International Journal of Scientific & Engineering Research, Volume 8, Issue 8, August-2017
ISSN 2229-5518

Design of Membrane Bio Reactor for Sewage Treatment Plant

Hilal Massoud Al-Sharji, Nedumaran Balasubramanian

Abstract— Wastewater is the water that are contaminated from source, hotel, restaurant, hospital and industry. Since the available potable water is limited, it is necessary to clean the wastewater for reuse. There are various way of cleaning the wastewater. Using of filter bioreactor is one possible technology. The sewage plants that operate on the filter bioreactor do not need a large space of area like other conventional plants. Since the simple type of the stations do not need of settling tank and they do not need dryer ponds, which need large areas for drying sludge. In addition to that, the membrane bioreactor (MBR) can install in small area unlike with normal filter system which require large area. Complete procedure for design of MBR system filter is discussed. The membrane bioreactor plant is dependent fully upon the ability of the filter, to get good quality of water. The ability of this type of filter in filtration using membrane unit 0.2-0.05 µm pore size range would give high quality water. The design of membrane depends upon the two main things analysis and the use purpose of water after treatment. The results decide the capacity of the membrane and which media can be used. Membrane bioreactor is friendly to the environment, because it does not take large, area and the quantity of sludge removed is very less comparing with regular plant. This study covers, the design of full membrane bioreactor (MBR) plant of capacity 200 m^3/day, including all the parameters requirements to design the plant such as the population of a residential area in order to determine the capacity of the plant, mathematical computations for designing.

Index Terms— Airlift Design Program, PVDF, Membrane Bio reactor

1 Introduction

Membrane Bio Reactor includes the use of semi-permeable membranes where it works on the separation of suspended solids and dissolved water and there are two ways to separate either through using hydraulic pressure (negative pressure) or by electrophoresis. The separation system under pressure is the most common where the contaminated water is forced to pass through the semi permeable membrane. This leads to reservation of pollutants to be removed, and only let treaded water exit. Also membrane separation techniques include pressing a number of membrane filtration systems, and in accordance with diameters of pores contained within the membrane. They influence the semi-material capable of passing there. They are classified as shown in Table.1. The mechanism of heavy metal ion removal in processes involving multi-layered tubular ultrafiltration and nanofiltration (UF/NF) membranes was investigated by conducting retention experiments in both flow-through and cross-flow modes. The prospect of the regeneration of the membranes through an acidic process was also examined and discussed. The UF/NF membranes were functionalised with alginates to develop hybrid inorganic/organic materials for continuous, single pass, wastewater treatment applications. The deposition and stabilization of alginates was carried out via physical (filtration/cross-linking) and chemical (grafting) procedures. The grafting process led to the development of alginate layers with adequate stability under acidic regeneration conditions and metal retention enhancement of 25–180%, depending on the silane involved as grafting agent and the solvent of silanisation [1]. The world's water is a finite and precious resource. It is continually used and reused in the water cycle for the benefit of us all and the sustainability of our environment. To obtain the full benefit we need to manage and protect it [12]. Moving Bed Biofilm Reactor (MBBR), [2] Jet Loop Membrane Bioreactor (JLMBR), [3] and the current status of all kind of membrane reactors [6] helps in development of Airlift Design.

Activated sludge process of 35 L working volume was used to investigate its applicability in industrial cheese whey wastewater. A loading rate of 22.2 kg COD/m^3/day and 1.6 days of sludge age was achieved with 97% COD removal efficiency. During the study, the activated sludge was found non-settable and slimy characteristic and non-flocculating motile bacteria structure. Therefore, it has been proved that the membrane separation is indispensable to obtain high performance from jet loop bioreactor (JLB). From the investigation of crossflow microfiltration characteristic of the system, it was found that the fluxes decreased and MFI increased with increasing mixed liquor suspended solid (MLSS) concentration. The increasing crossflow velocity greatly reduced the cake formation on the membrane surface and increased the steady state permeate fluxes, decreasing specific cake resistance (α) values. The cake layer was in a highly compressible form. The

- *Hilal Massoud Al-Sharji, Department of Mechanical and Industrial Engineering, Caledonian College of Engineering, (Haya Water, O&M), Muscat, Sultanate of Oman, alhleem-86@hotmail.com*
- *Nedumaran Balasubramanian, School of Mechanical, Chemical and Materials Engineering, Adama Science and Technology University, POBox 1888, Adama, Ethiopia, nedumaran_b@yahoo.co.in*

International Journal of Scientific & Engineering Research, Volume 8, Issue 8, August-2017
ISSN 2229-5518

compressibility coefficient was calculated as 0.98. In addition to this, the pseudo gel concentration on the membrane surface was estimated to be 73,130 mg/L. Fouling mechanism showed high compatibility with complete pore blocking model and particularly cake filtration model [4].

