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PERFORMANCE EVALUATION OF MEMBRANE BIOREACTOR TECHNOLOGY FOR TREATMENT OF INDUSTRIAL WASTEWATER: A REVIEW

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ABSTRACT
Membrane Bioreactor (MBR) is adevelopingwastewater treatment process which utilizesbenefits of membrane filtration. Owing to the flexibility, strength and consistency, MBR technology is extensively acceptance in field of wastewater treatment. Risingindustrial development in developingcountries like India, Conventional universal technologies are projected to be replaced by MBR systems in the recent years, due to low operation and maintenance costs of MBR systems. This review article represents a comprehensive literature survey for various industrial wastewater treatment by using membrane bioreactor technology (MBR) with speciallyfocused on selection of membrane, configuration of membrane and potential applications of MBR technology in industrial wastewater treatment, From the present review literature, it reveals that, MBR represents a competent and cost effective process that handles excellently with the rising needs for transforming wastewater into clean water that can be give back to the environment without harmful effects.

Keywords: *Membrane fouling, Industrial effluent, Bioreactor, Ultra filtration and wastewater treatment.*

ABBREVIATIONS
ASP- activated sludge process
MBR- Membrane Bioreactor
UF- Ultrafiltration
COD-Chemical oxygen demand
MLSS-Mixed liquor suspended solids
BOD-Biochemical oxygen demand
HRT-Hydraulic retention time
SRT-Solid retention time
TSS-Total suspended solids
TN-Total nitrogen
OLR-Organic loading rate
CFV-Cross flow velocity
SAnMBR-Submerged anaerobic membrane bioreactor
MLVSS- Mixed liquor volatile suspended solids

I. INTRODUCTION
Water is a natural source which must be well-sustained in consideration of public health and it would be protect by minimizingimpuritiesrelease into the aquatic life. The contaminants like total solids, total organic solids and total dissolved solids are dischargedby the household and industrial activities into the water. Therefore, putting the significance to reduce the contaminants in the effluent by following thedischarge standards for effluent and decrease the adverse impacts on water body[1].

Over the last century, continuous population growth and industrial development has resulted in the depletion of numerous ecosystems on which human life depend on. In the case of marine and river water quality, such contaminantsarechieflytriggered by the release of improperly treated industrial and municipal wastewater. On earlyrelease, these wastewaters can encompass high amounts of inorganic contaminants which can be easily decomposable, but whose influence load on the ecosystems, either in Total Suspended Solids (TSS), Biochemical Oxygen Demand (BOD5), or Chemical Oxygen Demand (COD), may be in the terms of thousands mg/L^2.

Nowa day ,for industrial and domestic wastewater treatment the Membrane Bioreactor (MBR) technology is extensively utilized. Membrane bioreactor is a combination of activated sludge process those utilize membranes for filtration of wastewater, it achieves the removal of total solids, high organic and nutrients for a minor bioreactor volume. Membrane bioreactor is fetching the technology of selection due to these potential characteristics. Nevertheless, in compare to their benefits, MBRs have a main disadvantage i.e., membrane fouling which can cause many complications during their application[3].

Membrane bioreactor (MBR) technology is an arrangement of the conventional activated sludge process, a wastewater treatment process categorized by the composed development of biomass with a micro or ultra-filtration MBR system[4].The benefit of MBR technology is its capability to decompose the waste compounds and discrete the treated effluent from the mixed liquor due to the small pore size of the membrane.The microorganisms and suspended solids can be set aside back out of the effluent subsequently the membranes typically have a pore size from 0.01 to 0.1μm [5].

The specific function of bioreactor and membrane module each have a:

(i) with the help of revised microorganism's biological degradation of organic contamination is carried out in the bioreactor.

(ii) by using the membrane module separation of microorganisms from the treated effluent is achieved. The membranes establish a physical inhibition for all suspended matter and consequently allow not only production of a permeate free of suspended solids, bacteria, and viruses but also recovering of the activated sludge to the bioreactor.

The purpose of membranes for isolation organic contaminant and treated wastewater is the chief variance between MBRs and traditional treatment technology for which the efficacy of the ultimate clarification step depends mostly on the activated sludge settling properties.

