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CFD ANALYSIS OF MEMBRANE DISTILLATION PROCESS USING TLC THROUGH MODELING THE HYDRODYNAMICS

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ABSTRACT :- Membrane distillation (MD) has gained significant regard from industrial and academic perspective in recent years, thus the frequency of publications related to the field has greatly accelerated. New perspectives have boosted the research activities related to deeper understanding of heat and mass transport phenomenon, novel applications and fabrication of the membranes specifically designed for MD. Desalination is one of the proposed methods to meet the ever increasing water demands. It can be subdivided into two broad categories, thermal based desalination and electricity based desalination. Multi-effect Distillation (MED), Multi-Stage Flashing (MSF), Membrane Distillation (MD) fall under former and Reverse Osmosis (RO), Electro-Dialysis (ED) fall under later. MD offers an attractive solution for seawater as well as brackish water distillation. It shows highly pure yields, theoretically 100% pure. The overall construction of a MD unit is way simpler than any other desalination systems. In previous work [1] gives reviews of recent researches utilizing CFD simulations to study the momentum, heat and mass transfer in conventional and newly designed MD modules, such as those including spacer-filled feed channels. In which also reviewed the different ways in which the CFD techniques are used to improve MD performance. Possible concepts and perspectives for applying CFD to new MD processes are discussed, comprehensively. Enhancing the MD production is an anticipated goal, therefore, two main control strategies are proposed. Consequently, we propose a nonlinear controller for a semi-discretized version of the dynamic model to achieve an asymptotic tracking for a desired temperature difference. Principles of the MD process are taken in four types in proposed method direct contact MD (DCMD), Sweeping gas MD (SGMD), Air-gap membrane distillation (AGMD), vacuum membrane distillation (VMD) are taken and analysis gives better result as compared to previous works.

1.INTRODUCTION

Water desalination is a technique of converting saline, impure water from sea or in-land reserve and converting it to potable water. Several desalination techniques exist today, such as, Multi Stage Flash (MSF), Multi Effect Distillation (MED), Vapor Compression Desalination (VC), Membrane Distillation (MD), Reverse Osmosis (RO), Forward Osmosis (FO), Electro-Dialysis (ED) etc. Each desalination technique has its advantages and disadvantages.

Membrane distillation is particularly attractive owing to simple construction, inexpensive operation and low maintenance. A MD unit has seawater and coolant separated by a hydrophobic membrane. The feed stream or saline water stream is heated above the temperature of coolant externally. Because of the temperature gradient, there exists a vapor pressure gradient and conjugately a vapor concentration gradient. The concentration gradient drives vapor from the saline channel to the coolant channel. It condenses on the coolant channel to form pure water.

Hence, theoretically it is possible to produce permeate at 100% purity. Based on the mode of operation and construction MD is classified into Direct Contact Membrane Distillation (DCMD), Air Gap Membrane Distillation (AGMD), Sweeping Gas Membrane Distillation (SGMD), Vacuum Membrane Distillation (VMD) etc. Goal of the present studies is to understand DCMD to a greater detail. In a DCMD module, permeate and saline streams are in direct contact with the hydrophobic membrane. DCMD shows simples construction among all MD techniques.

In the same time, the existing desalination technologies need vital improvement in term of sustainability aspects, such as energy consumption factor, or alternatively new technologies have to be developed and progressed to achieve a convenient level of sustainability. Desalination term refers to the process of minerals removal from saline water, and thus producing fresh water from seawater or brackish water. During the last two decades, desalination plants have evolved rapidly to reach more than 150 countries. Globally, 80 million cubic meters of desalinated water is being produced daily by more than 17; 000 desalination plants, 50% are utilizing sea water as the source [24]. Kingdom of Saudi Arabia (KSA) is the largest desalinated water producer in the world, and it currently produces about one-fifth of the world productions, in which it produced 955 million cubic meters of water in 2012. Desalination plants cover major regions in the Kingdom, where 26 plants are located along the Arabian Sea and Red Sea. East coast has 6 plants which produce 504 million cubic meters of desalinated water making up about 52:8% of the total water produced in the Kingdom. Red Sea has additional 20 plants which support Jeddah, Makkah and Taif and produce about 451 cubic million cubic meters of water [1, 28].

