CFD Analysis of Membrane Distillation Process Using TCL through Modeling the Hydrodynamics

[1]Siddharth Jain, [2]Praveen Mishra
[1]Student, [2]Assistant Professor
Department of Mechanical Engineering, Oriental college of Technology, Bhopal, India
teenuawesome@gmail.com, mmpkmishra@gmail.com;

Abstract *– 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. 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.*

Keywords*: Membrane distillation (MD), Computational fluid dynamics (CFD), Momentum, heat and mass transfers, Modeling and simulation Membrane and module design,*

I. 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.

Water desalination becomes an insistent need, due to the huge demand of fresh water across the globe, and the accompanied decrease in its availability worldwide.

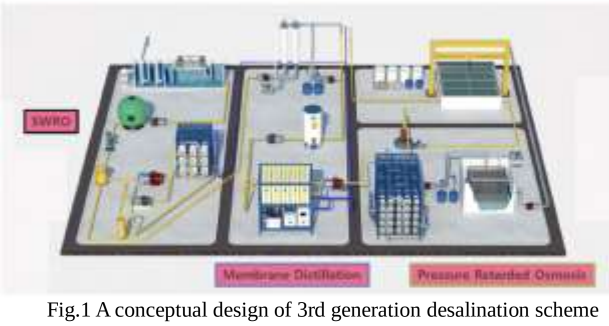

Fig.1 A conceptual design of 3rd generation desalination scheme

As alternative to 1st generation thermal based desalination techniques, 2nd generation desalination technologies based on membrane operations (mainly reverse osmosis (RO)) gained popularity during last two decades or so [4]. Currently, RO accounts for 60% of desalination erections across the globe, thanks to its order of magnitude which requires less energy than its thermal counterparts. However, desalination technologies have to address the issue of disposal of produced brine and further decreasing of energy consumption for their sustainable growth. To address these limitations, several other techniques are being investigated. These techniques mainly include membrane distillation (MD), forward osmosis and capacitive deionization and will be incorporated into 3rd generation desalination installations (for instance see Fig. 1. for the layout proposed by Global MVP

II. Water Desalination Technologies

Although water is the most common substance in the whole world, this does not mean that it is freely open for domestic applications. Studies showed that 97% of the available water is salty in the oceans, and only tiny 3% is drinkable fresh water. This tiny amount is supposed to supply humans, animals and plants needs, in addition to be available for domestic use at the same time. The shortage of clean water is a problem that is accompanied with other severe problem represented by the high increase of world's population [4]. Statistical studies showed that human's population is expected to reach nine billions from the current seven billions in the next 50 years, which means a huge increase in the environmental pollution as well. According to the World Health Organization (WHO), about 2:4 billions people do not have access to basic sanitation facilities, and more than one billion people do not have access to safe drinking water.

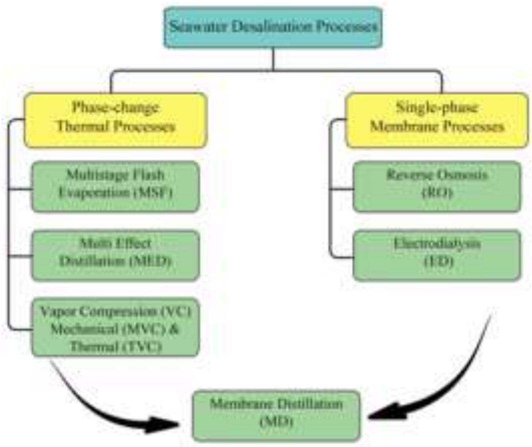

Fig.2 Classification of water desalination techniques

The severity of the problem pushed people from ancient ages to find and address feasible solutions for the water shortage problem. Some suggested conserving the water, sharing it or performing water desalination. Later, water desalination appeared to be the most sustainable solution. Water desalination processes is the removal process of the minerals from the seawater or brackish water to produce freshwater [3, 6, 8]. It is as old as the Greek nations, where Aristotle obtained potable water by evaporating impure water and then condenses it. By the time, the development of the desalination methods continued rapidly using the available tools and energy sources. However, the first big industrial desalination plants were built in 1912 in Egypt with 6 stages Multiple Effects Evaporator, producing about 75 m3/d of desalinated water. The next big jump followed the petroleum revolution in the 70s in the Gulf area, where several thermal plants were built. That revolution satisfied the quick growing of water demand in the region. This was facilitated by the availability of thermal energy sources at cheap costs. Desalination plants are classified mainly to either thermal separation processes or membrane separation processes like in Figure. 2.

III. Methodology

III.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 3. 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.

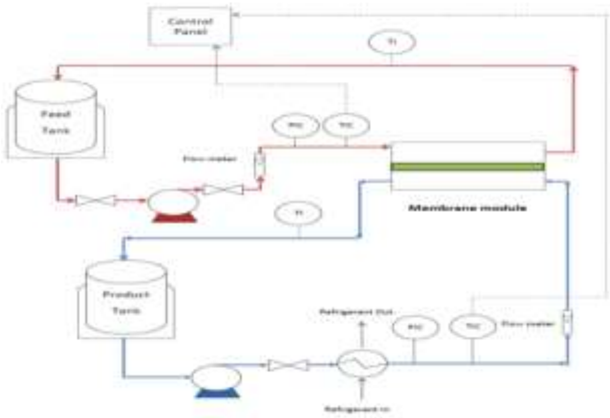

Fig.3 A general scheme of the DCMD process

III.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.