From this detailed review article, we represent the detailed literature survey on wastewater treatment by the help of membrane bioreactors with a special attention on municipal and industrial wastewater treatment. We have also discussed the recent advances in membrane filtration technology, selection of membrane and configuration of membrane with respect to various references.

II. SELECTION OF MEMBRANE

There are mostly two different kinds of membrane material, i.e., (i)polymeric and (ii) ceramic. However metal lic membrane filters do exist their very definite applications do not relate to MBR technology[6]. Therefore ,the membrane module should be planned in such away as to permit effluent to pass through it. In principle, any polymer can be used for membrane manufacturing. Nevertheless, only an inadequate number of polymers are appropriate for performing the responsibility of membrane separation i.e., (i) polyethylsulphone(PES) (ii) polyvinylidenedifluoride (PVDF) (iii) polypropylene (PP)and(iv) polyethylene(PE).

Microfiltration(MF) and Ultra filtration(UF) types of membrane has frequently utilized in MBRs. The choice of membrane had better consideration of the surface charge, pore size, mechanical strength, hydrophobicity, morphology, chemical permanency packing compactness and ultimately, price. The membrane foulingen courages by the variety of membrane material and pore size. The enhanced pore size of membrane may not be too big to facilitate pore blocking[7, 8] andalso it would not be too small to decreasethemembranepermeability[9].Moreover,afine pore sizedistributioncandecreasefouling[10].In overall, the membrane has less fouling, when the MBR operation has negatively charged. The elements in wastewater effluents has typically resisting each other because of the presence of colloidal particles in nature and negatively charged[11] .Moreover the use of hydrophilic membranes is beneficial to decrease fouling rather than the hydrophobic membranes.[10,12] stated higher critical flux using hydrophilic membranes.[13,14] have compared the filter ability of activated sludge through a hydrophobic membrane.

III. MEMBRANE CONFIGURATION

Membrane filtration are composed of two important fragments, the organic component held responsible for the decomposition of the solid composites and the MBR unit used for the corporal separation of treated wastewater from assorted wastewater. MBR schemes has been divided in two main sets conferring to their arrangement. The primary set, generally known as the submerged MBR scheme, contains external casing membranes those are inside to the bioreactor (Figure 1a)[15]. Usually, hollow fiber membranes are used in submerged MBR (Table 1, Figure.2). The cogent force beyond the membrane is accomplished to forcing the bioreactor or engendering negative pressure on the permeate side. Washing of the membrane has attained complete regular permeate backwashing and frequently chemical back washing. An air diffuser is typically located in a straight line below the membrane unit for accessible cleaning of the superficial filtration. Mixing and aeration are similarly accomplished through by the component. Anaerobic or anoxic segments has been united to allow instantaneous organic nutrient subtraction.

Table 1: Membrane characteristics and types of Membrane used in submerged MBR systems.

Sr. No.	Type	Membrane Geometry	Pore Size(µm)	Wastewater	Reference
1	Flat	MF-Polyethylene	0.4	Domestic	16
2	Hollow Fiber	Polyethylene	0.1	Municipal	17
3	Hollow fiber	Zenon	0.1	Synthetic raw milk	17
4	hollow fiber	Zenon	0.1	Municipal	16
5	Hollow Fiber	Polypropylene	0.1	Synthetic Municipal	18
6	Hollow Fiber	Hydrophilic Polyethylene	0.1	Municipal	18
7	Hollow Fiber	Polyethylene	0.1	Domestic	19
8	Hollow fiber	MF-polyethylene Mitsubishi	0.1	Synthetic	20
9	Hollow Fiber	MF	0.1	Municipal	10
10	Flat hollow fiber	MF polyolefin	0.4	Municipal	21
11	Hollow Fiber	MF-Polyethylene	0.1	Municipal	22
12	Plate	MF- polyolefin	0.4	Municipal	22
13	Plate and frame Hollow fiber	Polysulphone	0.4	Domestic	23
14	-	Polypropylene nonwoven	0.5-5	Domestic	23

Another configuration is the external MBR (Figure 1.b), which includes the recirculation of the mixed wastewater through a membrane unit present in outside the bioreactor. Both internal casing and external casing membranes can be used in this operation. The determined force is formed by high traverse stream velocity by the side of the membrane surface .Normally, in external MBR systems tubular types of membranes are used (Table 2, Figure.3).A graphic of the re-circulated and sturdier polymeric membranes contiguous with low pressure supply and high permeate flux have enhanced the world wide profitable use of submerged MBRs.