Combining membrane technology with biological reactors for the treatment of municipal and industrial wastewaters has led to the development of three generic membrane processes within bioreactors, for separation and recycle of solids, for bubble-less aeration of the bioreactor, and for extraction of priority organic pollutants from hostile industrial wastewaters. Biosolid separation is, however, the most widely studied and has found full-scale applications in many countries. The commercial application of the biosolid-separation membrane biological reactor, which is commonly known as membrane bioreactor [5].

An integrated numerical approach was developed and implemented to study the hydrodynamic characteristics of pilot plant systems of membrane bio-reactor (MBR). The approach incorporated Eulerian multiphase model, porous medium scheme, and also successfully took into account the vertically dependent filtration flux and the effect of mixed liquor suspended solids (MLSS) on mixed liquor viscosity. Utilizing this integrated numerical approach, a clear distinction of up-flow and down-flow regions within the single module had been simulated. The simulated mixed liquor velocity and air hold-up agreed well with published experimental measurements and theoretical estimation, respectively. However, when a total of 160 modules were consolidated into an actual plant operation, the average mixed liquor and air velocities of each module encountered a drop of approximately 50–80% lower compared to the pilot system. With this minor design modification, the mixed liquor and air velocities were improved by 50% and noticeable up-flow and down-flow circulations were achieved [7]. The performance of ultrafiltration (UF) and nanofiltration (NF) membranes on disinfection by-products (DBPs) precursor removal in a surface water having low-to-medium dissolved organic carbon (DOC) and specific ultraviolet absorbance ($SUVA_{254}$) levels was evaluated. While higher molecular weight (HMW) DOC fraction was successfully rejected (>90%), lower molecular weight (LMW) fraction could be removed only 1.5–30% by the tested four different membranes. This finding suggested that although NF and UF membranes with pore sizes of ≤1000 Da are highly effective on the removal of HMW NOM from waters having low-to-medium DOC and $SUVA_{254}$ levels, such membranes are not effective in these waters in rejecting LMW fractions (i.e., <2000 Da) [8].

Porous ceramic membranes of various pore sizes (0.05–5.0 μm) were evaluated with synthetic electroplating wastewater containing $Cr(OH)_3$ suspension. Filtration experiments with and without backpulsing show that backpulsing is effective in minimizing membrane fouling. Up to five-fold increase in steady-state permeate flux and 100% flux recovery were observed. Pilot and commercial scale operating results on several industrial applications, such as yeast filtration, process slurry filtration and oily wastewater filtration are presented and backpulsing in reducing long-term membrane fouling while allowing the realization of high product recovery. Optimization of process parameters with backpulsing typically results in higher flux and reduces the total capital cost required to achieve the desired production rate [9].

The viscosity of activated sludge plays a major role on oxygen transfer and mass transport and consequently influences the hydrodynamic regime and the system performance of a membrane bioreactor (MBR). The study of rheological characteristics of activated sludge were sampled in a pilot airlift MBR system for domestic wastewater treatment under ambient desert conditions, using a rotational rheometer equipped with cone-plate geometry. Both static and dynamic yield stresses were observed at the transition point of 25 s^{-1} of shear rate for an MLSS concentration range of 2.74–10.2 g/L. The relationships between viscosity, MLSS, temperature and shear rate were obtained statistically. The activation energy for the viscosity of the sludge in the airlifts MBR was found to be 9.217 kJ mol^{-1}, and could be the cause of rapid fluctuation of transmembrane pressure with temperature variations [10]. A novel membrane process, airlift crossflow filtration, is developed using the airlift effect to drive liquid flow tangentially across the membrane surface whilst simultaneously making use of the enhancing effect of gas bubbles on membrane performance. The compressed air also provides the transmembrane pressure for the filtration operation. The feasibility of this new concept was demonstrated by the ultrafiltration of a dextran solution, proving that higher permeate fluxes can be achieved with a very low gas injection rate. Compared to conventional single phase crossflow operation at the same liquid flowrate, about a 30% increase in permeate flux was obtained with the airlift crossflow operation without the need of a recirculation pump. A specific design comprising a tubular membrane module with internal circulation was presented. Evaluation of the process energy requirement indicated that this would be a low energy cost process compared to conventional single phase crossflow operation, whilst also saving process capital cost due to the elimination of a recirculating pump. Hence, this process is particularly attractive to cost-sensitive processes such as waste effluent treatment [11].