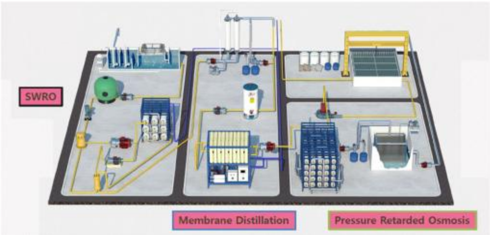


Fig. 1.1. A conceptual design of 3rd generation desalination scheme

Membrane distillation (MD) may be a thermally driven method that utilizes a hydrophobic micro-porous membrane to support a vapor-liquid interface. If a temperature difference is maintained across the membrane, a vapor pressure difference happens. As a result, volatiles (water during this case) evaporates at the new interface, crosses the membrane within the vapor part and condenses at the cold side, giving rise to a internet trans-membrane water flux. Membrane distillation (MD) may be a comparatively new method and was introduced within the late 1960s (Lawson and Lloyd; 1997, Alklaibi and Lior, 2004). At that point, MD didn't receive vital interest because of many reasons, e.g. the determined lower MD production compared to the reverse osmosis technique and inaccessibility of appropriate membranes for the method (Lawson and Lloyd; 1997; El-Bourawi, et al; 2006). The MD method received renewed interest at intervals the tutorial communities within the early of 1980s once novel membranes and modules with higher characteristics became offered (El-Bourawi, et al; 2006). Moreover, the flexibility of MD to utilize low grade heat during a kind of waste heat/renewable energy supply had boosted the interest and analysis so as to search out appropriate application areas also as raising the merits of the technology. However, MD isn't implemented however in business for water purification or desalinization. a radical historical perspective of MD development may be found within the review articles by Lawson and Lloyd (1997), Alkaibi and Lior (2004), and El-Bourawi et al. (2006).

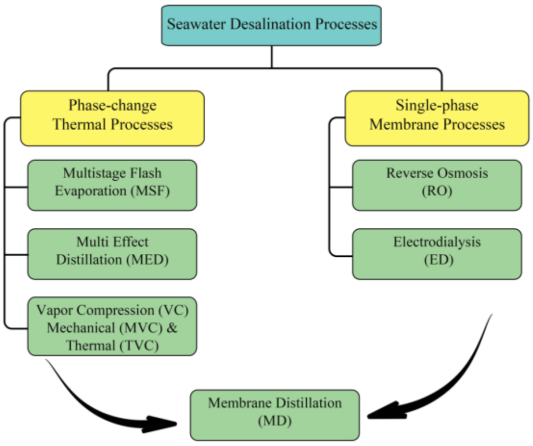


Figure 1.2 : Classification of water desalination techniques.

2. LITERATURE SURVEY

Mohammad Mahdi A. Shirazi et al.[1] “Computational Fluid Dynamic (CFD) opportunities applied to the membrane distillation process: State-of-the-art and perspectives”, Generally speaking, it ought to be noted that CFD-based models are very qualitative. Actually, in apply the choice of the simplest case, i.e. the particular microstructure for membrane or spacer geometry and also the module geometry includes a trade-off between prices of membranes required to provide the specified production and costs of the energy supply. it's not only the price of the applied membrane; with it comes variety of MD modules, piping, fittings, pumps, compressor and vacuum pumps, and etc. Most of works on CFD approaches are investigated the DCMD method through modeling the hydrodynamics conditions and heat transfer. However, a mix of those things with mass transfer shall be studied a lot of extensively and comprehensively. Moreover, different MD configurations, particularly the SGMD and AGMD, got to be any investigated, within the case of their varied aspects, e.g. the distillate aspect and planned boundary layer conditions, as well. Any to several benefits and opportunities of CFD for modeling MD processes, there are some vital issues that shall be investigated in future works.

Ali Kargari et al.[2] “A Review on Applications of Membrane Distillation (MD) Process for Wastewater Treatment”, The MD method has been in the main used for desalination; but, the water recovery from wastewater streams is one in every of the most promising applications of MD for the longer term. It’s additionally proved to be an appropriate technology for removal of different impurities. Whereas it's capable of treating several sorts of wastewaters and brines, its ability to compete with current technologies, like ro and thermal-based water treating technologies, remains restricted because of its lack of experimental information in pilot scale and specific membranes and modules. On the opposite hand, finding new and appropriate applications for the MD method presently looks to be one among the most important impediments to its industrial use. Moreover, there's another major challenge against MD to be applied for wastewater treatment. Wastewater streams commonly embody several chemicals that would probably result in membrane surface fouling and membrane pore wetting. This can be because of the very fact that the deposition of those contaminants on the membrane surface may build the membrane less hydrophobic and result in pore wetting and therefore the flux decline.

This can be the reason that restricted works on wastewater treatment using MD are compared with desalinization. Therefore, fabricating specific membranes for MD application in wastewater process is one in every of the promising future views.

Enrico Drioli et al.[3] “Membrane distillation: Recent developments and perspectives”, Membrane distillation could be a relatively new method, investigated worldwide as a low price and energy saving different with respect to standard separation processes (such as distillation and reverse osmosis). it's one among the few membrane operations supported a thermal method. Energy consumption thus is, in theory, a similar because the traditional phase changes method. However, the specified operative temperature is far under that of a traditional distillation column as a result of it's not necessary to heat the method liquids higher than their boiling temperatures. In fact, the method may be conducted at temperatures usually below 70 °C, and driven by low temperature difference (20 °C) of the new and therefore the cold solutions. Therefore, low-grade waste and/or energy sources like star and heat energy may be including MD systems for a value and energy efficient liquid separation system. Consequently, this operation would possibly become one in all the most interesting new membrane techniques. It will overcome not only the limits of thermal systems however additionally those of membrane systems like Ro or NF. Concentration polarization doesn't affect significantly the drive of the method and thus high recovery factors and high concentrations may be reached within the operation, in comparison with Ro method. All the opposite properties of membrane systems (easy scale-up, easy remote and automation, no chemicals, low environmental impact, high productivity/size ratio, high productivity/weight magnitude relation, high simplicity operational, flexibility, etc.) also are present. This technology may be used much during a giant style of industrial and bio-medical processes as for the purification, extraction, concentration (to very high values), and final formulation of organic and inorganic species. a lot of recently, membrane bioreactors (MBRs) with membrane distillation membranes (MDBR) are developed for the treatment of commercial and municipal waters so as to exceed the boundaries of the existing MBR systems (i.e., the problem to retain effectively little size and protracted contaminants).