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Table:2: Types and membrane characteristics of Membraneused in external MBR systems.

Sr. No.	Type	Membrane Geometry	Pore Size(µm)	Wastewater	Reference
1	Tubular	Alumina Zircon	0.2 0.05	Municipal	24
2	Tubular	UF-cellulose acetate -Sulfonated polyether sulfone -Hydrophobic polyether sulfone	-	Synthetic	25
3	Plate	UF	-	Distillery	26
4	Tubular	UF ceramic	0.02	Municipal	27
5	Tubular	MF ceramic	0.2	Municipal	28
6	Tubular	Ceramic Zircon	0.2 0.05	Food (ice cream)	29
7	Plate	UF polyacrylonitrile	-	Synthetic	30
8	Tubular	Ceramic Kerasep	0.1	Municipal	31
9	Tubular	MF	0.1	Municipal	32
10	Tubular	UF	-	Synthetic (fuel oil)	33
11	Tubular	Ceramic Kerasep	-	Municipal	34

Numerous categories and configurations of membranes are used in Membrane filtration technology. In this rotary disk, frame and plate, hollow fiber, tubular, metallic, organic and inorganic ultra-filtration and microfiltration membranes are mostly used. The opening of size of pore of the membranes used in MBR system ranges from 0.01 to 0.4 µm and flux attained ranges to 0.05 to 10 m/d (m^3 m^{-2} d^{-1}), powerfully reliant on material of the membrane and the configuration of membrane. The distinctive flux required to internal casing membranes has defined as 0.5 to 2.0 m/d and for external casing membranes has 0.2-0.6 m/d at 20 Co.for efficient pressure of trans-membranes varies between 20 to 500 kpa used for internal casing membranes and for external casing membranes it varies from 10 to 80 kpa. In the MBR systems the membranes satisfy essential various criteria which is used for filtration.

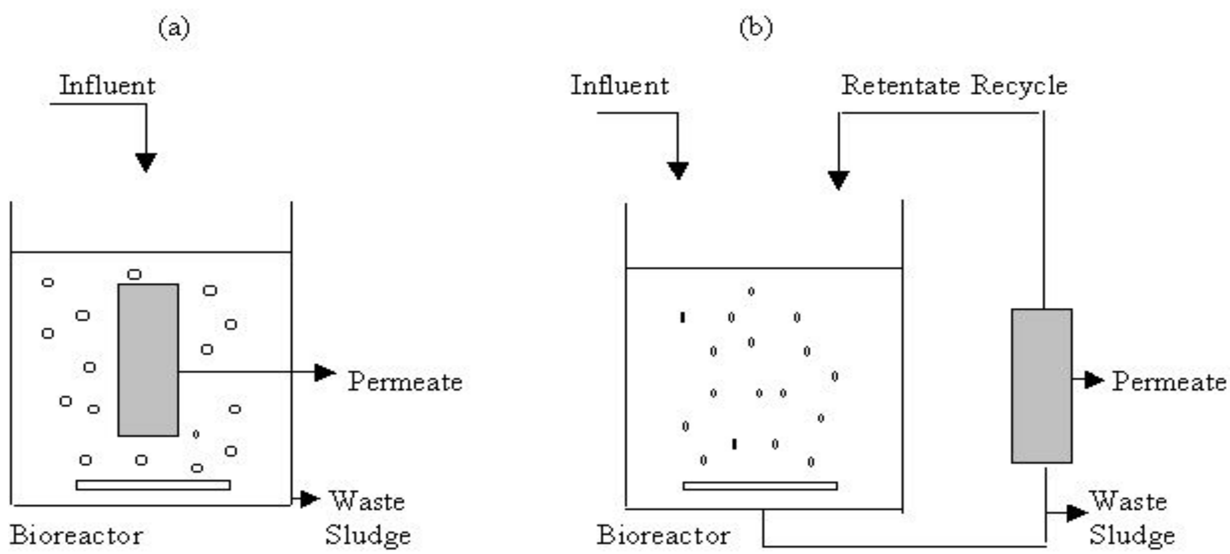

Figure:1: a) model of internal MBR system b) model of external MBR system[35]

