DESIGN AND FABRICATION OF SOLAR POWERED MEMBRANE DISTILLATION SYSTEM

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AZZURA IZZATY ABU BAKAR

Thesis submitted in fulfilment of the requirements
for the award of the degree of
Bachelor of Engineering Technology in Manufacturing

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STATEMENT OF AWARD FOR DEGREE

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SUPERVISOR'S DECLARATION

We hereby declare that we have checked this thesis and in our opinion, this thesis is adequate in terms of scope and quality for the award of degree of Bachelor of Engineering Technology in Manufacturing.

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ABSTRACT

Membrane distillation system is one of the solution to overcome the pollution issues that have been wide spreading. The system also solves the issue in the shortage of clean water supply that were escalating day by day especially in our own country, Malaysia. Membrane Distillation required two form of energy in order to perform its activity that is heat and electrical energy. In order to improve the system, the energy consumption of the system could be lowered by solar power. As solar power are reliable for providing thermal and electrical energy for the system as solar thermal collector and photovoltaic cells. With the solar thermal collector combined with the membrane distillation system, the temperature of the heat needed for the solar collector could be provided without having the auxiliary electric heater accompanied. The performance of the collector were simulated and the best design parameters were identified for the thermal collector so that it could worked at its maximum efficiency. The performance of the solar collector plays an important role in the first step on establishing this project to see whether the combining of solar thermal collector with the membrane distillation system could give the same result as there are no electrical heater included in the system. The mechanism of the solar powered membrane distillation system were reviewed to make sure the system would be able to maintain the temperature of the desired fluid in the feed tank of the system and increase the temperature of the fluid at the same time.

ABSTRAK

Sistem penyulingan membran adalah salah satu penyelesaian untuk mengatasi isu-isu pencemaran yang telah luas merebak. Sistem ini juga menyelesaikan isu tentang kekangan bekalan air bersih yang semakin meningkat hari demi hari terutama di negara kita sendiri, Malaysia. Membran penyulingan memerlukan dua bentuk tenaga untuk melaksanakan aktivitinya iaitu tenaga haba dan tenaga elektrik. Dalam usaha untuk menambah baik sistem, penggunaan tenaga sistem boleh dibekalkan oleh kuasa solar. Kuasa solar boleh dipercayai untuk menyediakan tenaga haba dan elektrik untuk sistem sebagai pemungut haba suria dan sel solar photovoltaic. Dengan pengumpul haba suria digabungkan dengan sistem penyulingan membran, suhu haba yang diperlukan untuk pengumpul solar boleh disediakan tanpa pemanas elektrik bantu disertakan. Prestasi pengumpul disimulasikan dan parameter reka bentuk yang terbaik telah dikenal pasti untuk pengumpul haba supaya ia boleh bekerja pada kecekapan maksimum. Prestasi pengumpul solar memainkan peranan yang penting dalam langkah pertama dalam mewujudkan projek ini untuk melihat sama ada menggabungkan pengumpul haba suria dengan sistem penyulingan membran boleh memberikan keputusan yang sama oleh kerana tidak ada pemanas elektrik termasuk dalam sistem. Mekanisme sistem membran penyulingan berkuasa solar telah dikaji semula untuk memastikan sistem itu akan dapat mengekalkan suhu bendalir yang dikehendaki di dalam tangki suapan sistem dan meningkatkan suhu bendalir pada masa yang sama.

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LIST OF SYMBOLS

Cu	Cupper
Cm	Centimeter
°C	Degree Celsius
L	Liter
M	Meter
Ml	Milliliter
Mm	Millimeter
Min	Minute
Sec	Second
V	Velocity
T	Temperature
KW	Kilowatt
W	Watt
H	Hour
%	Percent
Mm	Micrometer
K	Kelvin
mld	Millions of liter per day

LIST OF ABBREVIATION

TES	Thermal Energy Storage
HTF	Heat Transfer Fluid
MD	Membrane Distillation
NTU	Nephelometric Turbidity Unit
PUR	Polyurethane
PP	Polypropylene
SPMD	Solar Powered Membrane Distillation
MIG	Metal Inert Gas
SHS	Square Hollow Section
PVC	Polyvinylchloride
HVAC	Heating, Ventilation, and Air Conditioning
DCMD	Direct Contact Membrane Distillation
PPE	Personal Protective Equipment
VMD	Vacuum Membrane Distillation
PV	Photovoltaic
TF	Thin Film
RO	Reverse Osmosis

CHAPTER 1

INTRODUCTION

1.1 Background of study

The sun lies at the center of the solar system, where it is by far the largest object. It holds about 99.8 percent of the solar system mass and is roughly 109 times the diameter of the Earth where about one million Earths could fit inside the sun (Charles, 2017). The sun radiates energy in all directions. Most of it dissipates into space, but the tiny fraction of the sun's energy that reaches Earth is enough to heat the planet and drive the global weather system by warming the atmosphere and oceans. The delicate balance between the amount of heat Earth receives from the sun and the heat that Earth radiates back into space makes it possible for the planet to sustain life (David, 2017). The Sun emits heat and energy as the by-product from the millions of chemical reactions that had occurred on the ball of gas. Electromagnetic radiation, including visible light, infrared radiation, ultraviolet light and X-rays, can travel through the vacuum of space. Other forms of energy require a physical media to move through. For example, sound energy needs air or another substance to be transmitted, and the wave energy of the oceans needs water. Solar energy, however, can travel from the sun to the Earth without the need for a physical substance to transmit the energy. This feature of electromagnetic energy makes it possible for the Earth to receive solar energy, including heat (Ramos, 2017). Parts of the radiations that was emitted by the Sun were used and converted into energy by using solar energy power plant such as concentrated solar power, photovoltaic and concentrated photovoltaic.

In contrary to photovoltaics, solar thermal power plants indirectly generate power from sun light. The conversion of solar irradiation into thermal energy follows the Principle of Absorption. It can be performed by solar collectors, which directly absorb the sun irradiation. Large thermal solar power plants work with concentrators following the principle of reflection. The concentrators bundle the sun beams to increase the intensity of the incident light on the absorber. Thus the temperature in the heat carrier is increased (Ammonit Measurement, 2018). Solar thermal systems are mostly used in residential and industrial application such as domestic water heating, desalination plants and solar cooker. This shows that it is necessary to apply solar thermal collector in the membrane distillation system. Membrane Distillation (MD) is a thermally-driven separation process, in which only vapour molecules transfer through a microporous hydrophobic membrane. The driving force in the MD process is the vapour pressure difference induced by the temperature difference across the hydrophobic membrane (Abdullah et al., 2012).

