DEVELOPMENT OF NOVEL MEMBRANES FOR DESALINATION

AN INTERNSHIP REPORT

Submitted by

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(SHR20BT007)

to

the APJ Abdul Kalam Technological University

in partial fulfillment of the requirements for the award of the Degree

of

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in
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EDUCATION IS DEDICATION

Department of Biotechnology

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DECLARATION

I, undersigned, hereby declare that the project report "DEVELOPMENT OF NOVEL MEMBRANES FOR DESALINATION", submitted for the partial fulfillment of the requirements for the award of the degree of Bachelor of Technology of the APJ Abdul Kalam Technological University, Kerala is bonafide work done by me under the guidance of Dr. Noel Jacob Kaleekkal Assistant Pro- fessor, Department of Chemical Engineering, National Institute of Technology Calicut. This submission represents my idea in my own words and where ideas or words of others have been included; I have adequately and accurately cited and referenced the sources. I also declare that I have adhered to the ethics of academic honesty and integrity and have not misrepresented or fabricated any data, idea, fact, or source in our submission. I understand that any violation of the above will be a cause for disciplinary action by the institute and/or the University and can also evoke penal action from the sources that have thus not been properly cited or from whom proper permission has not been obtained. This report has not been previously formed the basis for the award of any degree, diploma, or similar title of any other University.

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EDUCATION IS DEDICATION

BONAFIDE CERTIFICATE

This is to certify that the project report entitled **DEVELOPMENT OF NOVEL MEMBRANES FOR DESALINATION** submitted by **ANANNYA SHAJU (SHR20BT007)** to the APJ Abdul Kalam Technological University in partial fulfillment of the requirements for the award of the Degree of Bachelor of Technology in Biotechnology is a bonafide record of the project work carried out by her un- der our guidance and supervision. This report in any form has not been submitted to any other University or Institute for any other purpose.

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Anannya Shaju

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LIST OF ABBREVIATIONS

ABBREVIATION	DESCRIPTION
AGMD	Air Gap Membrane Distillation
DCMD	Direct Contact Membrane Distillation
LPH	Litre Per Hour
MD	Membrane Distillation
PEG	Polyethanol Glycol
Ppm	parts per million
PVDF	Polyvinylidene fluoride
RO	Reverse Osmosis
SAGD	Steam Assisted Gravity Drainage
SGMD	Sweep Gas Membrane Distillation
VMD	Vaccum Membrane Distillation

CHAPTER 1

INTRODUCTION

1.1 MEMBRANE DISTILLATION

Over the past few decades, there has been a significant advancement in membrane science and technology, resulting in membrane processes becoming competitive with traditional separation techniques in a wide range of applications. Membrane distillation (MD) is a newly developed non-isothermal membrane separation technique that involves the thermally induced transport of vapor through hydrophobic membranes that are porous and nonwetted. The driving force behind this process is the difference in vapor pressure between the two sides of the membrane pores. The academic community finds MD appealing as a type of didactic application because of the simultaneous heat and mass transport phenomena that occur via the membrane, the diverse MD configurations and the numerous MD uses. Making use of the low temperature and transmembrane hydrostatic pressure necessary for MD activities, several strategies are put forth to establish MD as a practical method of separation. These strategies include exploring new areas for the application of MD, collaborating with other processes as a pretreatment or posttreatment step, conducting research on membrane preparation in conjunction with MD modules, and examining factors that impact MD production through the use of specific enhancement techniques [1]. MD can be categorized into four basic types based on how the water vapor is collected on the distillate side: direct contact membrane distillation (DCMD), air-gap membrane distillation (AGMD), vacuum membrane distillation (VMD), and sweep gas membrane distillation (SGMD). The distillate side varies while the feed side stays constant in all basic combinations. In the past ten years, these layouts have been altered to increase their effectiveness [2]. Currently, RO, multiple effect distillation, and multi-stage flash distillation dominate the large-scale desalination sector. Reverse osmosis is known to be costly for small-scale water purification applications, despite having lower energy requirements than the other cutting-edge technologies. A promising technique called membrane distillation (MD) uses the partial vapor pressure differential that forms across a membrane as its operating principle. MD is a promising technology in terms of energy efficiency because it can operate with minor temperature differentials and low-quality heat sources. This makes it a large-scale purifying method that can be inexpensively implemented because it can make use of natural temperature gradients, waste heat, or solar thermal energy. In addition to being competitive with RO due to its low energy need, MD techniques can also be used in high-temperature applications where RO is not appropriate. For use in rural locations and developing nations without adequate electricity and water infrastructure, small-scale and portable water distillation devices are quite beneficial. The current costly water purifying methods may be replaced by renewable energy-assisted MD techniques, which would enhance living conditions in these areas without raising the demand for pricey and scarce electricity. Consequently, a great deal of study has been done on the use of solar energy in membrane distillation systems [3].

