Study the Potential of Biological Growth on Dead-end Hollow Fiber Membrane using Oilfield Effluent

Noura Ali Al Balushi[1,*], Shabib Al Rashdi[1], Shima Al Saadi[2] and Syed M Rizwan[1]

[1]National University of Science and Technology Muscat, Oman

[2]RWTH Aachen University Germany

Abstract: Oil and gas-producing countries are suffering from water resource depletion without any treatment or with technologies that have the same impact, regardless of how expensive or large a land area required. On the other hand, domestic wastewater also has many treatment technologies, and biological full cell is one of them. Using an end-of-tube hollow fiber membrane in domestic wastewater allows biological microorganisms to grout and treat the water, whereas using oil-filled water has not been studied so far. This study addresses the potential of biological growth on two different types of dead-end hollow fiber membranes by using three samples of oilfield water *i.e*., Membrane Aerated Biofilm Reactor OxyMem and MEMCOR® Ultrafiltration. The Membrane Bioreactor Systems are selected for the current studies and scanning electron microscopy (SEM) is used to show the biological growth on selected types of membrane to treat the oilfield wastewater. As a result, the growth in OxyMem is better which is 54% of COD removal and 55% NT removal for 55 days, whereas MEMCOR shows comparatively less growth in SEM results with 33% of COD removal and 9% NT removal during the same period. Therefore, this confirms that both types of membranes can be used to treat oilfield water in biological cells and noticed a better performance in OxyMem compared to MEMCOR.

Keywords: Biological Growth, OxyMem, MEMCOR oilfield Effluent, Hollow fiber membrane.

1. INTRODUCTION

Five Mbbl/day of water are produced in Oman (PDO), compared to 550,000 bbl/day oil. Produced water contains a variety of different elements, such as iron, suspended particles, organic and inorganic pollutants, and toxins. The weight percentages of these contaminants vary from one oil production well to another depending on the well's type, age, and production conditions. The produced water might have radioactive particles in it, which would be bad for the environment.

Chemical Properties of Oilfield Effluent

Salt content Salinity, conductivity, or total dissolved solids (TDS) are frequently used to express salt content. The majority of produced water is saltier than salt water (35,000 mg/L) and can be over 300,000 mg/L, despite the fact that some of it are almost fresh (3,000 mg/L TDS) [1].

Organic chemicals many methods have been developed to assess the organic content of wastewater. Chemical oxygen demand (COD), total organic carbon (TOC), and biochemical oxygen demand (BOD) are three standard laboratory techniques for calculating the quantity of organic matter in wastewater (TOC). VOCs are vaporized organic carbons. In industrialized and commercialized areas, volatile organic pollutants like benzene, toluene, xylenes, dichloromethane, and trichloroethylene are frequent soil pollutants.

Inorganic chemicals free ammonia, organic nitrogen, nitrites, nitrates, organic phosphorus, and inorganic phosphorus are the main chemical assays. Because these two nutrients are necessary for the development of aquatic plants, nitrogen and phosphorus are crucial nutrients. Other tests, including those for chloride, sulfate, pH, and alkalinity, are carried out to determine if treated wastewater may be reused and to regulate the different treatment procedures.

Produced Water Management Technologies/ Treatments De-oiling (removal of dispersed oil and grease), desalination, removal of suspended particles and sand, removal of soluble organics, removal of dissolved gases, removal of naturally occurring radioactive materials (NORM), disinfection, and softening are the general goals for operators treating produced water (to remove excess water hardness). To achieve these goals, operators have used a variety of standalone and combined physical, biological, and chemical treatment procedures for generated water management [1-3]. As a result, Membrane fouling becomes a severe matter of membrane operation that impacts the system's durability and cost and need to be improved [4].