Attempt at obtaining an order-of-magnitude estimate of the global burden of disease (GBD) of human infectious diseases associated with swimming/bathing in coastal waters polluted by wastewater, and eating raw or lightly steamed filter-feeding shellfish harvested from such waters. Such diseases will be termed thalassogenic - caused by the sea. Until recently these human health effects have been viewed primarily as local phenomena, not generally included in the world agenda of marine scientists dealing with global marine pollution problems. The massive global scale of the problem can be visualized when one considers that the wastewater and human body wastes of a significant portion of the world's population who reside along the coastline or in the vicinity of the sea are discharged daily, directly or indirectly, into the marine coastal waters, much of it with little or no treatment. Every cubic metre of raw domestic wastewater discharged into the sea can carry millions of infectious doses of pathogenic microorganisms. It is estimated that globally, foreign and local tourists

International Journal of Scientific & Engineering Research, Volume 8, Issue 8, August-2017
ISSN 2229-5518

together spend some 2 billion man-days annually at coastal recreational resorts and many are often exposed there to coastal waters polluted by wastewater. Annually some 800 million meals of potentially contaminated filter-feeding shellfish/bivalves and other sea foods, harvested in polluted waters are consumed, much of it raw or lightly steamed. A number of scientific studies have shown that swimmers swallow significant amounts of polluted seawater and can become ill with gastrointestinal and respiratory diseases from the pathogens they ingest. Globally, each year, there are in excess of 120 million cases of gastrointestinal disease and in excess of 50 million cases of more severe respiratory diseases caused by swimming and bathing in wastewater-polluted coastal waters. Filter-feeding shellfish/bivalves, which are often harvested from wastewater-polluted areas of the sea, can effectively filter out and concentrate the microbial pathogens in the seawater. It can be roughly estimated that annually there are some 4 million cases of infectious hepatitis A and E (HAV/HEV), with some 40 thousand deaths and 40 thousand cases of long-term disability, mainly chronic liver damage, from consuming raw or lightly steamed filter-feeding shellfish/molluscs harvested globally from polluted coastal waters. The total global health impact of the thalassogenic diseases - human infectious diseases associated with pathogenic microorganisms from land-based wastewater pollution of the seas--is estimated to be about 3 million 'disability-adjusted life years' (DALY)/year, with an estimated economic loss of some 12 billion dollars per year. Due to the preliminary nature of the estimates in this study it is appropriate to assume that all of the above figures are no more than first approximations and that the true figures may be 50% higher or lower. Nevertheless, it is the author's belief that this study indicates that wastewater pollution of the sea results in a multi-billion dollar per year health burden and that preventing wastewater pollution of the sea is worthy of inclusion on the global agenda of marine pollution prevention and control [13].

TABLE 1
TYPE OF MEMBRANE

MF	Microfiltration
UF	Ultra filtration
NF	Nano filtration
RO	Reverse Osmosis

Membrane Ultra filtration as shown in real view of Figure 1 is a low pressure-driven mechanical process for separating and concentrating suspended solids, colloids and high molecular weight materials in solution. Ultra filtration membranes are tubular filters as shown in the Figure 1, which rejects, starch and some pigments while allowing water to pass through. The unique design uses the wash water to flow over the membrane surface at a precise flow rate and pressure, which keeps the surface clean from debris to build up. (Unlike conventional filters which have dead end and clog up) This process is referred to as “cross flow”. The concentrated is referred to as “concentrate” while the clarified water produced for wash-up water recycle is referred to as “permeate”. The waste effluent is pumped through the tubular membranes, and is progressively concentrated until almost all the original water is removed. Upon completion of a batch, the membrane tubes are cleaned in position using the same process pump with a simple soap solution and unique sponge ball insertion feature, then returned back into service. The membrane tubes are rugged and durable, and designed to withstand the rigors of an industrial environment. With proper care they can be used hundreds of times without maintenance or repair.