1.2 DIRECT CONTACT MEMBRANE DISTILLATION

Direct Contact Membrane Distillation (DCMD) is a widely studied configuration of membrane distillation where the feed and permeate streams are in direct contact with the membrane surfaces. In DCMD, the feed solution, typically hot, flows on one side of a hydrophobic, microporous membrane, while a colder permeate solution flows on the opposite side. The temperature difference between the two sides creates a vapor pressure gradient, which drives the volatile components, primarily water vapor, from the feed side through the membrane pores to the permeate side, where it condenses. This method capitalizes on the hydrophobic nature of the membrane to prevent liquid water from passing through the pores, ensuring that only vapor is transported. Direct contact MD (DCMD) is a more energy-efficient technology for onsite wastewater desalination since it is a thermally driven process that may function at temperatures exceeding 100 °C. The yearly production of wastewater from the US oil and gas sector is estimated to be 3.3 billion m^3, with salt levels nearly seven times greater than those of seawater. It has been demonstrated that onsite desalination employing SAGD systems, which generate wastewater, is more economically and environmentally feasible than disposal via deep well injection technologies. A baseline for the development of this technology has been established by evaluating the energy consumption of wastewater desalination using a variety of models. A 50% recovery ratio requires a minimum of 1 kWh/m^3 of energy for seawater desalination; however, this energy consumption increases to 9 kWh/m^3 for the removal of different salt ions from the wastewater produced by SAGD. According to the study, multistage membrane distillation can be used for improved heat recovery and a higher recovery rate, even though RO is still more energy-efficient [4]. When compared to other MD technologies like SGMD, VMD, and AGMD, DCMD has an advantage because of its straightforward design and procedure, adaptability to different kinds of feed water, and functionality over a broad range of relative operating energies and temperatures. Due in part to its addition to 100% salt and organic removal rate, DCMD has been advocated as the most suitable technology for wastewater treatment in the oil and gas industry despite the possibility of membrane scaling, fouling, and wetting [3]. In DCMD, flux, and energy efficiency are closely linked and heavily impacted by various process variables like salinity and flow velocities, polarization (temperature and concentration), and membrane-related factors like thickness, tortuosity, thermal conductivity, pore size, and porosity [5]. It is evident from everything mentioned above that it is necessary to compile and assess the most recent research. A thorough evaluation of DCMD processes' energy efficiency will highlight its advantages and disadvantages. At the forefront of MD development, numerous technological issues still need to be resolved, such as its high energy consumption, low thermal efficiency, low water flux, membrane wetting, membrane scaling, and membrane structure and design [6].