*Address correspondence to this author at the National University of Science and Technology Muscat, Oman; Tel: 00968122641109;
E-mail: nouraalbalushi@nu.edu.om

E-ISSN: 2410-1869/23

A. Biological Aerated Filters

The term "biological aerated filter" (BAF) refers to a group of biological technologies that use the permeable medium in aerobic environments to promote biochemical oxidation and the removal of organic contaminants from contaminated water. The media has a maximum diameter of 4 inches to avoid pore spaces becoming clogged when sloughing takes place. Oil, ammonia, suspended particles, nitrogen, COD, BOD, heavy metals, iron, soluble organics, trace organics, and hydrogen sulfide can all be eliminated by BAF from generated water. It works well when producing water with chloride concentrations under 6600 mg/l [30]. To utilize the entire filter bed during this procedure, upstream and downstream sedimentation are needed. Up to 70% of nitrogen, 80% of oil, 60% of COD, 95% of BOD, and 85% of suspended particles can be removed with BAF treatment [5, 6]. Since the waste produced is removed in solid form, the water recovery from this method is almost 100%. BAFs typically live a long time. During routine operations, no chemicals or cleaning are needed.

It uses 1-4 kWh of power every day, and capital costs make up the majority of the price of this technology. Solids disposal in sedimentation basins is required for collected sludge and can account for up to 40% of total costs [7, 8].

B. Membrane Biofilm Fuel Cell

A microbial fuel cell (MFC) is a bio electrochemical device that produces power using electrons from the anaerobic oxidation of substrates [9]. An anode and a cathode are typically connected by a proton exchange membrane, which makes up the MFC (PEM) [5]. Cells can be designed in many shapes. Two types of membranes were used to test the ability of such membranes in treating oilfield wastewater in Oman. They are manufactured by “DupOnt Water Solutions” Company. The specification of each membrane is summarized in following sections [10].

1). Membrane Aerated Biofilm Reactor OxyMem

The Membrane Aerated Biofilm Reactor is an Aeration system that is specifically designed to allow low energy oxygen delivery from the carrier side to biofilms (fixed films). As well as acting as a support for biomass, OxyMem MABR's silicone fibers (460-μm outer diameter) deliver oxygen efficiently, making it a unique attached growth biofilm system.

It creates an ideal habitat for the growth of an extremely resilient biofilm that is capable of withstanding hydraulic shock loads and process upsets. Oilfield waters show good growth on it [12]. Carbon and nitrogen-based pollutants are absorbed and consumed by the biofilm, but it is astonishingly energy-efficient compared with conventional fixed film/biofilm systems [3, 11].

2). MEMCOR® Ultra Filtration and Membrane Bioreactor Systems

The MEMCOR® system is based on the MEMCOR Ultrafiltration System, which has been implemented successfully in tens of thousands of places throughout the globe. The high performance MEMCOR CS system is the ideal alternative for reused wastewater, RO pretreatment, municipal and industrial water supply. With MEMCOR membrane technology, which also minimizes the size and energy needs of the plant, large capacity treatment systems may be constructed inexpensively. Membranes are manufactured from polyvinylidene fluoride as hollow fibers (PVDF). The manufacturing process ensures that the fiber wall pores have a nominal size of 0.04 microns. It is used to treat water in Membrane Bioreactor (MBR) Systems.

2. MATERIAL & METHODOLOGY

a. Material

In this study, a hollow-fiber membrane from Oxymem Ltd., County Westmeath, Ireland, made of silicone fibers with a 460-μm outer diameter and the MEMCOR® Ultrafiltration and Membrane Bioreactor System made of polyvinylidene fluoride (PVDF) with a nominal pore size of 0.04 microns were used. Water samples from two different locations (the north and south of Oman) have been collected From Petroleum development Oman Company (PDO).

b. Flow Cell Design

A flow cell designed with dimensions of 5 cm in width, 2 cm in height, and 10 cm in length was used with various flow rates. Figure **1** depicts the system's components, which include the membrane, a reservoir, a flow cell, an air compressor, and a peristaltic pump. Transparent pipes were used to link a recycle reservoir with a 1 L volume to the flow cell's intake and exit. The rate at which wastewater entered and left the Reservoir was measured using a peristaltic pump. With a pressure of 0.2 bars, air was provided through the dead-end-operated hollow fiber membrane. A 108 mL