I. Hitsov et al.[4] “Modelling approaches in membrane distillation: A critical review”, Membrane distillation has been discovered 50 years ago, however up to now lacks vital industrial applications. So as to optimize the technology and create it competitive to different separation techniques the MD community should have an in-depth understanding of the processes that occur within the modules and also the membranes. The mass transfer modelling of the membrane region has been lined by many alternative mechanistic and statistical models that may predict the flux with variable accuracy. More recent models like the ballistic transport model and also the structural network models are innovative and interesting to the community however haven't however been totally tested and validated. Moreover, a number of the physical phenomena that occur within the membrane like the surface diffusion have forever been neglected in MD modeling which might prove to be necessary for membrane synthesis studies.

3. PROBLEM FORMULATION

While membrane distillation has a tremendous potential as a separation technology for hard streams when waste heat is available, MD is still lacking wide-spread adoption. This could be due to a lack of major reference cases where MD is applied successfully for a significant amount of time. The uncertainty associated with the long term performance and cost of the technology is driving the industry away from MD. One possible way to reduce this uncertainty associated with the technology is to carefully model the process and gather process knowledge. The models can be used to predict the process performance across production scale and operational conditions. However, modeling of MD to date is mostly limited to lab-scale.

4. MODULE DESIGNING FOR MD

After the availability of appropriate membranes for any application, the next most important step is to assemble these membranes in a particular configuration to ensure the required membrane area enclosed in a particular module volume. In addition to provide compactness, an appropriate module design can reduce the thermal/concentration polarization, fouling and energy consumption of the process. These advantages can be realized by disturbing the normal flow pattern that develops along the fiber. Adequate module design can improve the hydrodynamic on shell and lumen side, thus imparting a positive impact on the process. In this context, the module designing provides an economical alternative of the active techniques to change the hydrodynamic conditions in the membrane. Despite of these benefits, the investigations on module design are limited in number generally for membrane operations and particularly for MD. Similar to the other membrane based processes, module design for MD is crucial to use the process more rationally. An appropriate module design for MD applications should take into consideration the minimization of thermal polarization on up and downstream, appropriate packing density to ensure the module compactness, robustness, achievement of high energy efficiency, suitable length, high volume based enhancement factor and relatively easy fabrication with the flexibility to apply for the maximum configurations. In addition, the material implied for module fabrication must ensure the minimum thermal losses and must be heat resistance. There are several different industrial sectors looking at MD with different demands that further underline the importance of flexibility in module design. In MD, several possibilities have been considered to design an appropriate module

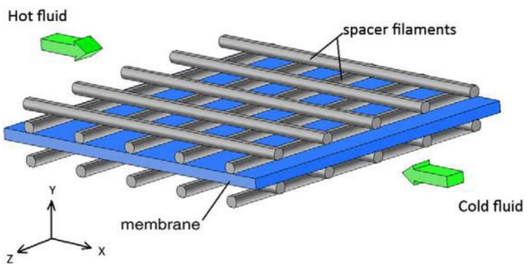


Figure. 4.1. Spacer-filled membrane distillation channels

The concept of heat recovery by interstate heating of the cold feed by using the permeate of previous stage in a cascade of modules. A schematic of the concept used by the author has been shown in Figure. 4.2. The authors have provided a theoretical analysis of countercurrent cascade of cross flow DCMD modules. Such cascades can be useful in improving the recovery and energy efficiency of the system.