The basic principle parameters for designing the ultrafiltration membrane bio reactor: TMP Excursion at Initial Concentration (Cb initial); Determine TMP for UF/DF; Determine Feed Flow (QF) for UF/DF; Demonstrate Flux Stability; Confirm Retention of Product. TMP Excursion at Final Concentration (Cb final).; Determine TMP for UF/DF; Determine Feed Flow (QF) for UF/DF; Confirm Retention of Product; Concentration /Volume Reduction (Cb initial → Cb final); Determine Flux as Function of Concentration; Determine Placement of Diafiltration Step; Determine Flux as Function of Buffer Conditions; Diafiltration / Buffer Exchange; Determine dia height and volume requirement; Confirm Retention of Product during DF; Product Recovery; Crude Assessment of Step Yield; Product Quality Evaluation.

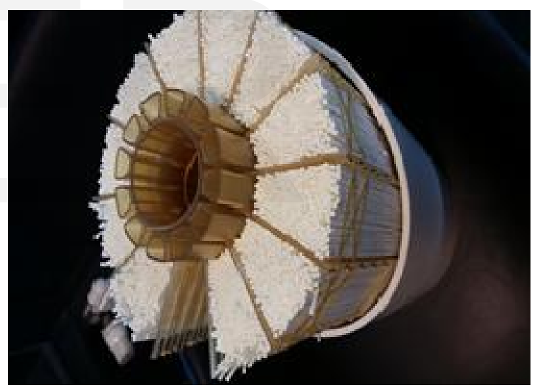

Fig. 1 Photo of ultra-filtration membrane bio reactor module madeup of Poly vinyly di Fluride (PVDF)

2 PROCESS DESIGN OF AIRLIFT MBR SYSTEM

The airlift UF membrane system as shown in Figure 2 is a part of the MBR process and is applied to separate the mixed liquor from treated effluent. The UF membrane system is fed with the mixed liquor from the bioreactor by means of a recirculation pump. This recirculation pump is also used to maintain relatively constant flow of mixed liquor from the bottom to the top side of the vertically positioned UF membranes, which are vertically placed. The three meter high membrane elements comprise tubular membranes with a typical diameter of 5.2 mm. with a total of 32 m^2 of membrane area. These membrane tubes are operated inside-out, i.e. mixed liquor is introduced at the lumen of the tubular membranes and extracted as per-

International Journal of Scientific & Engineering Research, Volume 8, Issue 8, August-2017
ISSN 2229-5518

meate at the shell side. The bottom side and the top side of the membrane element are covered by an end cap. The bottom end cap is equipped with an air distribution system (aerator). Figure 2 shows a schematic layout of the Airlift MBR system. In an Airlift membrane system, the membrane modules are vertically positioned. This vertical orientation of the membrane modules allows using of air injection in the bottom end cap to maintain a gentle cross flow through the membrane module. Due to this principle, the mixed liquor is transported via an "Air-Lift" pump through the membrane modules. In addition, the injected air causes a very high turbulence at the membrane surface and this ensures a continuous cleaning action and subsequent constant system flux at a very low transition membrane pressure. While using the reliable and proven technology of cross-flow tubular membranes, the benefit of this Airlift system design is that the energy consumption is significantly lower than the cross-flow system. The filtrate (permeate) production of the airlift system is measured by a flow transmitter and controlled by an automatic control valve and/or permeate pump to meet the set-point production flow. A part of the produced permeate is used for backwashing and cleaning operations of the UF membrane elements in the system. For this purpose, the system is equipped with a backwash pump and dosing pumps

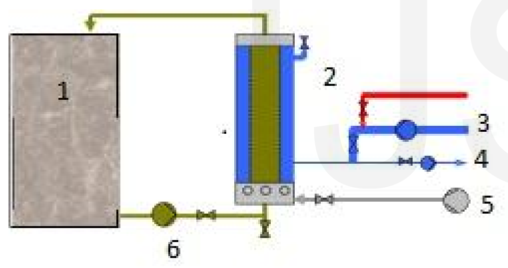

Fig. 2 Schematic representation of the Airlift MBR concept, 1- wastewater tank, 2-MBR skid, 3,4 pure water outlet, 5-compressed air inlet

The membranes are usually made from organic polymers or ceramic materials. The polymers are characterized for low cost in production, but are facing problems in the variation in the size of membrane pores. Hence they are more susceptible to clogging and pollution. The ceramic membrane provides high quality and long lifespan but is not considered an economical solution in the treatment of large quantities. They are considered an acceptable solution in industrial applications. All manufacturers of MBR they use polymers in membrane design.