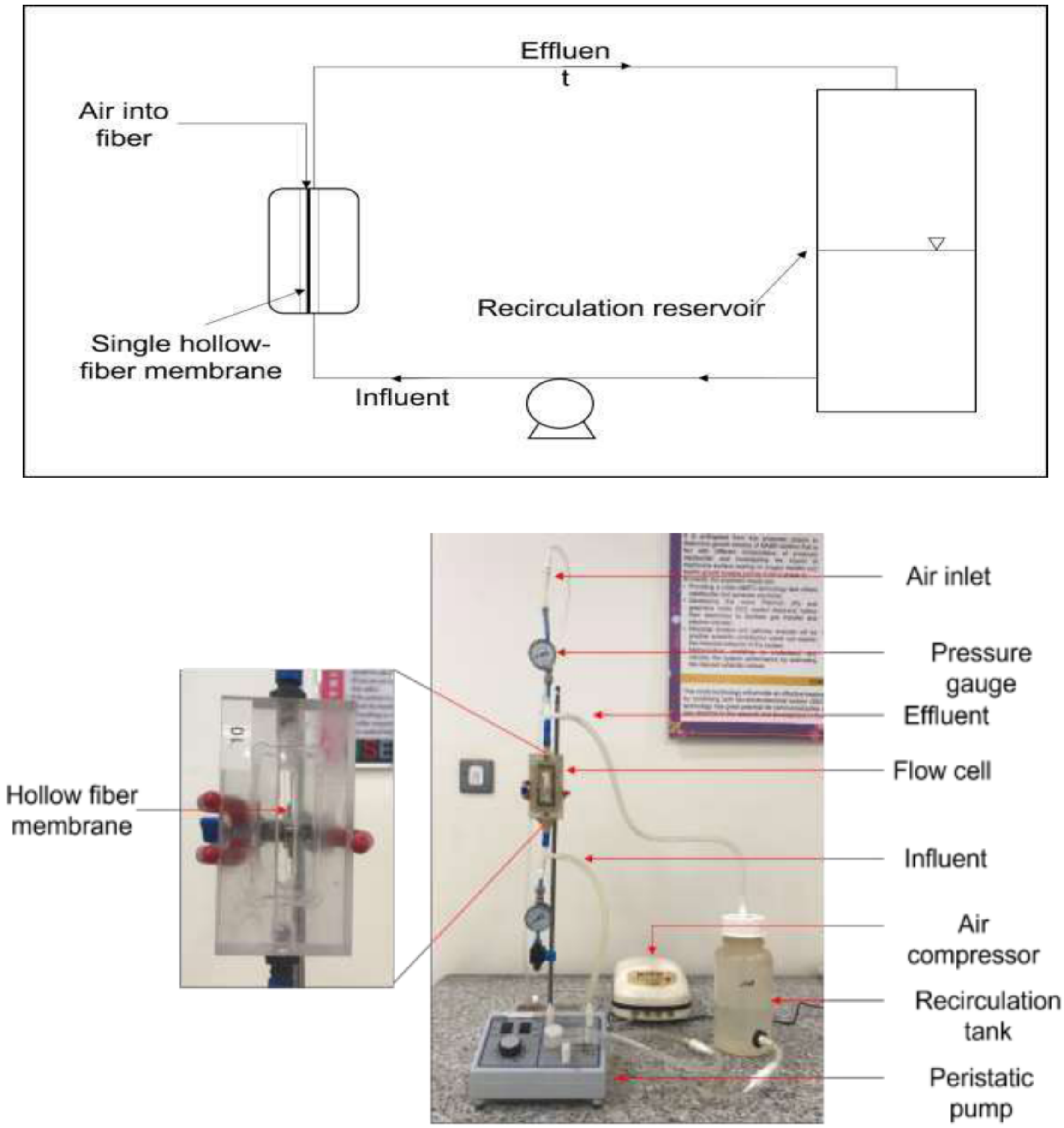


Figure 1: Flow diagram and set up of MBfR system.

per minute influent flow rate was used to generate a hydraulic retention time (HRT) of 60 minutes. The system operated at 25 °C, or room temperature. For 50 to 60 days, the effluent was continuously cycled through the flow cell.