III.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 4, 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.

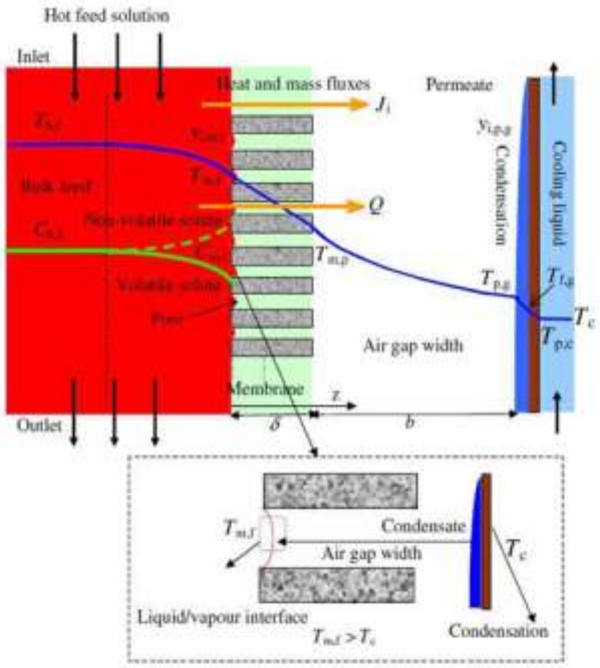

Fig.4 A detailed scheme of the AGMD process

IV. Simulation Result

The 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.

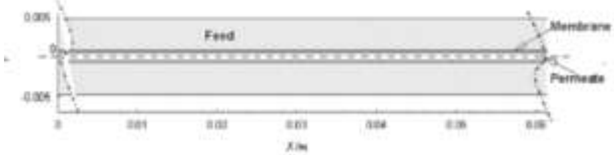

Fig.5 Design 1 of Membrane Distillation

Design 1 of Membrane Distillation with all parameters is shown in figure 5 with feed and permeates points also.

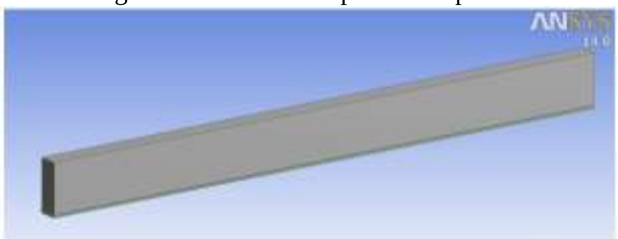

Fig.6 One Half Is Modeled and Symmetric Boundary Condition Is Applied

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

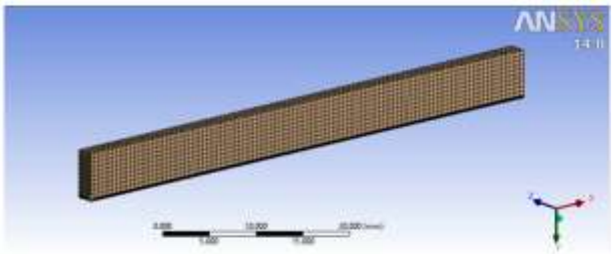

Fig.7 Meshed Modeled

In figure 7 ANSYS view of Meshed Modeled and Symmetric Boundary Condition Is Applied is shown which the Schematic of design1 is.

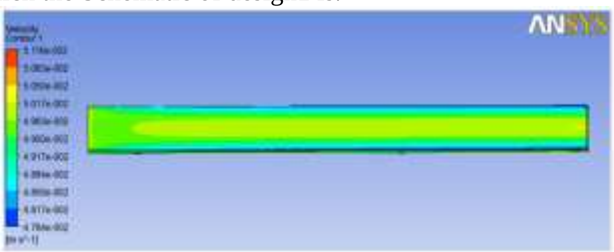

Fig.8 Velocity contour design 1

In figure 8 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.

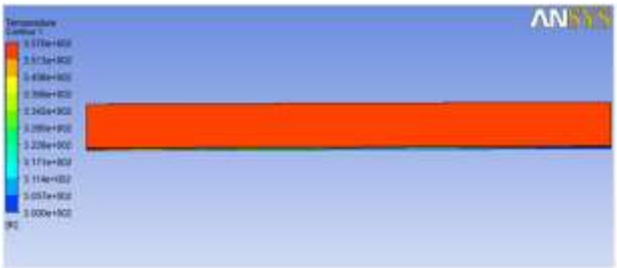

Fig.9 Temperature contour of design 1

In figure 9 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.

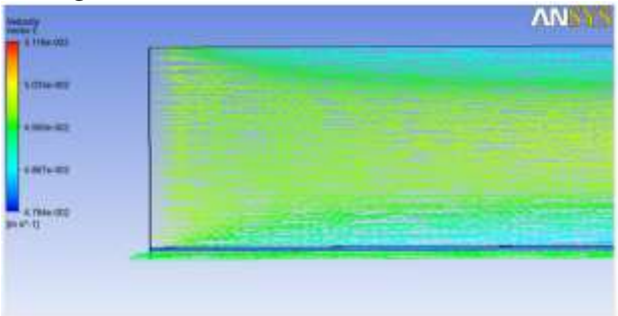

Fig.10 Meshed Modeled of design 1

In figure 10 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.

V. 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.

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