2.1 Design, Experimental Setup and Methodology

The setup and methodology of the study shall be divided in to four parts:

- Choice of area with number of population. From the number of population in the chosen area we will be calculate the average daily use of each person in m3/day; and multiplay this with the total number of the population to get the capacity of the design plant.
- Lab experimental setup.
  - Collection of sewage water samples from the chosen area.
  - After collection of the sample, necessary lab experiments will be carried out and for COD, TSS, MLSS, BOD, DO and pH.
  - The aim of doing these experiments is to check the volume of the MLSS which is important in membrane design and to check other quantitation from other experiments.
  - The design and type of the membrane module depends upon the result of lab experiments. The capacity of the membrane will depends up on the capacity of the plant, also the media of the membrane well depends upon the result of lab experiments.
  - Mathematical calculations of the plant by using special software program for build and simulation to reach to skid shape of MBR, as shown in figure 3.

2.2 MBR Modeling

After identified the bio reactor, then MBR membrane module can be identified and selected with, Airlift _design _ tool _rev3.8 program to choose the type of membrane according to the type of the source of water and the information of bio reactor and the use of permit water after filtration? The aim of the project to design ultra-filtration membrane bioreactor MBR to treat municipal water and tow reuse the permit water for irrigation purpose under a class standard of Ministry of municipal administration.

This program is given liberty for choosing the membrane type as shown in the figures 4, and 5. The filtrate (permeate) production of the Airlift system is measured by a flow transmitter and controlled by an automatic control valve and/or permeate pump to meet the set-point production flow. A part of the produced permeate is used for backwashing and cleaning operations of the UF membrane elements in the system. For this purpose the system is equipped with a backwash pump and dosing pumps.

TABLE 2
FLOW DATA

Parameter	Unit	Design	Remarks
Flow	m^3/d	200	Based on Max Flow
Average Flow	m^3/h	8.3	
Peak factor		1.5	
Peak duration	h	2	
Peak flow	m^3/h	12.50	Expected water buffercapacity, m3

International Journal of Scientific & Engineering Research, Volume 8, Issue 8, August-2017
ISSN 2229-5518

2.3 Membrane simulation

After selecting the type of membrane module, the modeling and calculation can be done by using Pentair projection tools-Dead End V-1, This program is specialize for build and simulation .The data of MBR module and bioreactor are entered in projection tools program as shown in figure 6.

2.4 Process simulation

In the figure 7, process description of the Airlift UF membrane system is a part of the MBR process and is applied to separate the mixed liquor from treated effluent. The UF membrane system is fed with the mixed liquor from the Bioreactor by means of a recirculation pump. This recirculation pump is also used to maintain a relatively constant flow of mixed liquor from the bottom to the top side of the vertically positioned UF membranes. The three meter high membrane elements comprise tubular membranes with a typical diameter of 5.2 mm. with a total of 32 m^2 of membrane area. These membrane tubes are operated inside-out, i.e. mixed liquor is introduced at the lumen of the tubular membranes and extracted as permeate at the shell side. The bottom side and top side of the membrane element are covered by an end cap. The bottom end cap is equipped with an air distribution system (aerator).

In an Airlift membrane system the membrane modules are vertically positioned. This vertical orientation of the membrane modules allows using air injection in the bottom end cap to maintain a gentle cross flow through the membrane module. Due to this principle the mixed liquor is transported,