Conditions and Analytical Method

Two separate MBfRs were used to analyses two bulk liquids from two independent sites (the north and south of Oman). Total nitrogen and chemical oxygen demand (COD) were assessed to compare the water quality before and after the experiments. Each experiment used an intramembranous pressure of 0.2 bars. In trials 1 and 2, the influent COD concentrations were, respectively, 319 mg/L and 259 mg/L. Each experiment was conducted for 55 days using a brand-new membrane material. SEM was used to scan the membranes and trace the growth of the biofilm at the conclusion of the experiment.

The USEPA reactor digestion technique was utilized to determine the bulk liquid's COD concentrations (Hach, Loveland, CO, USA). A pH meter with a glass electrode was used to test pH. Using the Hach techniques 10072 and 8048, nitrate (NO_3-N), nitrite (NO_2-N), and phosphate (PO_4) were analyzed, respectively.

3. RESULTS AND DISCUSSION

a. Scan Electron Microscopy (SEM) Test

Figure 2: Initial OxyMem SEM Analysis.

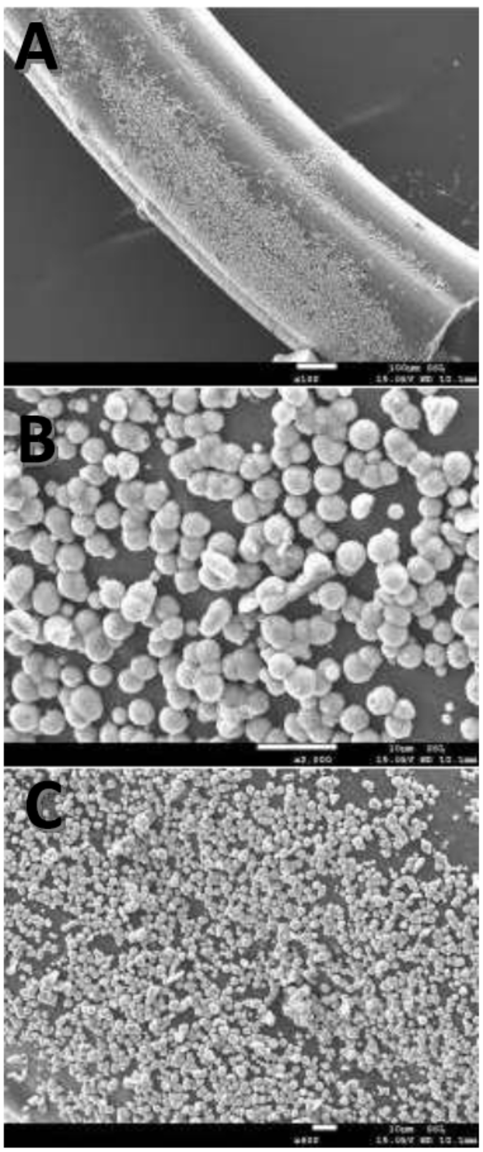


Figure 3: Figure 3 SEM After experiment (with growth). Sample 1 (**A**), sample 2 (**B**) and sample 3 (**C**).

Biological growth was successful in two different types of hollow membranes sourced from oilfield effluent, but with varying capacities depending on the effluent type and membrane that played the main role on it. Scanning electron microscope (SEM) analysis of the. Before and after the experiment with three different samples of oilfield effluent showed that the growth was most apparent in the sample containing 429 mg/L of COD.