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Figure:2: Example of Hollow fiber membrane module used in Submerged MBR system[36]

Figure:3: Example of tubular membrane module used in external MBR system[37]

IV. LITERATURE REVIEW

Huang Xia et al.[18] evaluated the performance of a SMBR efficiency, for the treatment of a Domestic wastewater, with the objective of a reuse of the treated water. The influent COD concentration was 95-362mg/L, NH_3-N was 14-27 mg/L and Suspended Solids 45-290mg/L and a polyethylene membrane having a pore size of 0.1µm was used. The higher efficiency of the reactor has been confirmed by a higher COD, NH_3-N and Suspended Solids removal efficiency (i.e.60%).

N. Fallah et al.[38] have reported the results of treatment of wastewater from a styrene containing synthetic wastewater with a pilot-plant sMBR. A flat sheet polyethylene membrane having 0.4µm pore size was used. It has been shown that the sMBR successfully removed pollutants measured as styrene, chemical oxygen demand (COD) and MLSS from the synthetic wastewater with an efficiency of over 99%.

Qusay F. Alsalhy et al.[39] tested a laboratory-scale MBR with an oil refinery wastewater from a AlDaura Refinery in Baghdad. Membrane used was made up of polyvinylchloride(PVC) with pore size of 0.12 µm. The average concentrations of COD, BOD, oil content, phenol and in the effluent, were 235mg/L,42mg/L,14ml/L, 0.7 mg/L respectively. From the detailed investigation by the author it reveals that the concentration of MLSS influence the removal efficiency of COD, BOD, oil content, and phenol. with an increase in the concentration of MLSS simultaneously the removal efficiency increases and the other operating conditions that are studied in this work, such as feed temperature and preheating time and that the average removal rates of COD, BOD, oil content and phenol at 1000 mg/l and 55^{0}C with 45 min preheating time were 71%, 60%, 100%, and 100% respectively.

Tri Widjaja et.al.[40] operated the submerged membrane bioreactors combined with activated carbon for treating an industrial wastewater, having a COD concentration of 1500-2500mg/L and the composition consisting mainly of Glucose, Glutamate acid, CH_3COONH_4, $NaHCO_3$, NH_4Cl, KH_2PO_4, K_2HPO_4, $MgSO_4.7H_2O$, $MnSO_4.H_2O$, $FeCl_3.6H_2O$, $CaCl_2.2H_2O$, NaCl along with some trace nutrients. A polysulfone type membrane with a pore size of 0.01µm was used. It has been concluded that the fouling potential occurred at high MLSS where the COD removal was higher with adding 10% powdered activated carbon (i.e.94.8%) respectively.

N.O. Yigita et al.[41] used a laboratory scale zenon submerged hollow fiber membrane module made of polyethylene with pore size 0.04µm to treat a textile industrial wastewater. It is stated that with 14 h HRT and a 25 d SRT, the average concentrations of influent before treatment of color, turbidity, TSS, BOD_5, COD, NH_3-N, NO_3-N and TN were 2443 Pt Co, 294 NTU, 137 mg/L, 455 mg/L, 1411 mg/L, 11.2 mg/L, 42.6 mg/L and 49.2 mg/L respectively. The results showed that the effluent of textile industry treated with submerged membrane bioreactor having the average value of color, turbidity, TSS, BOD_5, COD, NH_3-N, NO_3-N and TN were 53 Pt Co, 0.31 NTU, 0.6 mg/L, 15 mg/L, 37 mg/L, 1.0 mg/L, 9.6 mg/L and 10.5 mg/L respectively.