CHAPTER 2

COMPANY/ORGANIZATION PROFILE

The National Institute of Technology Calicut (NITC) is a premier autonomous technical university located in the scenic landscape of Calicut, Kerala, India. established in 1961, NITC has evolved into one of the most prestigious institutions for technical education and research in India, consistently ranking among the top engineering colleges nationwide. As an Institute of National Importance, NITC offers undergraduate, postgraduate, and doctoral programs in various engineering, science, and management disciplines, attracting a diverse and talented student body from across the country and around the world. The institute boasts state-of-the-art infrastructure, including advanced laboratories, well-equipped classrooms, modern hostels, and extensive sports facilities, fostering a conducive environment for academic excellence and holistic development. NITC's faculty comprises distinguished scholars and industry experts who are dedicated to imparting cutting-edge knowledge and conducting groundbreaking research in areas such as nanotechnology, artificial intelligence, renewable energy, and more. The institute maintains strong industry linkages and collaborates with leading global universities, providing students with ample opportunities for internships, placements, and international exposure. NITC is also committed to societal development, with numerous initiatives focused on sustainable development, community outreach, and innovation-driven entrepreneurship. Through its robust academic programs, vibrant campus life, and unwavering commitment to excellence, NITC continues to nurture future leaders, innovators, and technocrats who are poised to make significant contributions to society and the global technological landscape.

CHAPTER 3

OBJECTIVES OF THE INTERNSHIP

- Understanding the Fundamentals of Membrane Distillation: Gained a thorough understanding of the principles and mechanisms underlying membrane distillation (MD). This includes studying the thermodynamic and physical processes involved in MD, the types of membranes used, and the factors influencing performance and efficiency.
- Hands-On Experience with Experimental Techniques: The internship provided hands-on training in setting up and operating MD systems thereby making it easier to handle different feed solutions, maintain temperature gradients, monitor permeate flux, and ensure the proper functioning of the experimental setup.
- Enhancing analytical skills: Analyzing experimental data is a core objective to improve my ability to collect, interpret, and analyze data related to MD performance. This involves using software tools for data analysis and developing a keen eye for identifying trends and anomalies in experimental results.
- Exploring the impact of salinity: A significant objective is to investigate the impact of different salinity levels on the performance of MD. Interns will conduct experiments with feed solutions of varying salinities, such as 10,000 ppm and 35,000 ppm, to understand how salinity affects flux, efficiency, and membrane fouling.
- Developing Problem-Solving Abilities: Through troubleshooting and optimizing experimental setups, it is possible to enhance problem-solving skills, learning to identify and address issues related to membrane fouling, scaling, and operational challenges, contributing to the overall efficiency of the MD process.
- Research and development: Getting engaged in cutting-edge research projects to improve MD technology. This includes exploring new membrane materials, developing antifouling strategies, and optimizing process conditions to enhance performance and sustainability.

- Building Professional Networks: Provides a valuable opportunity to interact with industry professionals, academic experts, and fellow researchers and to build a robust professional network that can offer guidance, collaboration

- opportunities, and insights into potential career paths in membrane technology and desalination.
- Fostering Innovation and Entrepreneurship: Aim to inspire innovation and entrepreneurial thinking, and encourage the development of new ideas and solutions for water treatment challenges, potentially leading to the creation of startups or patentable technologies.
- Contribution to Sustainable Development: Engage in research that promotes energy-efficient and environmentally friendly desalination technologies, aligning with global sustainable development goals.

CHAPTER 4

WORK/PROJECT DESCRIPTION

4.1 INTRODUCTION

The technique of desalinating salty water which eliminates minerals and salts is essential to solving the world's water scarcity problems. Membrane distillation (MD) is one desalination technique that has attracted a lot of attention because of its ability to process feedwaters with high salinity levels. The efficiency of membranes in membrane distillation is examined in this report at two extreme salinity concentrations (10,000 ppm and 35,000 ppm), which are typically seen in saltwater and industrial effluents. The material qualities, surface features, and operational parameters of MD membranes, such as feed temperature, flow rates, and membrane pore size, are crucial to their efficacy. It is essential to comprehend how membranes behave in different salinity environments to maximize desalination procedures and raise water recovery rates.

