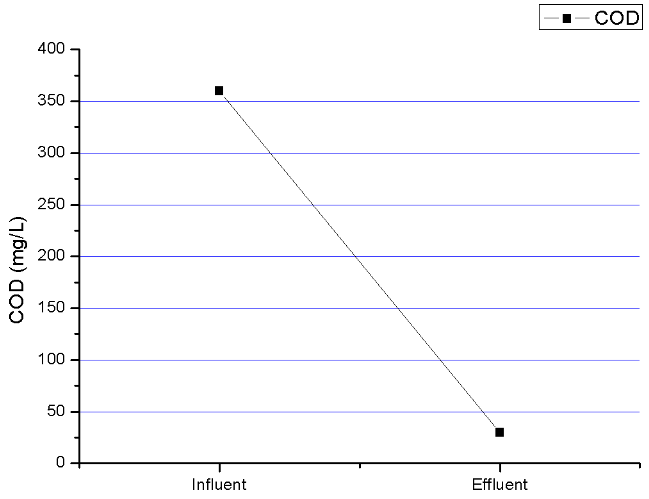

Figure 5. 9 Cod Removal in Trial Cycle 5

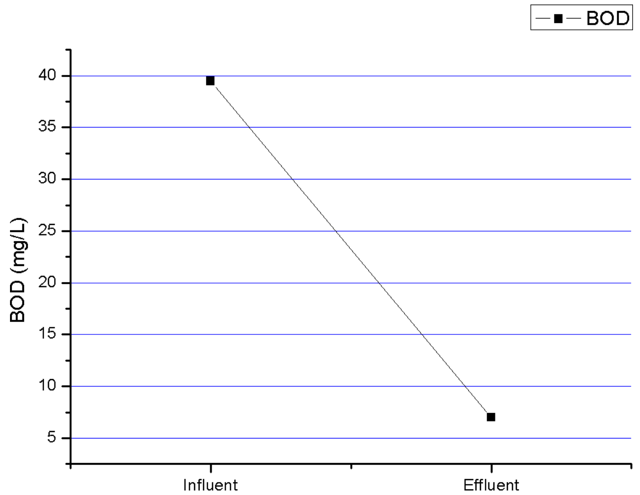

Figure 5. 10 BOD Removal in Trial Cycle 5

Water treatment of STP Pirana from MBR treatment shows the sign of a good amount of removal of BOD and COD parameter and achieving the efficiency to be 82.27% and 91.66% respectively. This high efficiency is achieved in the initial HRT. This shows the efficient working of MBR plant by treating the (sewage + industrial) wastewaters. One of the reasons behind this is that fresh wastewater is treated rather than in old cycles. The microorganisms are likely to be present in more amount than the previously treatment trial cycles. Figure 5.9 & 5.10 shows the parametric removal efficiency for COD and BOD parameter.