In contrast, SEM analysis of the MemCor membrane reveals growth, but at a lower capacity than OxyMem. Figures below depict the MemCor membrane before to and after biological growth in three samples of oilfield effluents.

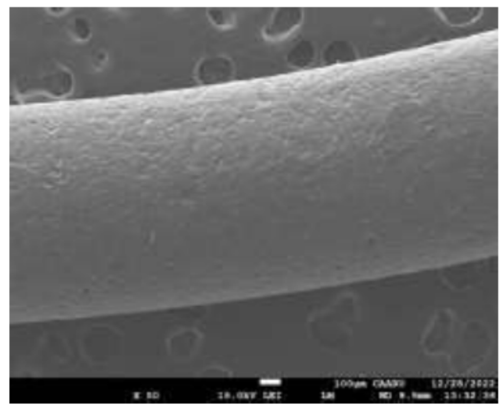
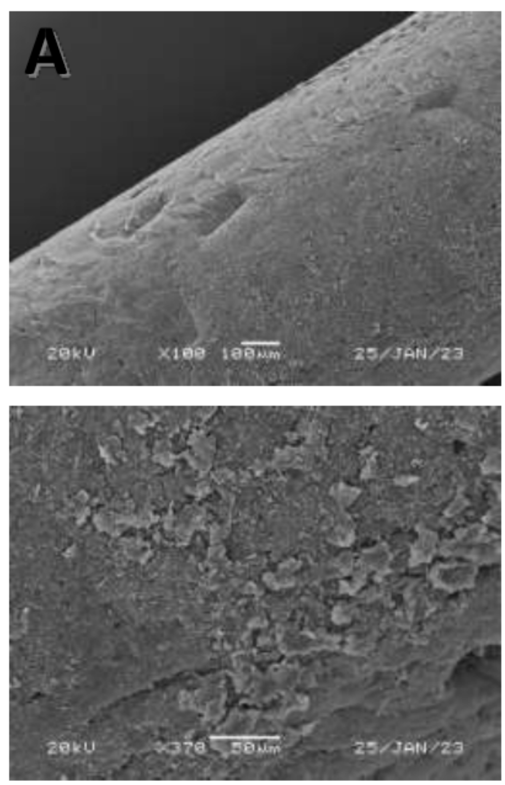
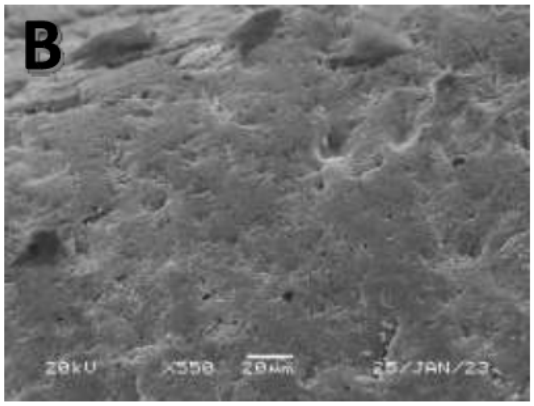
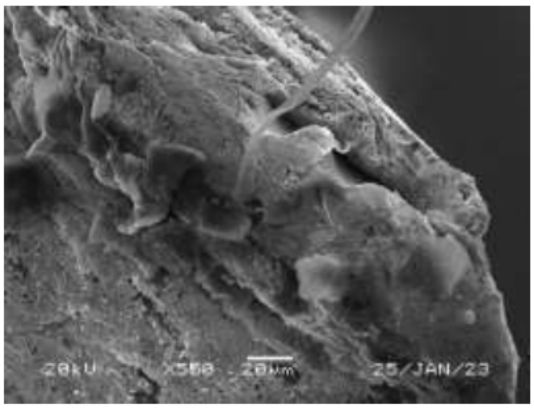
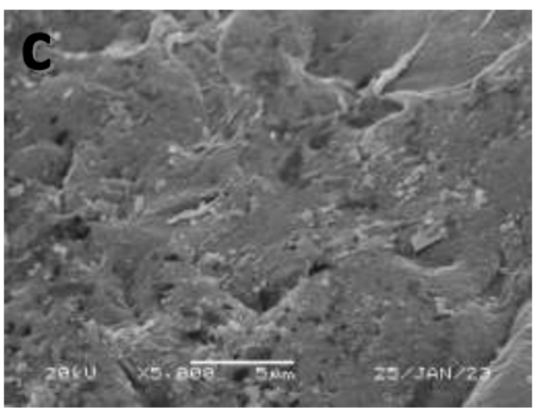