4.2 MATERIALS AND METHODS

The DCMD performance of the fabricated membranes was evaluated using a DCMD test skid purchased from M/s. Tech Inc, Chennai, India. The system comprises a jacketed feed and permeate tank (5 L each) with a membrane cell of 0.015 m2 active area. On the feed side, water with salinity concentrations of 10,000 ppm and 35,000 ppm whereas on the permeate side, purified water with electrical conductivity below 20 μS/cm was used. The feed solution was taken at around 4.5 L, while permeate was taken at around 3 L of RO water. A heater (Band type heater) and a chiller (KOLD KRAFT, SPC 1, India) are used to keep the hot feed and cold permeate temperatures stable. The channel flow rate were equal on the feed and permeate side which was set at 10 LPH (167 L/min) at 80°C on the feed side which was maintained by an external heat supply and 10°C to 20°C on the permeate side which was maintained by a chiller. Peristaltic pumps (Ravel, RHP100L-200) were used to recirculate the hot feed and cold permeate. A commercial membrane was used for 10,000 ppm salinity and 35,000 ppm concentrations. The feed and distillate were circulated counter-currently on their respective sides of the membrane using peristaltic pumps. The flux was measured by evaluating the weight variations in the feed and distillate tank, using an analytical balance (Tulya digital weighing tech Calicut). The electrical conductivity at the feed and permeate side was monitored by portable conductivity meters (Eutech PC

2700, Oaklon). Additionally, to ensure stable membrane performance during the different experiments vernier readings and electrical conductivity of the permeate sample were measured at regular intervals of 1 hour.

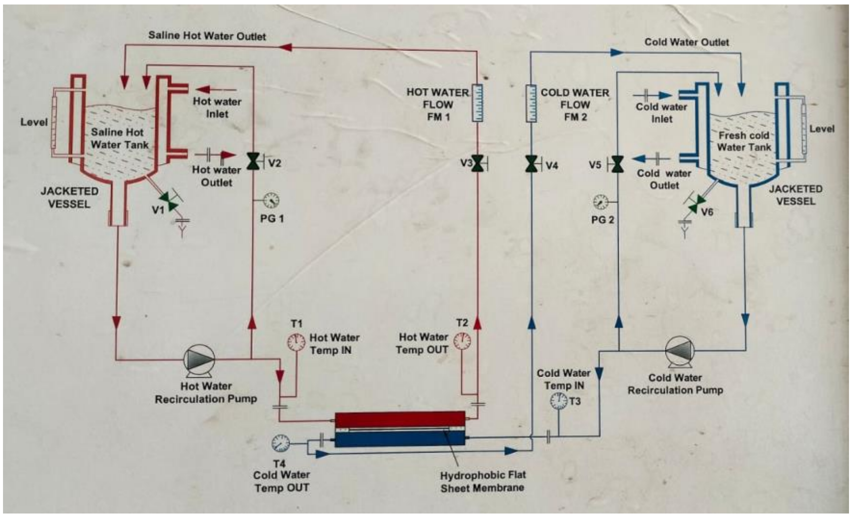

Fig. 4.1: Diagrammatic representation of an MD Skid

4.3 CALCULATIONS

The DCMD permeate flux J (L/m^2h;LMH) and NaCl rejection (% R) of the membranes were calculated using Equation (1) and (2).

$$J(LMH) = \frac{\Delta V}{A \times \Delta t} \qquad (1)$$

$$\% R = \left(1 - \frac{C_P}{C_F}\right) 100 \qquad (2)$$

where ΔV is the change in the volume of water in the permeate tank (L), A is the active membrane area (m^2), Δt is the time interval (h), and C_P and C_F are the concentration of permeate and feed streams.

4.4 RESULTS AND DISCUSSION

4.4.1 Membrane Distillation Performance

In the desalination membrane distillation (MD) run at 10,000 ppm salinity, the membrane usually maintains a good performance with flux values ranging between

6-8 $L/m^2 \cdot h$ and salt rejection rates above 99.5%. The lower osmotic pressure in the 10,000 ppm feed water allows for more efficient water vapor transport through the membrane, resulting in sustained high performance. In contrast, the MD process at 35,000 ppm salinity concentration poses significant challenges to membrane performance. The high osmotic pressure of the feed water at this salinity level considerably reduces the water flux and makes it unstable. The presence of surfactants and other fouling agents in high-salinity feed water exacerbates the problem, leading to more frequent occurrences of wetting. This wetting allows salts to penetrate through the membrane pores, resulting in slightly lower salt rejection rates when compared to the first run. The compromised salt rejection not only affects the quality of the permeate but also indicates deteriorating membrane integrity.