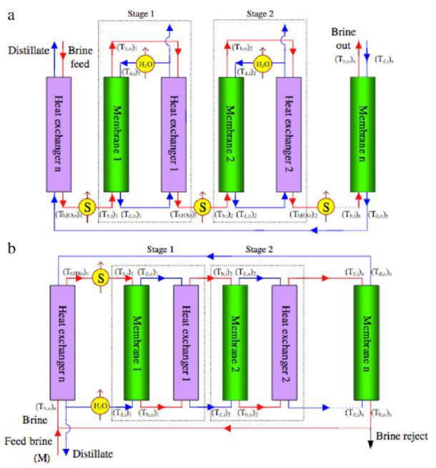


Figure. 4.2. Cascade module design used by

The authors have claimed a recovery of 60% and gain output ratio of more than 60% for appropriate configurations and temperature difference. Investigated the effect of various fiber geometries on performance of DCMD both experimentally and theoretically. The flux enhancement as high as 300% has been claimed due to reduced thermal boundary layer resistance. Experimental and theoretical feasibility of roughened surface for DCMD process has been demonstrated by [27]. Rotational and tangential to the membrane surface flow have been proven very affective in increasing the performance of the AGMD [129]. Such flow combined with the partial contact of membrane with condensing surface in AGMD has caused synergetic effects. The authors have claimed the permeate flux as high as 119 kg/m2·h at feed inlet temperature of 77 °C. The claimed flux is ~2.5 times higher than the flow observed in traditional AGMD studies carried out under the identical conditions. The authors have associated the improvement with improved heat and mass transfer due to the specific flow patter generated and due to the contact of membrane with the cooling plate. AGMD module designing involves bulky modules in order to incorporate the air gap, condensing plate and cooling channel. In their proposed configuration as illustrated in (figure 4.3) [28] have introduced porous and non-porous hollow fibers in the same lab scale modules to compact the module volume. The vapors from hot feed passing through the porous fibers are condensed at the outer wall of non-porous fiber which has been cooled by the circulation of a cold fluid inside the fiber. On the similar lines, [31] have designed a module with the heat exchanging hollow fibers that collect the latent heat of vapors and transfer to the cold feed.

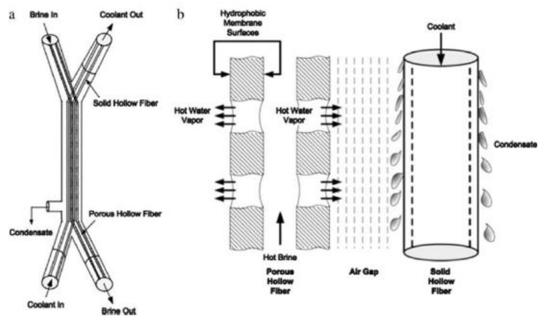


Figure. 4.3. Conceptual mechanism of hollow and heat recovery fibers

The authors have claimed a thermal efficiencyof80%or higher in all the studied cases. Zhao et al. [13] have explored the performance of a V-MEMD module introduced by memsys under solar and diesel heating arrangements. The authors have identified the number of stages and the size of each stage as the key parameters for optimizing the module performance for large scale applications. The module efficiency is mainly controlled by the hot and cooling fluid temperatures. From optimization results, it was concluded that the module has a very attractive gain output ratio. Zhang et al. [132] have explored the effect of fiber packing density and module length on their performance in

VMD. The initial flux decay under constant operating conditions was attributed to the membrane compression that took place due to the hydraulic pressure. The shorter modules with compact packing have been recommended by the authors for a high yield per unit module volume. The authors have also pointed out that increase in flux at high feed flow rate is due to increased average temperature instead of enhanced thermal polarization coefficient. The effect of liquid distributor on the performance of VMD process has been investigated theoretically by. [33]. The authors have claimed that the appropriate design of distributor plays a significant role in optimizing the performance of VMD process. The liquid distribution in dome-like and pyramidal distributor was better than plate-like distributor. In the recent years, a further MD enhancement was developed and produced by Fraunhofer Institute for Solar Energy Systems (ISE) which works on the development of energy self-sufficient desalination systems based on solar driven MD technology since many years. Recently, studies and productions of spiral wound MD-modules in permeate gap membrane distillation (PGMD) have been carried out (Figure. 4.4a).

5. METHODOLOGY

5.1. Water recovery and wastewater treatment using the MD process

5.1.1. DCMD process

As mentioned earlier, the direct contact MD is the most used mode of the MD process, especially for desalination and water/wastewater treatment. One of the reasons is due to the condensation step that can be carried out inside the MD module enabling a simple MD operation mode. However, it should be noted that the heat transferred by conduction through the membrane, which is considered as the heat loss in MD, is higher than in the other MD configurations. During the DCMD process, evaporation and condensation take place at the liquid-vapor interfaces formed at the pore entrances on the feed and distillate side, respectively. A typical DCMD system used for flat sheet, capillary or hollow-fiber membranes is shown in Figure 5.1. It is worth quoting that DCMD is mainly suited for applications in which the major component of the feed stream contains nonvolatile solutes such as salt.

5.2. SGMD process

Sweeping gas MD consists of a gas that sweeps the distillate side of the membrane carrying the vaporous distillate away from the permeate side. In this configuration, i.e. SGMD, the condensation of the vapor takes place outside the membrane module. Therefore, an external condenser is required to collect the vapor in the distillate stream. It is worth noting that in SGMD, the gas temperature, the mass transfer and the rate of heat transfer through the membrane change considerably during the gas circulation along the MD module, which can potentially decrease the distillate flux. Although, the SGMD process has a great perspective for the future, especially for desalination and water/wastewater treatments, it combines a relatively low conductive heat loss through the membrane with a reduced mass transfer resistance. Similar to the DCMD process, the SGMD can also be used for high-purity water production and concentration of ionic, colloid and/or other non-volatile aqueous solutions. In SGMD, the feed temperature together with the sweeping gas flow rate was found to be the important operating parameter controlling the distillate flux. The change in partial vapor pressure corresponding to the same temperature change increases as the temperature rises.

5.3. AGMD process

As mentioned earlier, the most important drawback of the DCMD configuration is the high rate of heat loss through membrane heat conduction. Furthermore, the need for an outside condenser is the limitation of the SGMD configuration. To solve these drawbacks, a new configuration of MD was introduced, called air-gap membrane distillation (AGMD). In this mode, the temperature difference between the process liquid and the condensing surface is the driving force. As could be observed in Figure 5.2, mass transfer occurs according to the following four steps, including movement of the volatile molecules from the bulk liquid (i.e. hot feed) towards the active surface of the membrane, evaporation at the liquid-vapor interface (i.e. at the membrane pores), transport of evaporated molecules through the membrane pores and diffusion through the stagnant gas gap, and condensing over the cold surface.