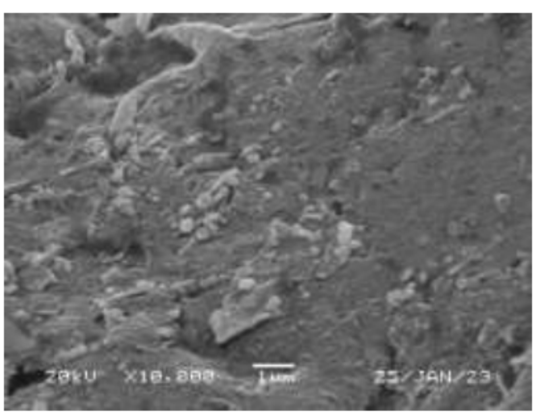
Figure 4: Initial MemCor SEM Analysis before.











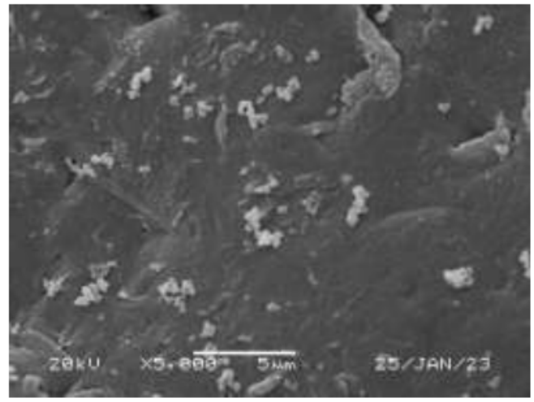


Figure 5: SEM After experiment (with growth). Sample 1 (**A**), sample 2 (**B**) and sample 3 (**C**) with different magnifications.

b. Performance of the Treatment System

Since COD and NH_3-N are the two most important monitoring indices for petrochemical wastewater discharge, process was going on.

c. Water Quality Parameters

The same water sample was used to study the growth of biofilm on both membranes, which was from Lekhweir station (south), particularly from the outlet of the dehydration tank. Table **1** shows the characteristics of three samples of oilfield water. The first two samples were from the Musalam station (common header outlet and hydro cyclone outlet), and the third one was from the Lekhweir station (dehydration tank outlet).

d. Chemical Oxygen Demand (COD) Removal

To investigate the impact of feed flow rate on the COD removal process, various feed flow rates were applied in this experiment. The findings show that as the feed flow rate is increased (decreasing hydraulic retention time (HRT)), the COD concentration clearly decreases. Different trials were conducted at flow rates ranging from 0.02 m/s to 0.06 m/s, resulting in a decrease in the effluent COD in the samples from 319,259 and 429 mg/l to 302,233 and 198 mg/l, respectively in OxyMen and 313,228,289 mg/l in MemCor as well. The biofilm experiences more hydrodynamic shear as the feed flow rate is increased. The mass transfer efficiency of organic matter into and out of the biofilm is enhanced by turbulence brought on by feed flow and the shaking of hollow fiber membranes. In contrast, increasing the flow rate to 0.08 m/s caused detaching of biofilms from hollow fibers due to the intense hydrodynamic shear, resulting in a high

Table 1: Oilfield Wastewater Characteristics (Before Treatment)