Table 4.1 represents the hourly readings of 10,000 ppm salinity concentration Desalination run whereas Table 4.2 represents the hourly readings of 35,000 ppm salinity concentration Desalination run. Flux and Rejection were calculated using equations quoted in the Calculation section from Equation (1) and Equation (2).

Table 4.1 Hourly readings of 10,000 ppm salinity concentration Desalination run

Sl no	Time (h)	Level (mm)	Permeate conductivity (μS)	Flux	Rejection
Initial	0	94	22.84		
1	1	99	21.04	6.66666667	100.0100727
2	2	104	21.3	6.66666667	99.99854505
3	3	110	20.93	8	100.0020705
4	4	115	21.03	6.66666667	99.9994404
5	5	120	21.5	6.66666667	99.99736989
6	6	125	22.06	6.66666667	99.99686626
7	7	131	22.32	8	99.99854505
8	8	136	22.87	6.66666667	99.99692222

Table 4.2 Hourly readings of 35,000 ppm salinity concentration Desalination run

Sl no	Time (h)	Level (mm)	Permeate conductivity (μS)	Flux	Rejection
Initial	0	110	12.76		
1	1	113	55.5	4	99.9218647
2	2	115	66.6	2.666666667	99.9015722
3	3	120	106.3	6.666666667	99.8289945
4	4	127	175.6	9.333333333	99.7804388
5	5	130	254.3	4	99.6568556
6	6	133	495.6		

4.4.2 **Membrane wetting**

At high salinity levels, the risk of membrane wetting increases due to several factors. Firstly, the high osmotic pressure exerted by the concentrated salt solution can force the feed solution through the membrane pores, especially if there are any defects or the membrane material degrades over time. Secondly, surfactants and organic matter in the feed solution can reduce the surface tension, making it easier for the solution to penetrate the hydrophobic membrane. Also, high salinity levels can exacerbate fouling, altering the membrane’s surface properties and promoting wetting. Numerous articles showcase new MD membranes, whose non-wettability was achieved by generating the right surface characteristics. Nevertheless, the protective layers may be harmed and the feed may start to seep through the membranes’ holes if the salts crystallize on the membrane surface during the MD process [7].

Fig. 4.2: Membrane wetting of the 35,000 ppm salinity concentration MD run

During the MD run at 35,000 ppm salinity, low and unstable flux values were observed. This indicates membrane wetting, where the feed solution intrudes into the membrane pores, allowing salts to pass through into the permeate. Typically, the flux values should be stable; however, in the presence of wetting, it becomes unstable. This instability compromises the quality of the produced water, making it unsuitable for consumption or industrial use without further treatment. The water flux, which is the rate at which water passes through the membrane, is negatively impacted by wetting because the effective area available for vapor transport is reduced. This not only decreases the efficiency of the desalination process but also increases the operational costs due to the need for more frequent cleaning and maintenance of the membrane. In this 35,000 ppm salinity run, the flux values can be seen to be changing irregularly as wetting progresses.