Fig. 3 The membrane skid system view

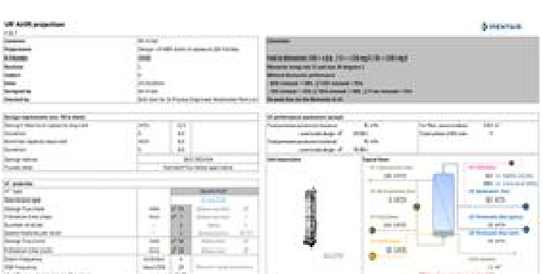

Fig. 4 UF Airlift projction

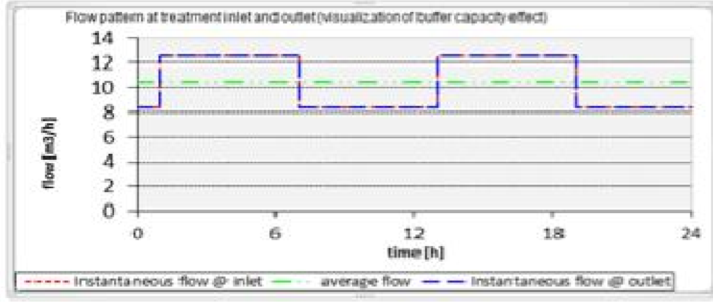

Fig. 5 Configuration UF unit

through an "Air-Lift" pump through the membrane modules. In addition the injected air causes a very high turbulence at the membrane surface and this ensures a continuous cleaning action and subsequent constant system flux at a very low Tran's membrane pressure. While using the reliable and proven technology of cross-flow tubular membranes the benefit of this Airlift system design is that the energy consumption is significantly lower than the cross-flow system. The filtrate (permeate) production of the Airlift system is measured by a flow transmitter and controlled by an automatic control valve and / or permeate pump to meet the set-point production flow. A part of the produced permeate is used for backwashing and cleaning operations of the UF membrane elements in the system. For this purpose the system is equipped with a backwash pump and dosing pumps.

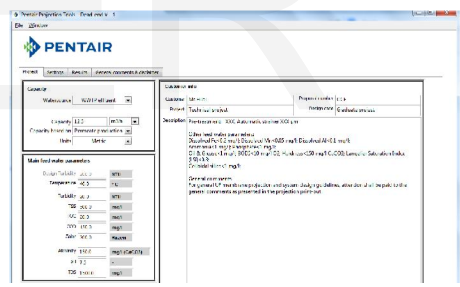

Fig. 6: Membrane Modeling and simulation.

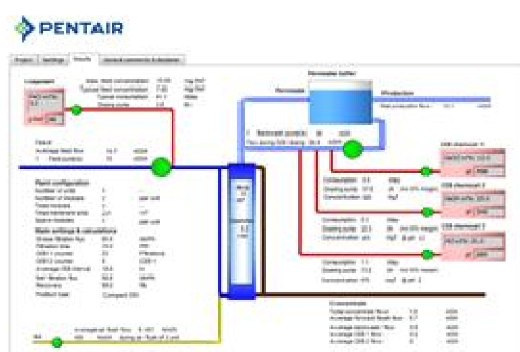

Fig. 7: Process simulation

International Journal of Scientific & Engineering Research, Volume 8, Issue 8, August-2017
ISSN 2229-5518

3.0 Results and Discussions

MBR membrane module of 8 inch, is used for MBR membrane bio reactor application for industrial and communal waste water filtration. Mode of operation is the H-flow Airlift, as shown in table 2. Combined with regular backwash, chemically enhanced backwash and advanced draining procedure.

3.1 UF configuration.

Each membrane skid comprises a fixed amount of membrane positions, however not all of these positions are necessarily filled with membrane modules, as shown in table 3 and table 4. Each membrane skid is controlled individually, i.e. all operating programs such as filtration, backwash, drain procedure and CEB are performed on a skid level. All the membrane skids in one section are backwashed consecutively, i.e. in a so called "stream backwash".

3.2 Pilot Plant Test

Data obtained from pilot plant test is compared with simulation results. As shown in below Figure-8 the pilot plant for testing. This pilot plant is prepared for testing the MBR process as full plant with providing all instruments and mechanical and membrane skids, in addition to that the control panel connected with digital monitor screen. All out valves are work by pressure. The MBR skid is installed in vertical ship, the mix liquid well pressures from the bottom and permit water will permit from the top. To run the process in pilot plant, first we enter all the data required and select the number of membrane skid as per how many we got it from the Airlift _design _ tool _rev3.8 program is tow number of MBR skids. The mix liquor is provided from conventional plant to the bio rector.

TABLE 3
UF FILTER CAPACITY

Parameter	Unit	Design	Remarks
Maximum capacity required	m^3/h	13	Based on Max Flow
Maximum Flow duration	h	6	
Nominal capacity required	m^3/h	8	
Nominal Flow duration	h/d	6	
Required daily throughput	m^3/d	250	Expected water buffer capacity, m^3

4 Conclusion

Membrane bioreactor (MBR) plant is a physical and chemical process which is essential to get clean, fresh water free of germs and bacteria for re-use. We may also enjoy clean and non-staining window. We expect, in the near future, to obtain a friendly source of energy from sludge which is extracted from water. This research will introduce a new idea for removal of the organic substances which are suspended in wastewater. Comparing with conventional plant, MBR plant has lesser area of installation required and also in terms of number of units required and lower energy consumption for ultra-filtration of water purity and silent plant with no noise it can instill within residential neighborhoods.