Sample ID	Unit	Sample No.1	Sample No.2	Sample No.3
Location		Musalam station		Lekhweir station
Sample point		Common header outlet	V-3943 hydro cyclone outlet	Dehydration tank outlet
Chemical oxygen demand (COD)	mg/L	319	259	429
Total nitrogen (TN)	mg/L	3.2	8.7	54.1
Total phosphorus (TP)	mg/L	0.21	0.26	0.242
Biological oxygen demand (BOD)	mg/L	7	5	9
Total organic carbon (TOC)	mg/L			34.4
Total dissolved solids (TDS)	mg/L	103950	99000	140250
Total suspended solids (TSS)	mg/L			16
Conductivity	uS/cm	189000	180000	255000
pH/DO	pH	5.9	6	6.43/ 8.5
Oil in water	mg/L	640	1800	600
Total petroleum hydrocarbons	mg/L	<0.5	<0.5	<0.5

COD concentration in the effluent. The recommended feed flow rate is 0.06 m/s.

e. Removal of Ammonia-Nitrogen (NH_3-N)

Pressure affected nitrogen removal. Because organic nitrogen is converted into NH_4+-N, the Concentration rises progressively in the first hours at 0.2 bar and 0.3 bar. NH_4+-N is converted into nitrate and nitrite, lowering its concentration. Due to high DO concentration, NH_4+-N concentration drops quickly at 0.3 bar in aerobic reactions like nitrification. The biofilm is mostly anaerobic at 0.1 bar, hence NH_4+-N concentration stays high. TN concentrations at 0.2 bar, 0.1 bar, and 0.3 bar differ significantly. TN removal requires nitrification and de-nitrification. Nitrifying and denitrifying bacteria can thrive in biofilms at 0.2 bar. Thus, TN removal is more effective at 0.2 bar pressure.

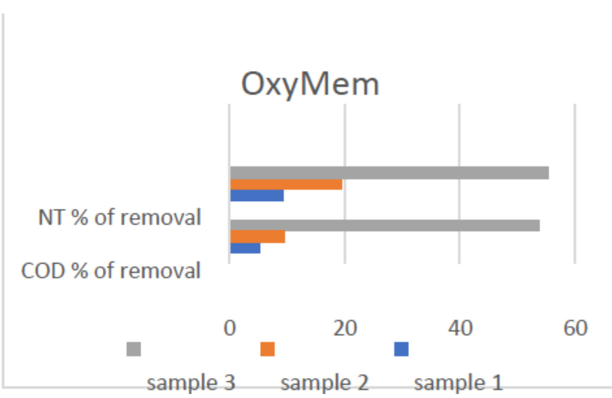


Figure 6: Percentage removal in COD and NT for three samples in OxyMem.

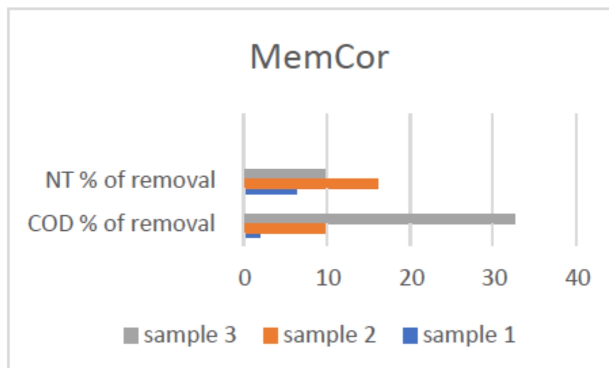


Figure 7: Percentage removal in COD and NT for three samples in MemCor.

4. CONCLUSION

This study examines the potentiality of biological growth on two distinct types of dead-end hollow fiber membranes using three samples of oilfield water. Both Membrane Aerated Biofilm Reactor OxyMem and MEMCOR® Ultrafiltration and Membrane Bioreactor exhibit the capability of biological growth; however, the growth OxyMen was superior, and this can be used to treat oilfield water in biological cells.