4.4.3 **Impact of salinity concentration**

To compare the DCMD performance of the membranes considered in this study, flux, and energy efficiency were measured at two different salinities. The commercial membrane showed a rejection above 99.5% for 10,000 ppm and 35,000 ppm. The flux was stable for the first run (10,000 ppm salinity) whereas the second of higher salinity was not stable. This happened because of pore wetting affecting the membrane efficiency. The reasons for the instability in water flux with an increase in salinity are reported as a decrease in water activity with an increase in salinity, a decrease in mass transfer coefficient due to concentration polarization, and a decrease in heat transfer coefficient [8]. Vapor pressure is also a function of salinity and an increase in salt concentration reduces the water activity and thus water vapor pressure. Raoult's law, shown in eqn (3) relates the vapor pressure of ideal solutions with the mole fraction of water in the solution. The law, however, defines a linear relationship between mole fraction and vapor pressure which is applicable only for ideal solutions. At higher concentrations, saline water deviates from ideality and this is incorporated with water activity. The activity of water is a function of salt concentration and temperature. It is defined as the ratio of water vapor pressure to the vapor pressure of pure water at the same temperature and represents the water availability at a certain temperature represented by the eqn (3) and (4), where p_w is the water vapor pressure, x_w is the mole fraction of water, w is the water activity coefficient and aw is the activity of water.

$$p_w = x_w p_w^0 \tag{3}$$

$$a_w = \frac{p_w}{p_w^0} = \gamma_w x_w \tag{4}$$

A substantial decline in activity and, consequently, a decline in water vapor pressure with an increase in salinity is observed. The impact of activity is important to consider in an MD system where the driving force is the vapor pressure gradient across the membrane and a decrease in activity reduces the availability of water vapor to permeate through the membrane. It is assumed that a minimum transmembrane temperature difference must be maintained to have a positive water flux from the feed to the distillate side since salinity lowers the effective water vapor pressure available at the membrane surface. However, due to current limitations on the maximum pressures under which membranes in pressure-driven processes can be used, processes such as RO are not always possible at high feed water salinity, and thermal processes such as MD must be utilized. For this, there is a need to upgrade the membranes by methods through which they would become more superhydrophobic and make the membrane distillation process more efficient.

4.5 FUTURISTIC ADVANCEMENTS

To make membranes used for desalination in membrane distillation super-hydrophobic and also to reduce the wettability of the membranes, a variety of innovative modifications and advanced techniques can be employed, most of which combine surface patterning and surface modification technologies. These include chemical modification [9], surface silanization [10], electrospinning [11], nanocomposite preparation [12], sol-gel approach[13] through nanoparticle coating, and plasma fluorination [14]. The hydrophobicity of the uniform polymeric structures is usually not sufficient for the MD process. In practice, the enhancement of the observed surface hydrophobicity is based on increasing the surface roughness and lowering solid/liquid interface energy [15]. According to the literature [16], an effective way for lowering solid/liquid interface energy is its functionalization by fluorinated alkyl units, however, there is a certain limitation in hydrophobicity improvement of smooth surfaces. For example, in the case of smooth PVDF, a surface that is saturated by fluorinated methyl groups, it is possible to reach a maximum 120 ° contact angle [17]. Therefore, the enhancement of the surface hydrophobicity is based on increasing the surface roughness. Thus, to achieve a strong water-repellent rough membrane, a proper modification has to be adopted focusing on the creation of micro- and nanostructured surfaces. As a result, water droplets sit on the top of surface protrusions and air gaps rather than follow the surface contours. In the case of multilevel roughness, there is an unusually strong water-repellency on the surfaces due to the increase in the number of sharp and narrow protrusions that are in contact with water droplets. In other words, the increase in surface roughness reduces the contact area between liquid and solid and as a consequence reduces the adhesion of a droplet to the solid surface [15]. Advanced manufacturing techniques, such as 3D printing and electrospinning, enable precise control over the membrane surface architecture. 3D printing can be used to fabricate membranes with intricate surface patterns and controlled porosity, optimizing their hydrophobicity and performance. Electrospinning, on the other hand, produces nanofiber membranes with highly controllable surface properties and porosity, allowing for the creation of superhydrophobic surfaces with enhanced separation capabilities. In general, the recent findings imply the preparation of anti-wetting membranes with strong water repellency to improve the membrane stability in long-term MD operation, enhance the vapor flux, and improve the permeate quality. Using specific filling materials (such as CNTs, graphene and its derivatives, TiO_2, silica, and ZIFs, among others), meaningful desalination performances have been obtained at the lab scale. Herein, it is important to mention that the right selection of the additive may bring multiple benefits and may be the key to obtaining membranes for large-scale processes. At this point, for the new researchers in the field, it is recommended to focus their research interest on cheaper substitutes of these materials but with the same effect on the membrane. Moreover, according to the main drawbacks of MD membranes. The formation of hierarchical micro/nano-scale surface morphology (reentrant structure) with air pockets gives the possibility to implement MD for real seawater desalination or industrial wastewater reclamation with low-surface-tension contaminants [18]. Ensuring the durability and fouling resistance of superhydrophobic membranes is crucial for their long-term application in desalination. Developing self-cleaning surfaces that can shed contaminants and maintain their hydrophobic properties is essential. This can be achieved through the use of photocatalytic materials or by designing surfaces that can repel both water and organic foulants. By integrating these advanced modifications and techniques, future membranes for desalination in membrane distillation can achieve superhydrophobicity, significantly enhancing their performance and operational lifespan.