Sami Sayadi et. al.[42] studied the start-up of a pilot-scale MBR equipped with submerged cross-flow ultrafiltration membrane bioreactor with consideration of microbial community dynamics to treat cosmetic wastewater. flat sheet membrane module with 38 cm in diameter, 63 cm in height, with an operating level of 58 cm, effective filtration area of 0.39 m^2, a cut-off 150 kDa were used in the study. The results showed that membrane filtration alone has a high effect on wastewater treatment, removing about 98.13% of Anionic Surfactant and 83.73% of COD at OLR of 1.5 g COD l^{-1} d^{-1} and HRT of 27 h. the results shows the performance of COD and surfactant removal in the different stage. In the above study, the polymeric chain reaction(PCR) and denaturing gradient gel electrophoresis(DGGE) method provided insights regarding the structures and dynamics over six months of bacterial communities of the bioreactor.

Gustavo Capannelli et al.[43] studied the performance of sMBR for treating a mineral oil storage tank wastewater containing. The hollow-fibre membrane used in this study was made of polypropylene with a pore size of 0.4 µm. The treatment performance was measured in terms of COD and hydrocarbon removal. High COD and hydrocarbon removal were reported ranging from 93 and 97%, respectively. The results show the concentration of COD and hydrocarbon at different HRT. The hydraulic retention times (2–3 days) used in this work where lower compared to those used in the activated sludge process.

Mustafa ASLAN et al.[44] conducted a pilot-scale test with an anaerobic submerged membrane (SAnMBR) system for treating slaughterhouse industry having COD 4600 mg/L. Hollow-fibre membrane modules with pore size of 0.1 µm with made up of polypropylene was used for the study. The average concentrations of COD, Volatile fatty acid(VFA), Total Nitrogen, Phosphorous, Oil and grease, MLSS and MLVSS in the effluent, were 4600 mg/L, 200-500mg $CaCo_3$/L, 150mg/L, 5mg/L, 1000mg/L, 1500-2200 mg/L and 1000-1300mg/L respectively. It has been shown that the SAnMBR successfully removed pollutants measured as COD, Volatile fatty acid(VFA), Total Nitrogen, Phosphorous, Oil and grease, MLSS and MLVSS from the slaughterhouse wastewater with an efficiency of over 95%, 34-45%, 30%,70% 97% and 95-98% respectively.

I.G. Wenten et. al.,[45] studied the performance of membrane bioreactor (MBR) for tapioca wastewater having COD of 4000-9000mg/L in continuous mode and batch mode operation. the Hollow-fibre ultrafiltration membrane with pore size of 100kDa with made up of polyacrylonitrile was used for the study. the experimental work was started with performance of membrane with its flux rate with highest concentration of MLSS i.e. 4500-10500mg/L. in batch mode operation COD is slightly decrease by low HRT.in a continuous mode, the COD was removed above 94% by using HRT for 24 hours. During this study MBR was severely suffered by membrane fouling in the 4^{th} day of operation. By using flushing, back flushing and chemical cleaning MBR gives 67% of flux was recovered.

Shyam Kodape et al.[46] studied the performance of sidestream MBR for treating an industrial wastewater by temperature varies between 30^0C,33^0C and 40^0C and having COD, $C_6H_{12}O_6.H_2O$, $CO(NH_2)_2$, $MgSO_4$, $CaCl_2$, KH_2PO_4, $FeCl_36H_2O$ as major constituents. Uniqflux hollow-fibre membrane with pore size of 0.01µm made up from polysulfone was used for the study. It has been shown that the sidestream MBR successfully removed pollutants measured as COD. The average removal rate of COD was 93% obtained at 30^oC with CFV 1.5 m/respectively. the results show the variation of COD removal in MBR system. The large COD removal, declining of flux and increasing in membrane fouling was due to the high concentration of MLSS.it was observed that the declining less flux tends to large permeate flux because of the high cross flow velocity(CFV).