As the distillate is condensed on a cold surface without direct contact with the membrane surface or condensing fluid, AGMD can be used in the fields where DCMD applications are rather limited.

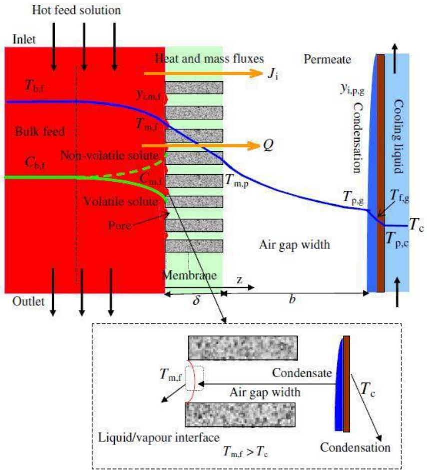


Figure. 5.2. A detailed scheme of the AGMD process

5.4 VMD process

Another possible way to increase membrane permeability in the MD process is removing air from its pores, either by deaeration or by using vacuum in the distillate side. It should be noted that this vacuum must be below the equilibrium vapor pressure, i.e. VMD process. In this configuration, low pressure or vacuum is applied on the distillate side of the module, usually by means of a vacuum pump. As mentioned earlier, condensation takes place outside of the MD module at temperatures much lower than the ambient temperature, and a nitrogen liquid filled condenser is used in the lab scale. There is a very low conductive heat loss in the VMD process. This is due to the insulation against conductive heat loss through the membrane provided by the applied vacuum, in which the boundary layers in the vacuum side are negligible. Moreover, in the VMD process it is a reduced mass transfer resistance.

5.5. Modelling Methodology

In proposed method three designs is considered for the demenonstartion of Analysis of different Velocity and Temperature on model.

5.5.1 CAD Modeling Design1

The CAD model is developed in CREO 2 which is sketch based, feature based parametric 3d modelling software developed by PTC. The model is developed in parts and then assembled using constraints.

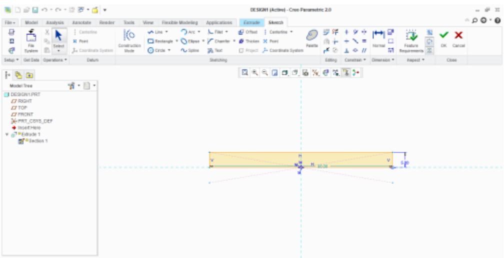


Figure 5.3 Using sketch

In above figure part 1 of the design 1 is taken whose sketch is mention on CREO 2 model of CAD tool. This part is mention is the sketch tool view of the part with parametric variation level.

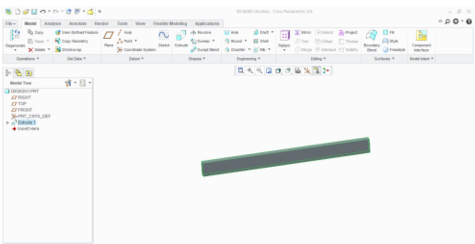


Figure 5.4 using extrude

In above figure 5.4 part 2 of the design 1 is taken on CREO 2 model of CAD tool. This part is mention is the extrude tool view of the design 1.

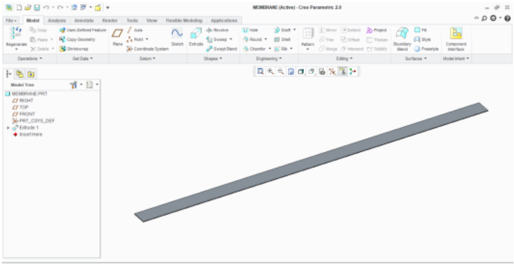


Figure 5.5 Membrane modelling using CREO

In above figure 5.5 part 3 of the design 1 is taken which is mention as the membrane model CREO 2 of CAD tool.

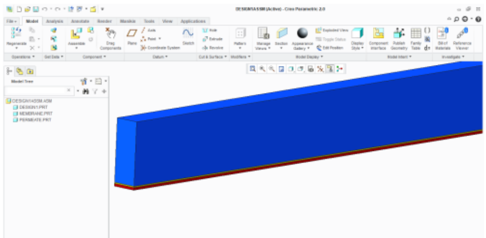
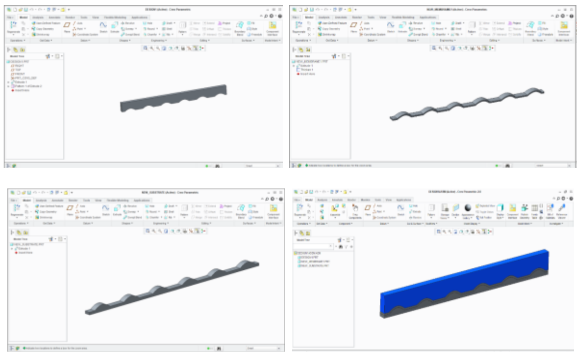


Figure 5.6 Assembly Using Coincident Constraints

Figure 5.6 shows the Assembly view of the design 1 with different parts taken is considered as the coincident constraints.