1.2 Problem Statement

Malaysia is a very fortunate country to receive a high average of rainfall that is from 2030 mm to 5000 mm every year. Water resources had become a booster in the development of the economy in the country for the past decades (Keizrul & Azuhan, 1998). Kilometers of pipelines and canals supplies clean water to sustain domestic, industrial and agriculture needs around Malaysia (Marlinda, Nor, & Leong, 2013). Recently, the water solution for the country has changed from a relative abundance to one of the scarcity for the government. Population growth, urbanization and the expansion of irrigated agriculture are imposing rapidly growing demands and pressures on the water resources, besides contributing to the rising water pollution (Shahrizaila, 1999). The seasonal distribution such as extended periods of drought also cause water supply to fall short of water demands in states that supporting large scale agriculture Perlis and Kedah. Other than that, the policy issues also had become a catalyst to the water demand in Malaysia. Instead of conserving the water resource, the government emphasis fore on the source utilization (Noor, 2011).

The 5th World Water Forum (WWF) held in Istanbul in 2009 with the theme "Bridging Divides for Water" ended with mixed conclusion and showed many divides in opinions. However, the true scope and urgency of the world water crisis had been recognized and many engaged to solve water related issues (Abdullah, 2004). In a recent survey, it was shown that the water demand for potable water in Malaysia for 2010 were 15.9 mld and continue to escalate to 28.5 mld during 2050 (Noor, 2011). Therefore, there are countries with least water supply develop technologies by using the unlimited seawater as another alternative sources (Sara, 2014). However, humans cannot drink saline water as it contains a significant amounts of dissolved salts but the source could be change into freshwater by undergoing certain methods (Perlman, 2018).

One of the ways to be applied is by distillation. Distillation is a process of heating a liquid until becomes gas, then changing them to liquid again by cooling (Cambridge Dictionary, n.d.), or a process of purifying a liquid mixture by successive evaporation and condensation (Merriam-webster, 2018). This principle was used in the membrane distillation system that is firstly patent by Bodell (United States Patent No. 285,032, 1963). Membrane distillation is a thermally driven separation process enabled due to phase change, in which only vapors molecules are transported through porous hydrophobic membranes. It involved simultaneous heat and mass transfer phenomena through the membrane.

However, a huge energy such as electrical energy will be consumed and will be lost in order to heat the feed solution to a certain temperature in order to convert the liquid into vapor depending on their specific heat. Based on a research, in five years from now, Malaysian electricity reserve margin will be in between twenty-five to twenty percent. Nowadays, the percentage of fuel consumption for electric generation is 44.7% from coal, 42.5% are based on gas, 3.7% based on fossil fuel, 3.4% based on distillate, and 5.7% based on hydro. However, by 2020, it is estimated that 60% of the electricity supply will be generated from coal, 23% from gas, 15% of them are hydro generated and the other 2% percent will be on the renewable energy source (Mohd Hayati, 2012). Based on this estimation, it is shown that the country is on their way to work on the usage of renewable energy and decrease the consumption of fossil fuel on the electricity generation.

Therefore, an initiative to replace the electric energy that was used by the membrane distillation system to renewable energy is very reasonable according to all circumstances. There are so many sources of renewable energy can be gained and one of them is solar energy. Malaysia is located in the equatorial region and has a tropical rainforest climate. The tropical climate has been categorized as having heavy rainfall, constantly high temperature and relative humidity throughout the year. Being a country that is close to the equator, Malaysia naturally has abundant sunshine and also solar radiance. It is reported that average daily solar irradiations for Malaysia were from 3.73 kWh/m^2 to 5.11 kWh/m^2 (Engel-Cox, Nair, & Ford, 2012) with the highest usually recorded in March or April and the lowest is in November or December during monsoon season. Northern region and few regions in East Malaysia have the highest average daily radiation. With this plenty of sunlight throughout the year, Malaysia has big potential for solar energy applications (Dahlan & Ismail, n.d.).

A solar thermal system is one of the simplest and economical ways to utilize solar energy. This proven and economical technology has been around for decades for hot water, pool and space heating applications. Greece was one of the pioneers in Europe for the last decades with approximately one million installed solar flat plate collectors to save energy by using the unlimited solar potential (Islam, Saidur, Rahim, & Solangi, 2010). Yet, solar heat for industrial processes is still in the infancy stage of development when solar collectors are indicated to be able to supply heat until a temperature of 30 degree Celsius to 2000 degree Celsius (Faninger, 2010). Moreover, the average temperature for distilling process between 110 to 300 degree Celsius. It is reported in 2014, there are about 120 operating solar thermal system systems for process heat have been installed worldwide (International Energy Agency, 2014). In short, the implementation of solar thermal energy on membrane distillation system is very reasonable especially in Malaysian climate.

1.3 Objectives

The objectives of this project are:

1. To design and fabricate the solar thermal collector.
2. To identify the potential of the solar thermal collector in maintaining the desired fluid temperature in the feed tank.
3. To evaluate the performance of the SPMD system in seawater desalination process.

1.4 Project Scope

The scope of this project is design and fabrication of solar thermal collector for heating seawater in the feed tank that starting with screening and propose few types of design and material of the solar thermal collector such as using copper for the coil, plastic for the container, glass, pebbles, aluminum plate, and rubber foam as insulator and pump. Next is integrate the solar thermal collector with the system by modify the tank to ensure it is suitable when combined and evaluate of energy efficiency of solar thermal collector. Lastly is evaluating the water quality of the seawater after treated using the Solar Powered Membrane Distillation (SPMD) system. The evaluating was based on the rejection rate of salt.