A.H. Mahvi et al.[47] tested a performance of pilot-scale submerged MBR under the continuous inflow with synthetic municipal wastewater. Membrane used was made up of polypropylene with normal pore size of 0.1 µm and filtration area of 0.4 m^2. The performance of submerged MBR in order removal of organic compound and nitrogen. the performance was carried out for the different solid retention time i.e. 10, 20, 30 and 40 days. The results showed that the maximum removal rates of COD, total kejeldahl nitrogen removal, total nitrogen and phosphorous were 99.3%,98.1%, 85.5% and 52% respectively.

V. CONCLUSION

Based on extensive review of literature on the treatment of various wastewaters using MBRs system it is concluded that, the MBR system is widely used in well developed nations for treatment of industrial waste waters and it have removed 95% to 98% of the total pollution load. The international demand for the membrane filtration technology is fast rising at a compound annual growth rate (CAGR) of 13.2% [48].As compare to other waste water treatment technologies the growth rate of membrane filtration technology is mostly higher. also, the worldwide market is projected to rise double over the existing growth rate in the next five years. Still, research on MBRs and the use of MBRs for treatment of wastewaters is relatively rare in India due to the cost considerations. It is clear that the future market situation is guaranteed for the MBR technology and its fetching progressively viable. Basically, the MBR treatment technology count on the concentration of the biomass that contains the transmission of mass through the bioreactor and the membrane filtration level. Therefore, it is enormously significant to enumerate and recognize the factors restraining the mass transfer. Various researchers claim that the problem of fouling of membrane in the presence of organic matter and microbes are associated to, concentration of microbial products and sizes of particles. Various approaches for cleaning of membrane or backwashing are projected for direction to sustain a stable flux rate of permeate in the MBR systems

REFERENCES

1. *P. Senthur Pandy (2015). Treatment of Textile Effluent Using Submerged Membrane Bioreactor. Inter. Journal of Sci., Envi. and Tech., 4 (02): 305 – 317.*
2. *W.J. Ng (2006). Industrial Wastewater Treatment, World Scientific Publishing Company.*
3. *Ioannis Palogos, Panagiota Babatsouli, Costas Costa and Nicolas Kalogerakis (2014). Computer simulation of a submerged membrane bioreactor treating high COD industrial wastewater. Frontiers in Env. Sci. 2(30): 1-9.*
4. *Judd, Sand C. Judd (2006). Principles and applications of membrane bioreactors for water and wastewater treatment. The MBR book Elsevier.*
5. *Tan Vu. Luonga, S. Schmidtb, S.A. Deowanb, J. Hoinkisb, A. Figolic, F. Galianoc (2014). Membrane bioreactor and promising application for textile industry in Vietnam. 13th Global Conference on Sustainable Manufacturing Elsevier.*
6. *Judd.S and C. Judd (2007). The MBR Book: Principles and applications of membrane bioreactors in water and wastewater treatment, Elsevier publication.*
7. *Lee, N.H., G.Amy, J.P. Croue, and H. Buisson (2004), Identification and understanding of fouling in low-pressure membrane (MF/UF) filtration by natural organic matter (NOM), Water Research, 38 (20), 4511-4523.*
8. *Fang, H.H.P. and X.L. Shi (2005), Pore fouling of microfiltration membranes by activated sludge, Journal of Membrane Science, 264 (1-2), 161-166.*
9. *Stephenson, T., S. Judd, B. Jefferson, and K. Brindle (2000), Membrane bioreactors for wastewater treatment, IWA Pub., London, UK.*
10. *Mulder, M. (1996), Basic principles of membrane technology, Kluwer Academic, Dordrecht; Boston.*
11. *Adin, A (1999). Particle characteristics: A key factor in effluent treatment and reuse. Water Science and Technology, 40(4-5), 67-74.*
12. *Madaeni, S.S., A.G. Fane and D.E. Wily (1999), Factors influencing critical flux in membrane filtration of activated sludge, Journal of Chemical Technology and Biotechnology, 74 (6), 539-543.*
13. *Chang, I.S. and Lee, C.H (1998), Membrane filtration characteristics in membrane – coupled activated sludge system – the effect of physiological state of activated sludge on membrane fouling, Desalination, 120 (3), 221-233.*