CAD MODELING DESIGN2



In above figures different view of CAD model of design 2 is mention in which three parts is taken, part 1 is the model of feed domain shown in figure 5.7, part 2 is CAD model of porous membrane is mention in figure 5.8. In figure 5.9 Substrate Model of CAD is mention for design 2. In figure 5.10 Assembly view of CAD model of design 2 is seen which the combined view of other three parts is.

ANALYSIS METHODOLOGY

1> IMPORTING CAD MODEL

The CAD model developed in CREO is converted in .iges format and imported in ANSYS CFX and check for geometric errors and data loss which includes correcting hard edges, spacing etc

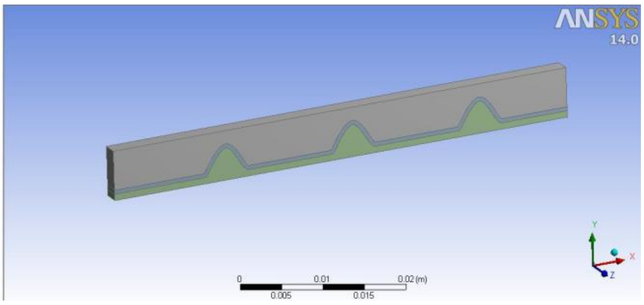


Figure 5.15 Imported CAD model in ANSYS

2> MESHING CAD MODEL

The model is meshed using hex dominant method and relevance sizing set to smooth, fine sizing substrate and membrane domain with element size .08mm and feed domain with element size .2mm , transition ratio .77 , growth rate 1.2

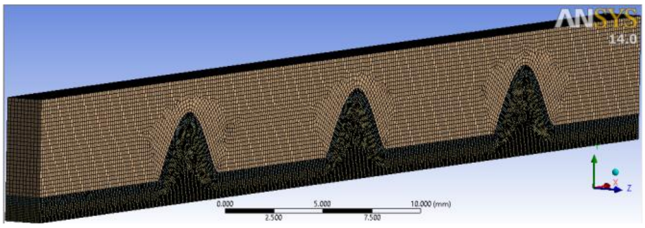
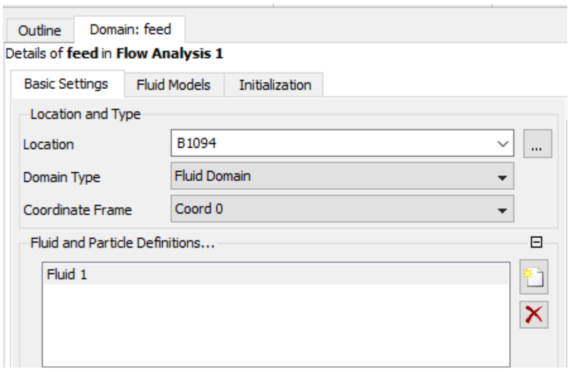
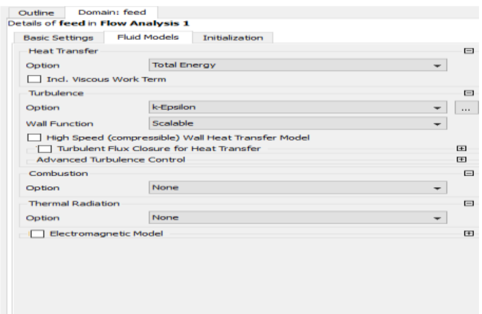


Figure 5.16 Meshing CAD model in ANSYS

3> DOMAIN DEFINITION

Three separate domains are defined i.e. 2 fluid domain for feed and substrate , porous domain . Reference pressure is set to 1atm and turbulence model to k-epsilon , energy model is set to total energy.