CHAPTER 2

LITERATURE REVIEW

2.1 Solar Technologies

Membrane distillation system could gain both thermal and electrical energy through solar collectors where solar thermal collectors could provide heat while electrical energy could be supplied by the photovoltaic solar cells. Photovoltaic (PV) cell are main applications that convert solar energy into electricity through the transfer of electrons based on various technologies that is the crystalline silicon (c-Si), amorphous silicon thin film (TF) and Nano-PV. The photovoltaic cell photo current is directly proportional to the solar intensity. Additionally, the solar cell depends on the cell temperature. Solar cell works the most efficient in low temperatures. It was determined by their material properties since all cell materials lose their efficiency as the operating temperature rises. The high temperature has negative impact on the electrical output of the PV module, especially crystalline Si based cells, where their conversion efficiency would decrease by 0.4 to 0.5% per degree in temperature rise (Tonui & Tripanagnostopoulos, 2008). A High temperature and humidity experiment were performed to determine the performance degradation of PV cells. It was found that the inception of moisture causes a significant degradation in the short circuit current and maximum power output (Tan, Chen, & Toh, 2010). Power conditioning equipment and energy storage batteries maybe needed to supply energy to a desalination plat. Charge controllers are used for the protection of the battery from overcharging. Inverters are used to convert the direct current from the PV module system to alternating current. The electricity produced can be used to power the pumps. PV is widely use to reverse osmosis (RO) system nowadays but the high capital cost is a challenge if this technology is use (Mohammed & Fawzi, 2013).

Solar collectors are used to absorb and transfer solar energy into a connection fluid. They are divided according to the temperature level reached by the thermal fluid in the collectors. Low temperature collectors are those operating in the range below 80°C while medium temperature collectors are those operating at the range from 80 to 250°C.

2.2 Solar Collector Efficiency

Solar heat collector are based on several designs. It differs on their mechanism and applications. The first type of solar collector is evacuated tube solar thermal systems. Evacuated tube collectors have better thermal insulation in comparison with the flat plate collectors. Evacuated tubes consist of two concentric glass tubes that are sealed at the ends and the inner tube is coated with a solar selective coating. High vacuum is produced between the two tubes, thus eliminating convection loss and providing excellent thermal insulation. (Papadimitratos, Sarvenaz, Vladimir, Anzar, & Fatemah, 2016). However evacuated solar collector consumed a lot of cost in making them (Mehalic, 2009).

The second design of solar collector are flat-plate solar collectors. Flat-plate collectors are the most common solar collector for solar water-heating systems in homes and solar space heating. A typical flat-plate collector is an insulated metal box with a glass or plastic cover (called the glazing) and a dark-colored absorber plate. These collectors heat liquid or air at temperatures less than 80°C (Struckmann, 2008). The main components of a basic flat-plate solar collector are black surface that act as the absorbent of the solar energy; glazing cover, which is a transparent layer that transmits radiations to the absorber and prevent radiative or convective heat losses from the surface. Other component of flat-plate solar collector are tubes that contain heating fluid that will transfer heat form the collector to the thermal storage and it also needs a proper insulation that covered the sided and the bottom of the collector to prevent heat losses (John and Willie Leone Family: Department of Energy and Mineral Engineering, 2009).

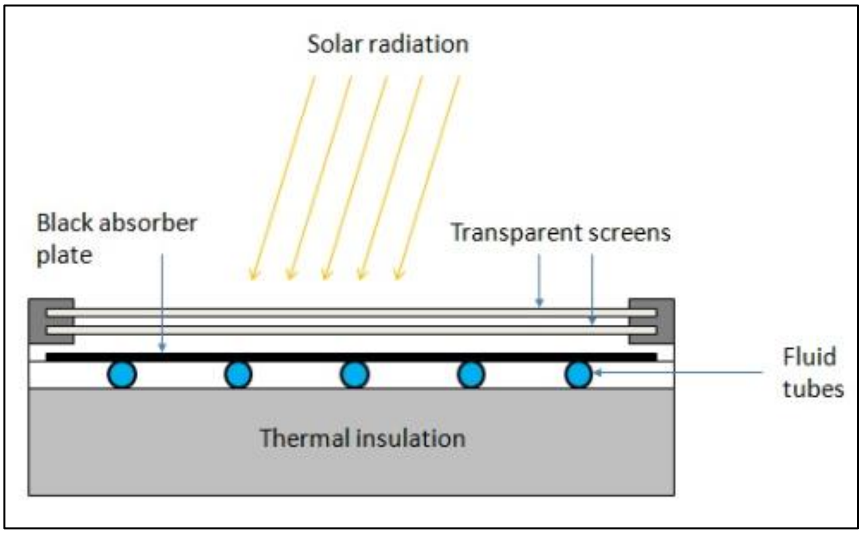


Figure 2.1: Flat-plate solar collector

When these two types of solar collector is compared together, evacuated tube shows that it has a higher efficiency compared to flat-plate collectors (Mario, Ingacio, Jorge, & Escobedo, 2016). Based on an efficiency testing performed at National Solar Test Facility Canada, they proves that evacuated tube are at the best when it comes to efficiency. In Sydney, New South Wales, based upon insolation of 426 W/m2 and an ambient temperature of 13.1 degrees Celsius, the evacuated tube solar collector is on average 104% more efficient compared to flat solar plate collector in winter. While in summer, the evacuated tube collectors are 50.5% more efficient with an ambient temperature of 21.3 degrees Celsius, based upon solar insolation of 840 W/m2. Figure below shows the result found by Hills Solar (Hills Solar, 2008).