14. *Chang, I.S., S.O. Bag and CH. Lee (2001), Effects of membrane fouling on solute rejection during membrane filtration of activated sludge, Process Biochemistry, 36, 855–860.*
15. *Amr M. Abdel Kader (2007). A review of membrane bioreactor (MBR) technology and their applications in the wastewater treatment systems. Eleventh International Water Technology Conference. Sharm El-Sheikh, Egypt, 269-279.*
16. *Bouhabila, E.H., Ben Aim, R. and Buisson, H. (1998) Microfiltration of Activated sludge using submerged membrane with air bubbling (application to wastewater treatment). Desalination, 118,315-322.*
17. *Bouhabila, E. H., Ben Aim, R., & Buisson, H. (2001). Fouling characterization in membrane bioreactors, Separation and Purification Technology, 22–23, 123–132.*
18. *Huang, X., Lui, R., & Qian, Y. (2000). Behavior of soluble microbial products in a membrane bioreactor, Process Biochemistry, 36, 401–406.*
19. *Huang. X, Gui P. and Qian Y. (2001) Effect of sludge retention time on microbial behaviour in a submerged membrane bioreactor. Process Biochemistry.36(10):1001-1006.*
20. *Lee, J., Ahn, W. Y., & Lee, C. H. (2001). Comparison of the filtration characteristics between attached and suspended growth microorganisms in submerged membrane bioreactor, Water Research, 35(10), 2435–2445.*
21. *Murakami, T., Usui, J., Takamura, K., & Yoshikawa, T. (2000). Application of immersed-type membrane separation activated sludge process to municipal wastewater treatment, Water Science Technology, 41(10 –11), 295–301.*
22. *Ogoshi, M., & Suzuki, Y. (2000). Application of MBR to an easily installed municipal wastewater treatment plant, Water Science Technology, 41(10 – 11), 287–29.*
23. *Shin H.S. and Park H.S. (1991). Enhanced nutrient removal in porous biomass carrier sequencing batch reactor (PBCSBR). Water Science and Technology. 23(4-6), 157-163.*
24. *C. Wisniewski, A. Grasmick, (1998) Floc size distribution in a membrane bioreactor and consequences for membrane fouling, Colloids Surf. A Physicochem. Eng. Asp. 138:403–411.*
25. *Choi, J. G., Bae, T. H., Kim, J. H., Tak, T. M., and Randall, A. A. (2002). The behavior of membrane fouling initiation on the crossflow bioreactor system, Journal of Membrane Science, 219, 1–11.*
26. *K.-H. Choo, C.-H. Lee, (1996) Membrane fouling mechanisms in the membrane-coupled anaerobic bioreactor, Water Res. 30:1771–1780.*
27. *Fan, X. J., Urbain, V., Qian, Y., & Manem, J. (2000). Ultrafiltration of activated sludge with ceramic membranes in a cross-flow membrane bioreactor process, Water Science Technology, 41(10 –11), 243–250.*
28. *Holler, S., & Trosch, W. (2001). Treatment of urban wastewater in a membrane bioreactor at high organic loading rates, Journal of Biotechnology, 92, 95–101.*
29. *J. Scott, K. Smith, (1997) A bioreactor coupled to a membrane to provide aeration and filtration in ice-cream factory wastewater remediation, Water Res. 31:69–74.*
30. *Kim, J. S., Lee, C. H., & Chang, I. S. (2001). Effect of pump shear on the performance of a crossflow membrane bioreactor, Water Research, 35(9), 2137–2144.*
31. *L. Defrance, M. Jaffrin, (1999) Comparison between filtrations at fixed transmembrane pressure and fixed permeate flux: application to a membrane bioreactor used for wastewater treatment, J. Membr. Sci. 152:203–210.*
32. *Messalem, R., Brenner, A., Shandalov, S., Leroux, Y., Uzlaner, P., Oron, G., & Wolf, D. (2000). Pilot study of SBR biological treatment and microfiltration for reglamation and reuse of municipal wastewater, Water Science Technology, 42(1–2), 263–268.*
33. *Scholz, W., & Fuchs, W. (2000). Treatment of oil contaminated wastewater in a membrane bioreactor, Water Research, 34(14), 3621–3629.*
34. *Xing, C. H., Tardieu, E., Qian, Y., & Wen, X. H. (2000). Ultrafiltration membrane bioreactor for urban wastewater reclamation, Journal of Membrane Science,177, 73–82.*
35. *Melin, T.; Jefferson, B.; Bixio, D.; Thoeye, C.; De Wilde, W.; De Koning, J.; Van der Graaf, J.; Wintgens, T. (2006). Membrane bioreactors technology for wastewater treatment and reuse. Desalination, Vol. 187, No. 1-3, (February 2006), pp. 271-282, ISSN 0011-9164.*
36. *Eclipse Membrane.http://eclipsemembranes.com/custom-module-design/potting-technology.html. 15/09/2017.*