Acknowledgment

Authors greatly acknowledge for the encouragement, facility and support provided by Caledonian College of Engineering, Oman. This research was supported by Caledonian College of Engineering, Environmental Engineering Services Company, Pentair Company and Haya Water Oman wastewater service company (SAOC).

TABLE 4
UF CAPACITY

Parameter	Unit	Design	Remarks
UF Type	-	PVDF	
Membrane Type	-	5.2mm PVDF	
Membrane area per module	m^2	33	
Max module per unit	-	6	
Max module per BW segment	-	6	Required for BW Flow
Spare module per unit	-	2	33%
Number of skids Total installation	-	32	
Required number of BW section	-	3	Max unit/segment/bioreactor=14
Actual area per unit	m^2	132	Max 198 m^2
Actual area of Installation	m^2	4224	Max 6336 m^2

International Journal of Scientific & Engineering Research, Volume 8, Issue 8, August-2017
ISSN 2229-5518

Fig.8 MBR pilot plant test white columns represent membrane skid

REFERENCES

[1] Athanasekou, C. P. Romanos, G E. Kordatos, K. Kasselouri-Rigopoulou,V. Kakizis, N. A. and Sapalidis, A. A. "Grafting of alginates on UF/NF ceramic membranes for wastewater treatment". *Journal of Hazardous Materials.* vol. 182, no. 10, pp. 611–623, 2010.

[2] Baki, M. and Alwan, A. "Wastewater Treatment in Baghdad City Using Moving Bed Biofilm Reactor (MBBR) Technology", *Journal of ENG&TECH*. vol. 30, no. 3, p 9, 2012.

[3] Calabro, Iorio, G. "Economic aspects of membrane bioreactors". *Handbook of Membrane Reactors: Reactor Types and Industrial Applications*, vol. 2, no. 9, pp. 888–911, 2013.

[4] Farizoglu, B. B. Keskinler, "Sludge characteristics and effect of crossflow membrane filtration on membrane fouling in a jet loop membrane bioreactor (JLMBR)", *Journal of Membrane Science,* vol. 279, no. 8, pp. 578–587, 2006.

[5] Hai, F. I., K. Yamamoto, "Membrane Biological Reactors". *Treatise on Water Science,* Elsevier, vol. 4, no. 7, pp. 571–613, 2011.

[6] Judd, S., "The status of membrane bioreactor technology". *Journal of Trend in biotechnology,* vol. 26, no. 2, pp 109–116, 2008.

[7] Kang, C. W., Hua J. S., Lou J., Liu W. and Jordan E., "Bridging the Gap between Membrane Bio-reactor (MBR) Pilot and Plant Studies", *Journal of Membrane Science*, vol. 325, pp. 861–871, 2008.

[8] Nuray Ates, Levent Yilmaz, Mehmet Kitis, Ulku Yetis, "Removal of disinfection by-product precursors by UF and NF membranes in low-SUVA waters". *Journal of Membrane Science*, vol. 328, no. 2, pp. 104–112, 2009.

[9] Sondhi, R. Bhave, R. "Role of backpulsing in fouling minimization in crossflow filtration with ceramic membranes", *Journal of Membrane Science,* vol. 186, no. 5, pp. 41–52, 2001.

[10] Yang, F., Bick, A., Shandalov, S., Brenner, A., Oron, and G., "Yield stress and rheological characteristics of activated sludge in an airlift membrane bioreactor", *Journal of Membrane Science*. vol. 334, no. 1-2, pp. 83–90, 2009.

[11] Cui, Z. F., Bellara, S. R. and Homewood, "Airlift cross flow membrane filtration — a feasibility study with dextran ultrafiltration", *Journal of Membrane Science,* vol. 128, pp. 83–91, 1997.

[12] Khan, Rashid I. A., Shrivastava Shilpi, "Recycling of wastewater", International transection *Applied Sciences*. vol. 3, no. 3, pp. 417, 2011.

[13] Shuval H, "Estimating the Global Burden of Thalassogenic Disease-Human Infectious Disease caused by Wastewater Pollution of the Marine Environment", *Journal of Water and Health*, vol. 2, no. 1, pp. 53-64. 2003