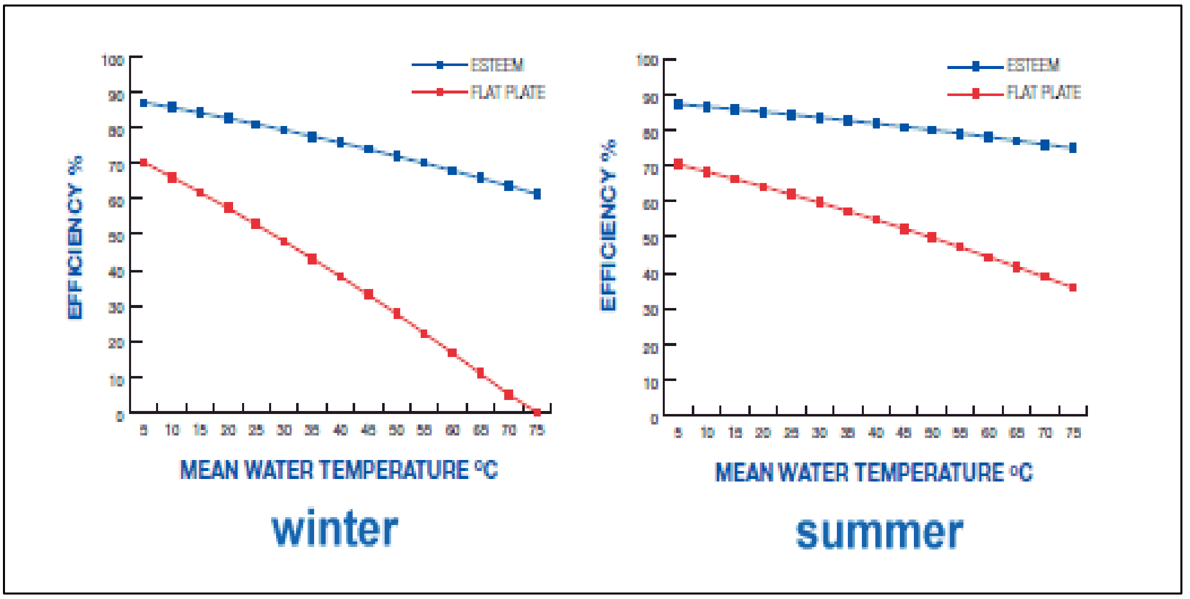


Figure 2.2: Sydney, New South Wales collectors' efficiencies

Generally evacuated tubes perform better in colder or cloudier conditions that their flat panel counter parts. This is because of the vacuum in the glass tube, which allows tube collectors to retain a high percentage of collected heat. They work well in freezing conditions while flat panels will not work. Moreover, due to the self-tracking design of evacuated tube collectors, they collect heat fairly evenly throughout the day starting within minutes of sunrise. Flat panel collectors must collect nearly all of their heat in the middle part of the day. Flat panel collectors need a constant presence of solar radiance and heat so that it can perform well in terms of efficiency.

2.3 Glazing Material

Glazing is the top cover of a solar collector. It performs three major functions in particular: to minimize convective and radiant heat loss from absorber, to transmit the incident solar radiation to the absorber plate with minimum loss, and to protect the absorber plate from outside environment (Society, 2009). An ideal cover should have maximum transmissivity for solar radiation and must be opaque to the long wave radiation emitted by the absorber plate. The important optical properties that determine the desired characteristics of cover are transmissivity, reflectivity and absorptivity, which are functions of incoming radiation, thickness of the cover, refractive index, and the extinction coefficient of the material. Apart from this the cover should be of low cost, durable, high abrasion resistant and weather resistant (Bansal & Sharma, 1986).

Usually the common materials used as glazing materials are glass and plastics (Bakari, Rwaichi, & Karoli, 2014). Glass is the principal material used to glaze solar collectors. Glass also have higher melting point that plastic making it more long-lasting. Glass material has highly desirable property of transmitting as much as 90% of the incoming short-wave radiation, while virtually none of the long wave radiation emitted by the absorber plate can escape outwards by transmission (Prasad, Byregowda, & Gangravati, 2010). To be specific, glass cover for solar collector normally should be at least 0.33 cm thick (Gang & Prakash, 2000). Compared to glass cover, a plastic cover possesses high short and long-wave transmittance and hence high performance.

Generally, the main advantages of plastics are resistance to breakage, light weight, and low cost. However, plastics have been reported to have limited life span due to the effect of UV radiation which reduces its transmissivity (Bakari, Rwaichi, & Karoli, 2014). Also, plastics are transparent to long-wavelength radiation and are therefore less effective in reducing radiated heat losses from the absorber plate. In addition, plastics cannot withstand high temperature encountered in collector especially when the collector is idle (Gang & Prakash, 2000).

2.4 Glazing Efficiency

An insulated glass solar thermal collector results from the combination of an insulating multiple glazing and a flat plate collector. In order to minimize the optical losses the solar absorber is positioned between the first (outer) and the second glass pane, even if the use of a double glazing as cover is also feasible with the aim of increasing the collector insulation and its efficiency (Giovanneetti, Kirchner, Kliem, & Hoeltje, 2014). Double glazing were usually applied at evacuated tube collectors, which has greater efficiency compared to flat-plate collectors. For this purpose, we use a double glazing with a low-emitting (low-e) coating on the inner pane to reduce the exchange of thermal radiation. Convective heat losses are reduced by filling the gap in the glazing unit with argon (Ehrmann & Reineke-Koch, 2012).

Single glazing should follow the suitable thickness to obtain the most efficiency for a flat-plate collectors. The major heat losses in the collector are from the glazing, since the sides and the back of the collector are often adequately insulated. The solar collector models with different glazing thickness had been successfully designed, constructed, and tested in this study. The experimental data were conducted and it could be concluded that the use of 4mm glass thick improves the performance of air solar collector by 7.6 compared to 3, 5, and 6 mm glass thicknesses. However, the risk for glass breakage during construction is high when using thinner glass, 4mm compared to 5mm and 6 mm, especially when constructing larger collector with longer/wider span. Therefore, optimization of efficiency and run ability owe to be made on whether to use 4mmglass thickness with precaution to avoid extra cost due to glass breakage (Bakari, Rwaichi, & Karoli, 2014)

2.5 Insulations

There are many common and cheap material that can be used as insulators for the flat-plate collectors. In order to decide which insulation is the best and suitable for thermal use, a few characteristic should be considered as benchmark and classification. To prevent heat loss through conduction, the back of the absorber and the side walls have to be insulated. The insulations must have a high R-value so that minimum heat losses can be obtained. When the collectors is assembled, the air trapped inside will contain moisture, which eventually will condense and soak the insulation. Insulations must be kept dry or it loses all or most of its insulating value (Alghoul, 2005). Besides, the insulation have to be resistance to vapour to avoid condensations from occurring.