CHAPTER 5

SKILLS AND KNOWLEDGE ACQUIRED

- Experimental Design and Execution: Planning and conducting experiments related to membrane distillation, including setting up equipment, handling chemicals, and ensuring safety protocols.
- Membrane Distillation Principles: Understanding the underlying principles of membrane distillation, including heat and mass transfer mechanisms across membranes.
- Membrane Selection and Characterization: Understanding the criteria for selecting membranes based on pore size, material composition (e.g., PVDF, PEG), and performance specifications and also knowledge of different membrane materials (e.g., PVDF, ceramic) and their applications in desalination, wastewater treatment, and other separation processes were acquired.
- Process Optimization: Techniques for optimizing membrane distillation processes to enhance efficiency, productivity, and cost-effectiveness.
- Lab Techniques and Instrumentation: Proficiency in using laboratory equipment such as spectrophotometers, conductivity meters, and thermal control systems for precise measurement and analysis.
- Environmental and Economic Implications: Awareness of the environmental impact such as temperature, humidity, etc and economic considerations associated with membrane distillation compared to traditional desalination methods.
- Literature Review and Research Skills: Conducting literature reviews to un-understand current research trends, emerging technologies, and advancements in membrane distillation.
- Regulatory and Safety Guidelines: Understanding regulatory standards and safety guidelines governing the use of membranes and chemicals in laboratory settings.
- Interdisciplinary Insights: Appreciation of interdisciplinary approaches involving chemistry, engineering, environmental science, and material science in membrane technology.

CHAPTER 6

CHALLENGES AND SOLUTIONS

- Membrane Wetting is a significant challenge in membrane distillation (MD), particularly in applications involving high salinity concentrations. It occurs when liquid water penetrates the membrane pores or surface, impairing its ability to separate the feed and permeate streams effectively. The high surface tension of water or surfactants in the feed solution and the accumulation of contaminants or salts on the membrane surface can lead to wetting. Use membranes with hydrophobic properties. Hydrophobic membranes repel water molecules, reducing the likelihood of wetting. Optimization of the pore size and structure of the membrane to minimize liquid penetration while maintaining adequate vapor transport. Narrower pore sizes or asymmetric membrane structures can help in this regard.
- High salinity solutions tend to have higher viscosities, which can impede heat transfer across the membrane surface. Scaling and fouling on the membrane surface due to high salt concentrations can insulate the membrane, reducing heat transfer efficiency. Maintaining adequate temperature differences between the feed and permeate sides is crucial for efficient vapor transport through the membrane. High salinity solutions may require higher temperatures for effective heat transfer. Adjusting the operating parameters such as temperature, feed flow rates, and pressure differentials to optimize heat transfer efficiency could be a solution. Use membranes with enhanced heat transfer properties, such as materials with higher thermal conductivity or structures that facilitate efficient vapor transport. Thin-film composite membranes or membranes with tailored pore structures can improve heat transfer rates.