37. *Forward Osmosis Tech. http://www.forwardosmosistech.com/tubular-forward-osmosis-membrane-modules/. 15/09/2017.*
38. *N. Fallah, B. Bonakdarpour, Nasernejad, M. R. Alavimoghaddam(2010). The use of a submerged membrane bioreactor for the treatment of a styrene containing synthetic wastewater, Iran. J. Environ. Health. Sci. Eng.,7(2),115-122.*
39. *Qusay F. Alsalhy, Riyadh S. Almukhtar, Harith A. Alani (2016). Oil Refinery Wastewater Treatment by Using Membrane Bioreactor (MBR), Arab J Sci Eng., 41, 2439-2452.*
40. *Tri Widjaja, Ali Altway, and Soeprijanto (2010) Performance of Submerged Membrane Bioreactor Combined with Powdered Activated Carbon Addition for the Treatment of an Industrial Wastewater.IPTEK, The Journal for Technology and Science21(1):18-22.*
41. *N.O. Yigita, N. Uzalb, H. Koseoglua, I. Harmana, H. Yukselerb, U. Yetisb,G. Civelekoglua, M. Kitisa (2009). Treatment of a denim producing textile industry wastewater using pilot-scale membrane bioreactor, Desalination, 240, 143-150.*
42. *Ines Friha, Fatma Karray, Firas Feki, Lobna Jlaiel, Sami Sayadi (2014). Treatment of cosmetic industry wastewater by submerged membrane bioreactor with consideration of microbial community dynamics, International Biodeterioration & Biodegradation, 88,125-133.*
43. *Federica Alberti, Barbara Bienati, Aldo Bottino, Gustavo Capannelli, Antonio Comite, Fiorenza Ferrari, Raffaella Firpo (2007). Hydrocarbon removal from industrial wastewater by hollow-fibre membrane bioreactors, Desalination,204,24-32.*
44. *Mustafa ASLAN, Halil ARI, Hakkı GULSEN, Hakan YILDIZ, Yusuf SAATCI (2013). Treatment of Slaughterhouse Wastewaters by Anaerobic Submerged Membrane Bioreactor, Turkish Journal of Science & Technology,8(1),29-36.*
45. *S. Subagjo, N. Prasetya, I.G. Wenten (2015). Hollow Fiber Membrane Bioreactor for COD Biodegradation of Tapioca Wastewater, Journal of Membrane Science and Research,1,79-84.*
46. *Shyam Kodape, V.S.Sapkal, R. S. Sapkal (2014). Study on Performance of Membrane Bioreactor (MBR) system at various temperatures for Wastewater Treatment, International Journal of Innovative Research in Advanced Engineering,1(7),108-116.*
47. *A. Naghizadeh, A.H. Mahvi, F. Vaezi, K. Naddafi (2008). Evaluation of hollow fiber membrane bioreactor efficiency for municipal wastewater treatment, Iran. J. Environ. Health. Sci. Eng., 5(4),257-268.*
48. *Er. Devendra Dohare and Er. Rohit Trivedi (2014). A Review on Membrane Bioreactors: An Emerging Technology for Industrial Wastewater Treatment.IJETAE.,4(12),226-236..*