Rubber foam is commonly used in the air conditioning system primarily to reduce heat gain or heat loss from piping. Other factors in usage of rubber as insulations include preventing the icing of water vapour and condensation on cold surface (Airconditioning-systems.com, n.d.). However, it can be apply on other purposes for example as a general insulations in solar collector as it serves the same properties needed as the piping insulations. Furthermore, rubber foam has a low cost of purchased with the low thermal conductivity which is about 0.037 W/m.K at 25 degrees Celsius (Netzsch, n.d.).

Mineral wool is a furnace product of molten rock at a temperature of about 16 degrees Celsius, through which a stream of air or stream is blown. More advanced production techniques are based on spinning molten rock in high-speed spinning heads somewhat like the process used to produce candy floss. The final product is a mass of fine, intertwined fibers with a typical diameter of 2 to 6 micrometers (GreenSpec, 2018). The thermal conductivity for mineral wool insulation are 0.045 W/m.K at a temperature of 25 degrees Celsius (Engineering ToolBox, 2003).

Figure 2.3: The Structure of mineral wool (GreenSpec, 2018)

Polyurethane is a polymer composed of organic units joined by carbamate (urethane) links. Polyurethane can be made in a variety of densities and hardness by varying the isocyanate, polyol or additives. The closed cell structure and high crosslinking density of PUR gives it the characteristics of good heat stability, high compressive strength and excellent insulation properties. The typical thermal conductivity for PUR is between 0.02 and 0.03 W/m.K (Zhang, Fang, Ling, & Tao, 2017).

2.6 Solar Thermal Energy Storage

There are three main aspects that need to be considered in the design of a solar thermal energy storage system: technical properties, cost effectiveness and environmental impact (Tian & Zhao, 2013). An excellent properties are the key factors to ensure the technical feasibility of a solar thermal energy storage system.

Firstly, a high thermal storage capacity (sensible heat, latent heat or chemical energy) is essential to reduce the system volume and increase the system efficiency. Next, a good heat transfer rate must be maintained between the heat storage material and heat transfer fluid, to ensure that thermal energy can be released/absorbed at the required speed. Thirdly, the storage material needs to have good stability to avoid chemical and mechanical degradation after a certain number of thermal cycles (Singh, 2016).

For cost effectiveness, it depends on the payoff period of the investment where it is mainly consists of three parts that is storage material, heat exchanger and land cost (Tian & Zhao, 2013). In general, these systems consist of a solar collector piped to the storage tank. The tank is levelled slightly higher than the collector to prevent reverse circulation (cooling) at night-time. Also, the distance between the collector and tank should be kept to a minimum to reduce hydraulic resistance for naturally circulated systems. Collector, piping and storage tank should be well insulated thermally to minimize heat losses to the ambient (Mohamad, 1997).

2.7 Heat Transfer Fluid

As for the heat transfer fluid, there are many types of sensible heat storage material that can be used in the system. Water can be circulated easily and hence can be used in active systems as both heat transfer fluid (HTF) and thermal energy storage (TES) material. Its advantages are high specific heat, non-toxicity, cheap cost and easy availability. Water can be used as ice, liquid and steam. Ice is used in cold storage. Liquid phase is used for low temperature heat energy storage below 100 degrees Celsius. Because it is easily available and it is a non-toxic, non-flammable material, it is completely harmless to people. Therefore water is the best suited thermal energy storage material for home space heating, cold storage of food products and hot water supply type of applications (Tian & Zhao, 2013). Water in liquid form can form thermocline heat storage. Due to density difference caused by heating of liquid, the buoyancy helps in creating a thermal gradient across the storage which is desirable (Gil, et al., 2010).

Other suitable heat transfer fluid are thermal oils. Advantage of thermal oils over water is that they remain in liquid phase at higher temperatures than water up to 250 degrees Celsius under atmospheric pressure. Thermal oils have an operating temperature range between 12 degrees Celsius and 400 degrees Celsius, which means higher temperature difference can be obtain and more heat storage. Thermal oil has low viscosity and good flow properties. It can be circulated easily with lower pumping costs. It is used in active systems as both heat transfer fluid (HTF) and thermal energy storage (TES) material. Thermal oils have mediocre heat transfer characteristics (Tian & Zhao, 2013).