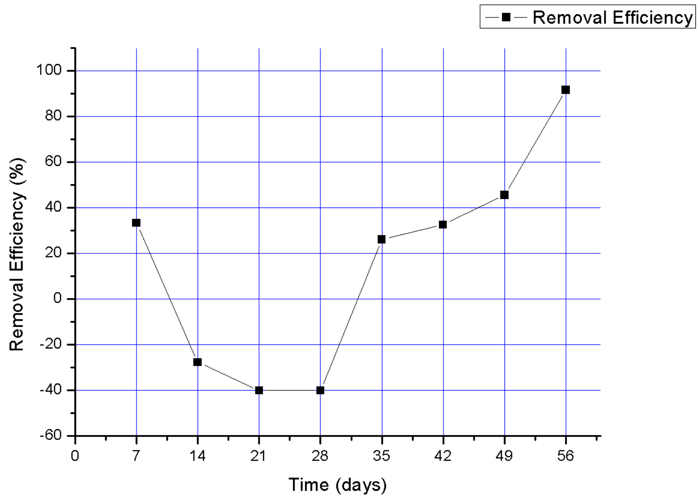

Figure 5. 11 Figure Removal Efficiency of COD Vs Time

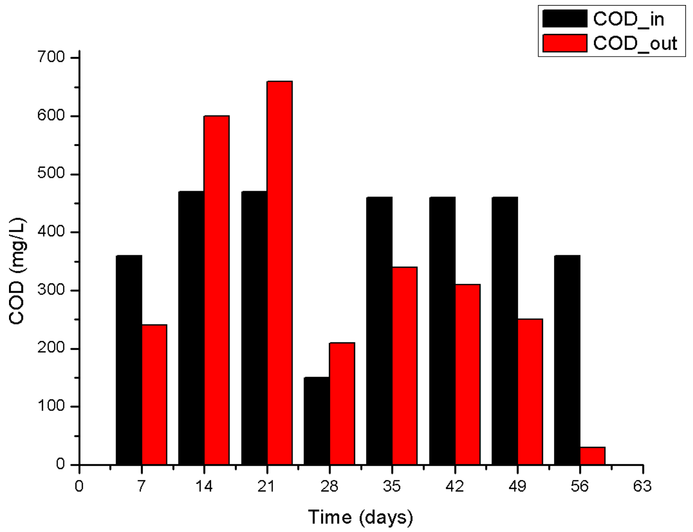

Figure 5.12 Inlet and Outlet COD Vs Time

Figure 5.11 and 5.12 shows the COD removal for this trial with respect to time and for inlet and outlet COD values with respect to time.

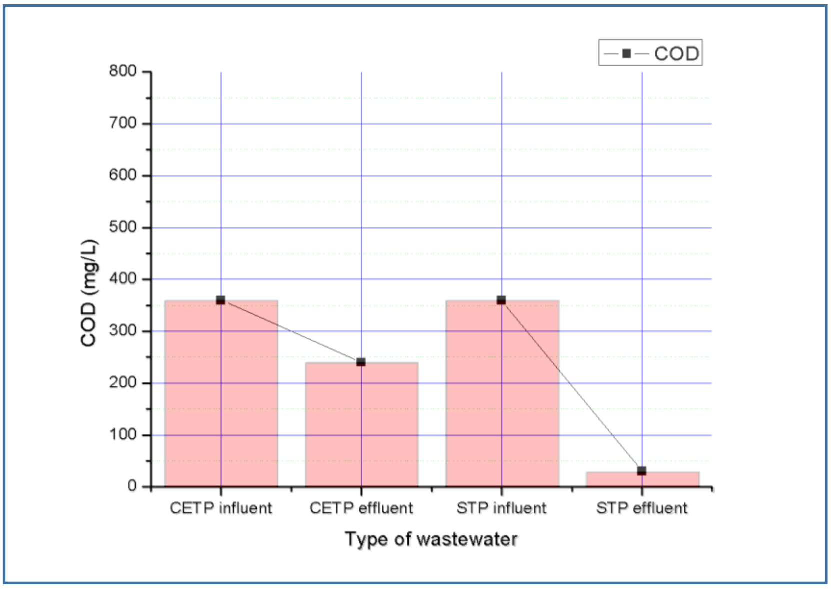

Figure 5. 13 Comparison Between CETP and STP (Influent and Effluent)

Figure 5.13 shows the comparison of industrial inlet and effluent values of parameter Chemical oxygen demand, as industrial wastewater has higher values of COD at Inlet and presence of refractory organic and other impurities cause low reduction COD value at outlet.

6. SUMMARY

In this study, attempt has been made to evaluate efficiency of MBR treatment for Industrial wastewater. Two types of wastewater, namely, (i) domestic waste water, collected from sewage treatment plant of the Ahmedabad municipal corporation and (ii) industrial wastewater, from one of the chemical industries has been taken for the study. The induvial analysis shown that the efficiency of treatment process through the MBR process for the raw industrial wastewater is not up to the mark. Hence, diluted samples were prepared by mixing industrial wastewater and domestic wastewater. It is observed that, the efficiency of the membrane bio-reactor increase as the dilution ratio of the industrial waste water to domestic water decreases.

It is also observed that, the presence of Nitrate (N) and Phosphorus (P) is very important for the biological activity in Membrane Bio-Reactor. Ratio of COD: N: P has to be maintained. Presence of Refractory organics can Severely affect the working of Membrane Bio-Reactor, and mainly parameters like Chemical Oxygen Demand and Bio-chemical Oxygen Demand will be affected.

To use MBR treatment effectively as part of Industrial treatment, combination of domestic wastewater with industrial wastewater is considered as favorable, however the dilution may be decided with suitable analyses based on the organic compounds and properties of the wastewater.

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