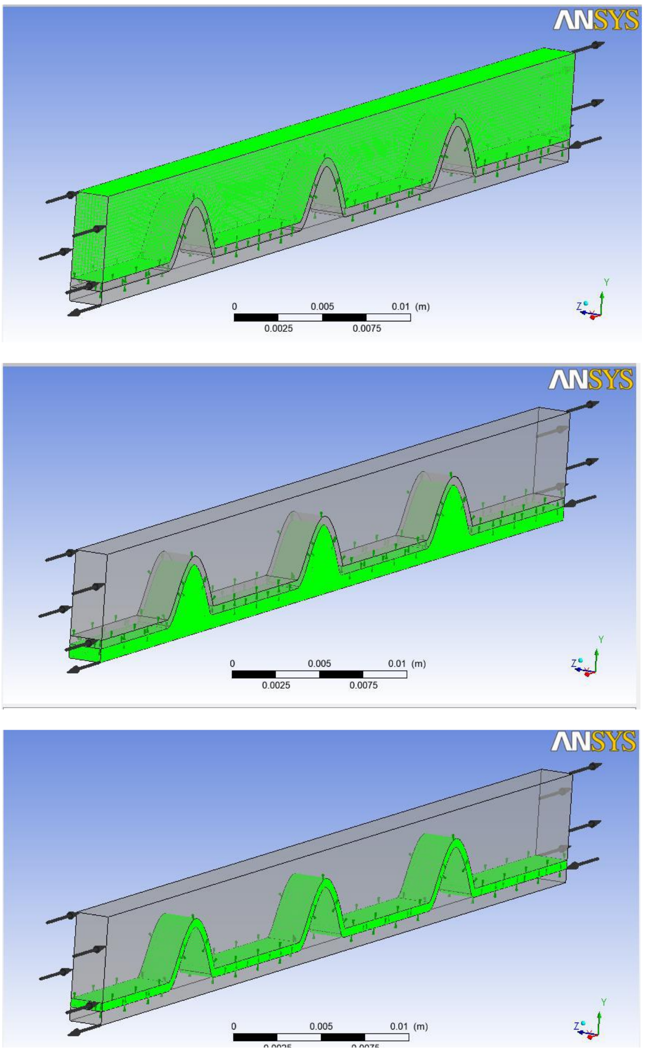


Figure 5.17 porous domain definitions for membrane

4> BOUNDARY CONDITIONS

Inlet and outlet boundary conditions are defined for feed domain. The inlet velocity is .05m/sec and temperature 357K . The inlet boundary conditions for substrate is .05m/s and temperature of 300K.

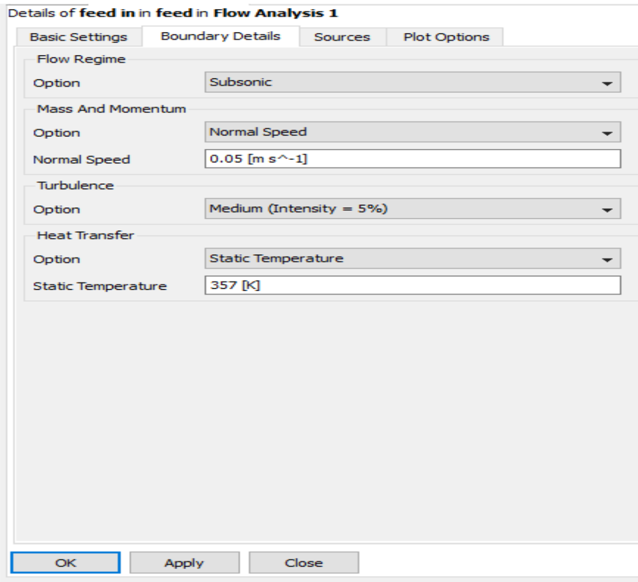


Figure 5.18 Inlet boundary condition

5> INTERFACE MODELING

Two interfaces are modelled to enable heat transfer across domain. The first interface is modelled between substrate and membrane with conservative interface flux and second interface is modelled between feed and membrane with conservative interface flux.

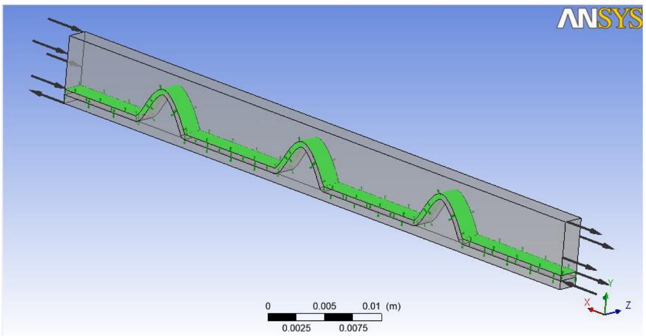


Figure 5.20 Feed membrane interface

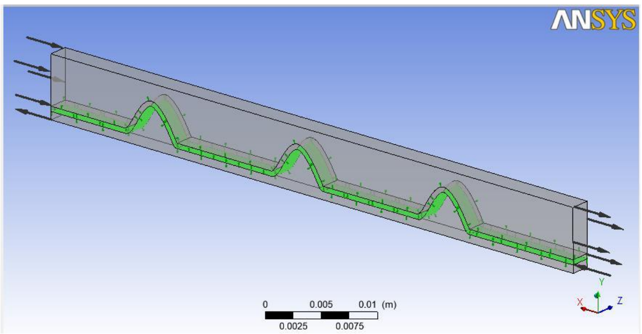


Figure 5.21 Substrate membrane interface

6. RESULT ANALYSIS

In this section analysis of different result outcome is shown after applied proposed method on three different designs which is considered for the demenonstartion of Analysis of different Velocity and Temperature on model.

6.1 Design1

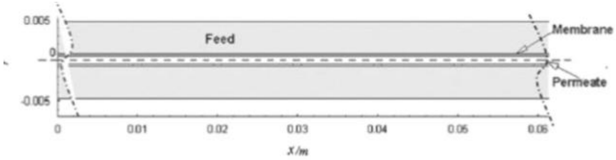


Figure 6.1 Schematic of Design1 of Membrane Distillation

Schematic Design 1 of Membrane Distillation with all parameters is shown in figure 6.1 with feed and permeates points also.