2.8 Coupling membrane distillation with solar energy collectors

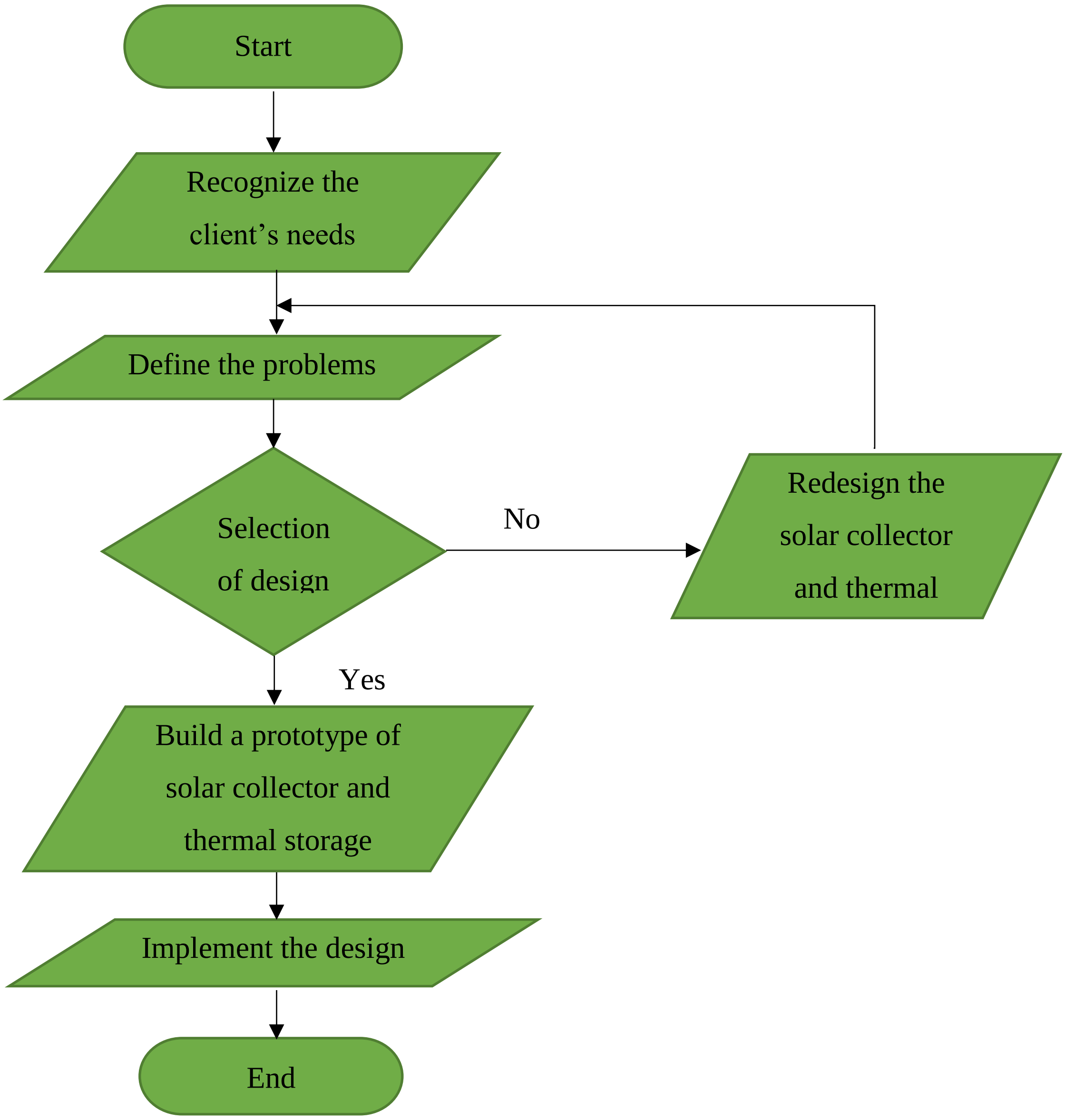
The combination of membrane distillation system with solar energy collectors has been in been in the interests of the researchers since membrane distillation could tolerate fluctuating and intermittent operating conditions as it requires low grade thermal energy. There are two configurations that is suitable of combining solar energy with membrane distillation. The solar assisted membrane distillation desalination system comprises solar collector which feeds hot water to the MD module. The heat were directly supplied to the MD modules either directly or through heat exchanger. Electricity needed by the system were supplied by the electric grid or auxiliary generator to drive all pumps and other electric powered components. Other alternatives are the stand-alone solar powered membrane distillation system that is improved with PV cells, integrated with direct current (DC) battery cells and electric current inverters instead of generators to supply the necessary electricity (Mohammed & Fawzi, 2013).

The first publication used a $3m^2$ flat solar collectors (Hogan, Sudjito, & Fane, 1991) described that the thermal and electrical energy consumption was 55.6 kWh/m3. Another solar powered membrane distillation system was installed by the Water Re-use Promotion Center. It is consists of flat plate PV module and a $12m^2$ field of vacuum tube collectors. The system were started automatically whenever sufficient sunlight is present to provide how water and electricity for the pumping from the solar collectors and PV panels. The plant had a maximum productivity of 40 liters per hour (Thomas, 1997). A design of a solar-heated hollow fiber vacuum membrane distillation (VMD) system for potable water production taken from underground water were described to have four major components that is the solar collector, a hollow membrane module, a permeation condenser ad two mechanical pump (Wang, Zhang, Chen, & Yang, 2009).

CHAPTER 3

METHODOLOGY

3.1 Design methodology



The flowchart shows the process of designing for solar powered membrane distillation system. Firstly, the needs of the clients or community need to be identify. In this case, the main need is to provide a stable supply of water for the community despite the irregular pattern of rain and hot season happening in Malaysia’s climate. It is crucial that it is needed for a system that are able to recycle and reuse raw water supply from many source so that it can covers the clean water demands.

Secondly, after identifying the community’s need, we need to define the upcoming problems that can be solve with this project. For example, the membrane distillation system requires a lot of energy especially in the heating and cooling process throughout the system. As huge energy will consume great amount of electricity supply, this system does not perform at its most efficient state as it consumed much electrical energy. As we know, Malaysia generates most of their electrical energy though hydraulic and non-renewable energy, so to solve the excessive usage for these sources, we need to create a new alternative to increase the usage of renewable energy instead on non-renewable energy. That is where, the solar powered membrane distillation system is needed in the community.

Thirdly, after recognizing the design parameters that is needed for the project, a few designs were established to make sure that the best design will be use for the project. During selection of design, the designs that were created are compared by certain features and characteristics so that the design will fit to its surrounding environment and satisfy the clients’ inquiries and needs. It is make sure that the project does not give negative impact on the environment in the future. If the design were rejected, a new series of design will be introduced so that the best product can be produce.

After the design was finalized, the prototype of the project is made to match the all the characteristics that is stated in the design. This is to make sure there will be no error in fabricating the design in the future. The process of the designing steps ended after the project is implemented and testing were done to make sure it is suitable and qualify with the parameters needed for the whole system.

3.2 Theory

There are many characteristics and aspects to be considered in order to build an efficient solar collector completed with effective thermal energy in order to minimize the use of electricity. Some factors that need to be considered for solar collector is types of solar collector used, which differs on their efficiency, surface area and cost factors. Next, other factors should be considered such as the amount of seawater need to be heated, the amount of sunlight/thermal energy received by the collector, space for the whole system, the backup thermal sources and the intended purpose for using the collectors.

3.2.1 Amount of solar thermal energy

The amount of solar thermal energy is needed to determine the flow rate and velocity of the heat transfer fluid so that maximum energy can be obtained. The types of solar collector used also is depending on this factors since a suitable solar collectors need to be chosen within the climate and the humidity factors.

3.2.2 Types of solar collector

The type of solar collector that will be used is very important since it will affect the efficiency of the whole system. The selection are depends on the cost investment and the surrounding environment.

3.2.3 Volume

The volume of the seawater that is needed to be heated need to be controlled since it will affect the height of coil containing the heat transfer fluid that will do the role of heating the seawater by heat exchange process. If the coil is too deep into the seawater or too small for the volume of the seawater, the heat will not be distributed equally. The volume of the sea water should be set as the volume of the thermal storage so that a fixed volume can be determine for every cycle.