ACKNOWLEDGMENT

All of the authors contributed equally to this study. This research is funded by the Ministry of Higher Education Research and Innovation, Sultanate of Oman, under the grant number BFP/RGP/EBR/20/217, and the entire team is thankful for the financial support.

REFERENCES

[1] MA. Al-Ghouti, MA. Al-Kaabi, MY. Ashfaq, and DA. Da'na, "Produced water characteristics, treatment and reuse: A review," J. Water Process Eng 2019; 28 no. February: 222-239.
https://doi.org/10.1016/j.jwpe.2019.02.001

[2] M. Bodzek, K. Konieczny, and M. Rajca, "Membranes in water and wastewater disinfection - review," Arch. Environ. Prot 2019; 45(1): 3-18.

[3] I. Veleva, W. Van Weert, N. Van Belzen, E. Cornelissen, A. Verliefde, and M. Vanoppen, "Petrochemical condensate treatment by Membrane aerated biofilm reactors: A pilot study," Chem. Eng. J 2022; 428, no. July 2021, p. 131013.
https://doi.org/10.1016/j.cej.2021.131013

[4] N. Al Balushi, S. Al Rashdi, SM. Rizwan, G. Patil, and A. M. Saravanan, "Development of a Noble Fouling-Resistant Membrane for Wastewater Treatment," Int. J. Membr. Sci. Technol 2022; 9(2): 55-60.
https://doi.org/10.15379/2410-1869.2022.09.02.04

[5] F. Zhang, Z. Ge, J. Grimaud, J. Hurst, and Z. He, "Long-term performance of liter-scale microbial fuel cells treating primary effluent installed in a municipal wastewater treatment facility," Environ. Sci. Technol 2013; 47(9): 4941-4948.
https://doi.org/10.1021/es400631r

[6] FJ. Hernández-Fernández *et al.*, "Recent progress and perspectives in microbial fuel cells for bioenergy generation and wastewater treatment," Fuel Process. Technol 2015; 138: 284-297.
https://doi.org/10.1016/j.fuproc.2015.05.022

[7] S. Jiménez, M. Andreozzi, MM. Micó, MG. Álvarez, and S. Contreras, "Produced water treatment by advanced oxidation processes," Sci. Total Environ 2019; 666: 12-21.
https://doi.org/10.1016/j.scitotenv.2019.02.128

[8] A. Bokhary, E. Maleki, Y. Hong, FI. Hai, and B. Liao, Anaerobic membrane bioreactors: Basic process design and operation. Elsevier B.V. 2020.
https://doi.org/10.1016/B978-0-12-819852-0.00002-6

[9] J. Dong, Y. Wang, L. Wang, S. Wang, S. Li, and Y. Ding, "The performance of porous ceramsites in a biological aerated filter for organic wastewater treatment and simulation analysis," J. Water Process Eng 2020; 34, no. February: 101134.
https://doi.org/10.1016/j.jwpe.2020.101134

[10] H. Zhou and G. Xu, "Integrated effects of temperature and COD/N on an up-flow anaerobic filter-biological aerated filter: Performance, biofilm characteristics and microbial community," Bioresour. Technol 2019 August; 293.
https://doi.org/10.1016/j.biortech.2019.122004

[11] EP. Date, "Investigation of the hydrodynamic behavior on submerged hollow fibre membrane bioreactors induced by pulse bubble aeration Investigation of the hydrodynamic behaviour on submerged hollow fibre membrane bioreactors induced by pulse bubble aeration," 2022.

Accepted but unpublished paper.

[12] N. Al Balushi, 'Characterization of Oilfield Wastewater and Treatment Feasibility using Membrane Biofilm Reactor Technology ', International conference on innovation and technological advance for sustainability., Doha, Qatar 2023 March; 1-3.

Received on 22-02-2023 Accepted on 10-03-2023 Published on 21-03-2023

DOI: https://doi.org/10.15379/2410-1869.2023.10.01.04