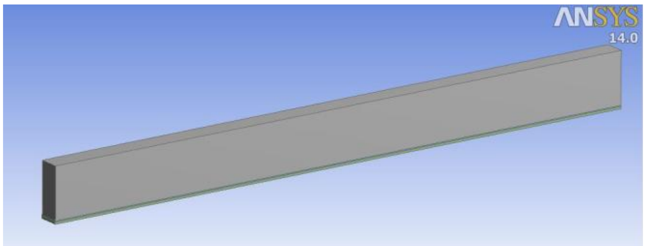
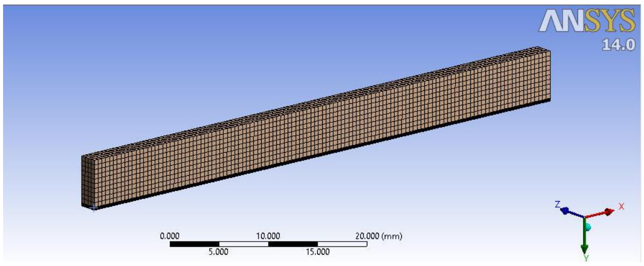


Figure 6.2 One Half Is Modeled and Symmetric Boundary Condition Is Applied

In figure 6.2 ANSYS view of One Half Is Modeled and Symmetric Boundary Condition Is Applied is shown which the Schematic of design1 is.



MESHED MODELED

Figure 6.3 Meshed Modeled of design 1

In figure 6.3 ANSYS view of Meshed Modeled and Symmetric Boundary Condition Is Applied is shown which the Schematic of design1 is.

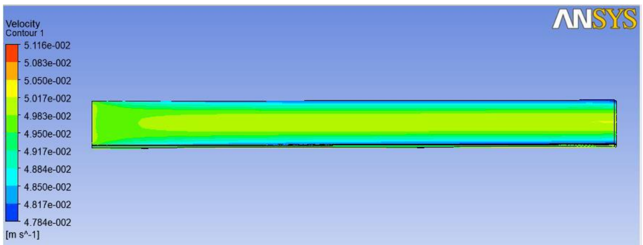


Figure 6.4 Velocity contour design 1

In figure 6.4 ANSYS view of velocity contour 1 on the design 1. In proposed different contour of velocity is taken to examine the work value of design1 is Applied is shown which the Schematic view of design.

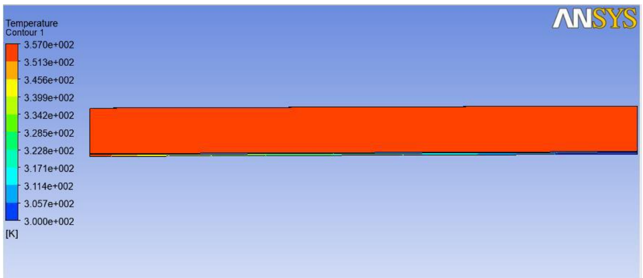


Figure 6.5 Temperature contour of design 1

In figure 6.5 ANSYS view of Temperature contour 1 on the design 1. In proposed different contour of temperature is taken to examine the work value of design1 is Applied is shown which the Schematic view of design.

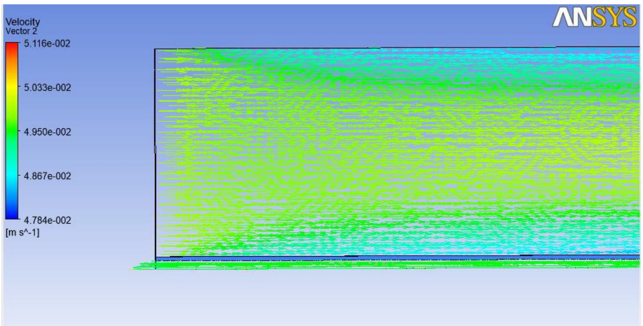


Figure 6.6 Velocity Vector of design 1

In figure 6.6 ANSYS view of velocity vector on the design 1. In proposed different contour of velocity is taken to examine the work value of design1 is Applied is shown which the Schematic view of design.

6. CONCLUSIONS & FUTURE WORK

6.1 CONCLUSION

In proposed work is a CAD analysis of Membrane Distillation, CAD model is developed in CREO 2 which is sketch based, feature based parametric 3d modelling software developed by PTC. The model is developed in parts and then assembled using constraints. The MD method has been mainly used for desalination; but, the water recovery from waste streams is one of the most promising applications of MD for the long run. It’s also proved to be a suitable technology for removal of other impurities. Whereas it's capable of treating several types of wastewaters and brines, its ability to vie with current technologies, like Ro and thermal-based water treating technologies, is still restricted due to its lack of experimental data in pilot scale and specific membranes and modules. On the other hand, finding new and suitable applications for the MD method currently looks to be one of the main impediments to its industrial use. Moreover, there's another major challenge against MD to be applied for effluent treatment. Effluent streams usually include many chemicals that would doubtless result in membrane surface fouling and membrane pore wetting. This can be because of the actual fact that the deposition of those contaminants on the membrane surface may build the membrane less hydrophobic and lead to pore wetting and thus the flux decline. This is often the reason that limited works on waste material treatment using MD are compared with desalinization. Therefore, fabricating specific membranes for MD application in waste matter processing is one of the promising future views. In proposed work the accuracy is increased by 10 percent better as compared to previous works.

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