3.2.4 Tubing and pressure

The tubing for the coil in the solar collector and the thermal storage will be the design factor that can affect the flow rate of the heat transfer fluid (HTF) in the coil. The pressure should be altered and monitored to determine the effective HTF flow rate so that enough energy could be transported and exchanged.

3.2.5 Solar powered heating mechanism on DCMD System

The solar powered heating mechanism in DCMD system is consist of two components that are solar thermal collector and thermal heat storage. The solar collector was filled with thermal fluid so that they can transfer the thermal energy to another medium. The solar collector was accomplished with an outlet and an inlet to enable the thermal fluid to circulate in the solar collector.

The first process begins at the exposure of the solar collector plate to the sunlight or any source of heat radiations. The solar collector then will change the solar radiation to heat energy by transferring the heat from the glass cover, to the thermal absorber and to the heat transfer fluid inside the coil tubing underneath the absorber. The cool thermal fluid that entered from the inlet of the coil tubing will continue to absorb as much heat from the absorber to be carried out to the thermal heat storage that contain the seawater.

Due to the height difference between the thermal heat storage and the solar collector, the hot thermal fluid will move to the higher places through thermosiphon mechanism. However, the pressure is not enough to support the required flow rate in the thermal heat storage. In the thermal heat storage, a backup heat source is added to the system since the solar thermal collector alone will not be able to heat the seawater to the desired temperature but the thermal heat storage is built at the most efficient way to avoid heat losses.

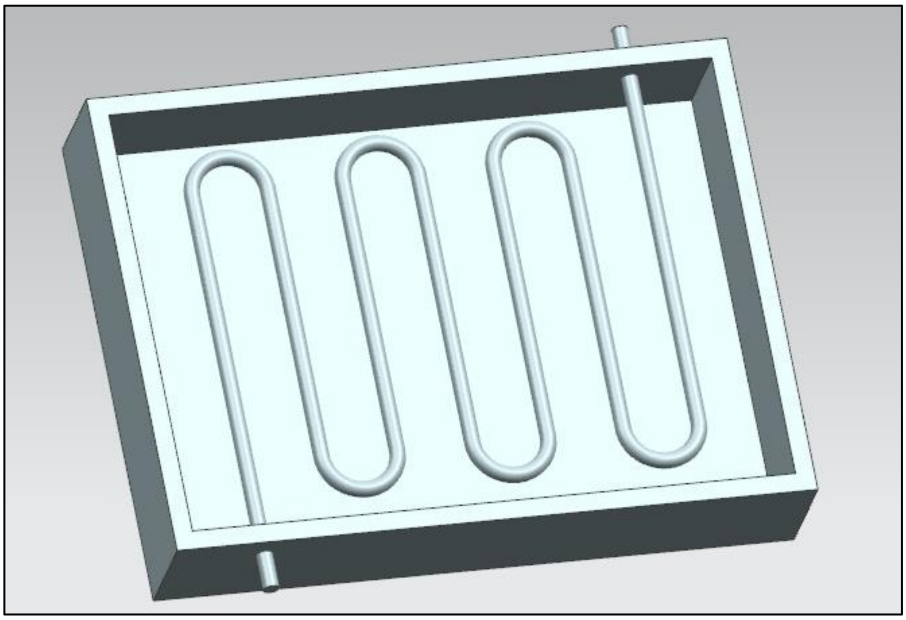


Figure 3.1: The design of the solar thermal collector.

Figure 3.2: The design of the heat exchanger tank.

These two design were combined by connecting both element using insulated plastic tubing so that the heat transfer fluid (HTF) could transfer the heat absorbed from the thermal collector to the heat exchanger, to the desired fluid to be treat by the membrane distillation system.

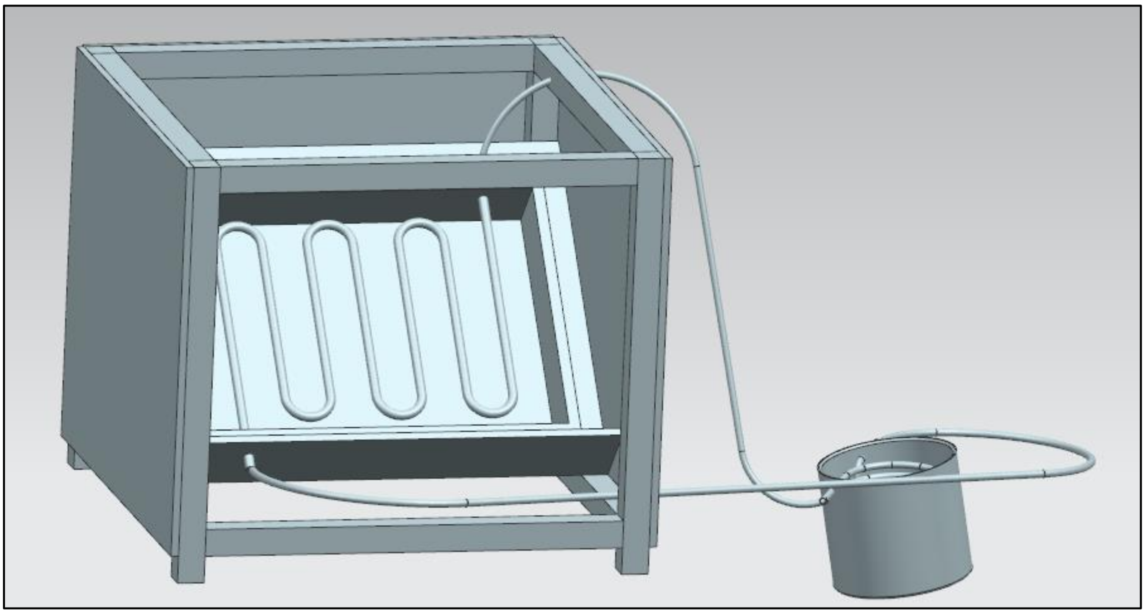


Figure 3.3: The combined oriented design for solar thermal collector and the heat exchanger tank.