- MD systems often require substantial energy input for heating the feed solution and maintaining temperature differentials across the membrane. Increased energy consumption can lead to higher operational costs and carbon footprint, impacting the overall sustainability of the desalination process. As a solution to this installation of MD systems in locations where renewable energy sources like solar or wind power are abundant. These sources can power the energy-intensive aspects of the MD process, reducing reliance on fossil fuels and lowering operational costs. Also, optimize the design of MD systems to minimize energy losses. This includes improving heat exchanger efficiency reducing resistance in flow channels, and maximizing heat recovery within the system.

- Exposure to high salinity concentrations, fouling agents, and mechanical stresses can degrade membrane materials over time. This will have serious impacts such as reduced separation efficiency, increased energy consumption, and shortened membrane lifespan. To solve this choose membranes with robust materials that resist chemical degradation and mechanical wear under high salinity conditions. Application of surface treatments or coatings that enhance membrane resistance to fouling and scaling. Hydrophobic coatings, such as fluoropolymers or silica nanoparticles, can reduce the adhesion of contaminants and prolong membrane life.
- MD systems can require a significant initial investment, particularly when specialized membranes and high-performance equipment are needed to handle high salinity concentrations. These processes often require more energy-intensive operations, leading to increased operational costs for heating and maintaining process conditions. Regular maintenance, membrane replacements, and system monitoring also contribute to ongoing operational expenses. As a solution, design MD systems that maximize energy efficiency and minimize material costs. This includes selecting appropriate membrane types, optimizing flow rates, and integrating heat recovery systems. Also, conduct comprehensive cost-benefit analyses to evaluate different membrane materials, system configurations, and operational strategies. This helps identify the most cost-effective approach over the long term.

CHAPTER 7

CONCLUSION

In conclusion, the study on membrane distillation for desalination purposes at varying salinity concentrations of 10,000 ppm and 35,000 ppm has yielded significant insights into the efficiency and feasibility of this technology. Through comprehensive experimentation and analysis, several key findings have emerged. When recommending MD treatment for high-concentration streams based only on bench scale data, caution should be exercised because temperature variations across the membrane fluctuate significantly between bench and pilot-scale settings. Due to this, caution should also be used when characterizing MD as being very little impacted by salinity. Bench-scale studies with smaller temperature variations are advised to mimic pilot- and commercial-scale applications [8].

Firstly, the performance of the membranes under these extreme salinity conditions demonstrated notable differences in terms of flux rates and salt rejection efficiencies. At 10,000 ppm, the membranes exhibited higher flux rates with satisfactory salt rejection, indicating a robust capability to handle lower salinity levels effectively. Conversely, at 35,000 ppm, flux rates decreased notably while salt rejection efficiencies remained commendable, albeit with a noticeable decline compared to lower salinity levels. Secondly, the study highlighted the critical influence of operating parameters such as temperature, humidity, feed flow rate, and membrane characteristics on the overall performance of membrane distillation. Variations in these parameters significantly impacted flux rates and salt rejection efficiencies, underscoring the importance of optimizing operational conditions for maximizing desalination efficiency. Moreover, the analysis of membrane morphology and material composition revealed insights into the structural integrity and durability of the membranes under high salinity conditions. Membranes with superior hydrophobicity and thermal stability demonstrated enhanced performance in terms of sustained flux rates and prolonged operational lifespan, thereby emphasizing the importance of material selection in membrane design for desalination applications. At higher salinity concentrations i.e. 35,000 ppm the MD couldn’t run for more time whereas comparatively lower concentrations i.e. 10,000 ppm of salinity showed longer running periods.

The findings underscore the robustness of MD as a promising technology capable of effectively treating highly saline water sources, crucial for regions facing water scarcity. Compared with higher salinity concentration of the feed, lower salinity concentrated feed shows stable readings and the run continues for longer periods. Despite challenges such as membrane fouling and energy consumption, optimizing operational parameters and membrane materials can significantly enhance performance and cost-effectiveness. As research continues to refine membrane designs and operational strategies, the potential for MD to emerge as a viable solution for sustainable water treatment remains promising, offering a pathway toward meeting global water demands in a resource-constrained future.

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