3.3 Material Selection

The function of a solar thermal installation is to take advantage of solar energy to generate heat. The solar panels of these facilities capture the heat of the solar radiation that falls on them to heat a fluid. The different ways to take advantage of this hot fluid allows us to use this type of renewable energy in multiple applications (Solar Energy, 2018). The main component of the solar thermal collector are the absorber plate, that was treated with selective surface type so that it could absorb radiation to its maximum amount, a transparent cover or glazing to trap the heat inside the collector by creating a phenomenon same as 'Greenhouse effect". Other than that, solar thermal collector a layer of insulation to avoid the heat from escaping, a flow tube for the heat transfer fluid to circulates and also a container to fit all those elements in one structure. Additionally, a tank contained flow tube coil are complimentary for the system since it acts as the heat exchanger.

For the container, a simple baking tray made out of high density polypropylene since the material type has high melting point and high thermal resistance that will make heat from inside of the container could not escape easily. The size of the container (350mm X 480mm) were suitable enough for the membrane distillation system capacity and size.

Figure 3.4: The container used as closure for the collector

For the absorbing plate, an aluminum plate were used as aluminum was the second best metal after copper when it comes to heat conductivity. Due to higher machinability, aluminum was used as the absorbing plate located between the flow tubing and the insulation. The metal plate were decided to be thin so that the heat could be absorbed faster and can be transferred faster to the flow tubing.

Figure 3.5: The 1mm aluminum used as the absorbing plate (Handy Steel Stock, 2018)

Copper works best as a flow tube in the solar collector and for the coil in the thermal exchanger tank. Copper is the best heat conductor among most metal. It will be able to absorb solar heat radiation at a maximum rate efficiently. With that, the time taken for the fluid in the heat exchanger tank to reach the desired temperature could be shortened. A small diameter of copper tube were used to ease the machining and bending process.

Figure 3.6: The 3/8" were used as the flow tube in solar collector

The insulation that were suitable for these design are made out of rubber. Rubber foam are mostly used in the heating, ventilating and air conditioning (HVAC) system as insulations. The insulation will be put at the bottom of the structure so it can limit the amount of heat losses from the collector.

Figure 3.7: The thickness of the rubber are 14 mm.

A low iron glass was used as the transparent glass that would cover the container. Glass are more durable and more resistance to high temperature compared to Perspex or acrylic since glass have a higher melting point compared to the other material suggested. The container needed to be sealed so that heat losses would occur less and that would increase the collector's efficiency.

The heat exchanger tank was made out of stainless steel due to its high resistance to corrode or rust. Since the tank will be exposed to fluid and air, a high resistivity from oxidation is crucial so that there would be no foreign substance from chemical reactions to be present in the fluid that will be treated by the membrane distillation system. A tank with a volume of 500ml were used to increase the consistency of the tank to maintain the temperature of the fluid inside.

Figure 3.8: The tank will be containing with copper coil and will be used as the feed tank

3.4 Fabrication process

3.4.1 Rack for solar thermal collector

To make sure that every parts in the system were organized, a rack that fit the solar collector were able to be transported and simulate the angle of the installation that is usually situated on the roof of the building. The rack was made out of mild steel hollow according to the designated measurement to make the rack's size to be suitable with the solar collector's size. The tools that were used to fabricate the rack were including portable abrasive cut machine, hand drilling machine, measuring tape, ruler, L-square ruler, MIG welding machine, abrasive angle grinder, rivets and others.

Material/ Machine	Description/Purposes
Mild Steel Hollow (SHS) 	The mild steel could withstand the weight of the solar collector. So it was used for the rack's material. Characteristic: 25mm X 25mm X 2mm Square Hollow Section (SHS)
Portable Abrasive Cut-Off Machine 	The abrasive cutter were used to cut the mild steel shaft into certain parts and measurement.

Table 1 (a): Parts of the material and machine used in fabrication process

Material/ Machine	Description
Combined Sander machine 	The sander were used to remove remaining chips on the mild steel shaft to ease the welding process.
MIG welding machine 	Welding were done to assemble all shaft into a structure of a rack. The process continue after all chips from the cutting process were removed.
Rivet 	The rivets were used join the 3.mm aluminum plate on the rack.
Cordless Hand drill and drill bit 	A 3.5 mm drill bit were used to make holes on the rack and the aluminum plate to allow the rivet to penetrate and able to attach the plate to the rack.

Table 3.1 (b): The tools, material and machines used in fabrication process

Figure 3.9: The hand riveter were used to rivet the aluminum plate to the rack

3.4.2 Solar thermal collector

The fabrication process for the solar thermal collector starts with the installation of the insulation at every wall inside the container for the collector. The insulation were firstly cut into a few sections to fit with each other to make sure there will be uncovered spaces exist in the container. The insulations were glued to the container by using Dunlop contact adhesive glue.

Figure 3.10 (a) and (b): The process of attaching the insulation on the container

For the absorbing plate, a 1mm aluminum sheet were sheared according to the inside measurement of the collector’s container. This cut aluminum sheet were then coated with dull black paint or a solar collector paint to allow the plate to absorb heat more efficiently.

Figure 3.11: The aluminum were coated with dull black paint

Next step is cutting and bending the copper tube into desired pattern that is the serpentine pattern. The copper were straightened and the required length for the copper needed to be put in the collector were calculated so that the copper could be cut into smaller length to ease the bending procedure.

Figure 3.12 (a) and (b): The tools used to cut and bend the copper tube

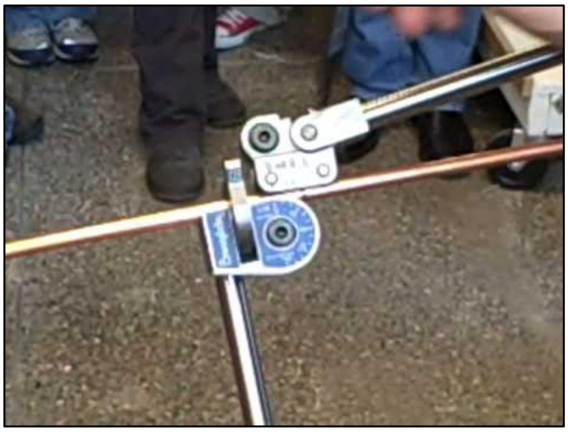


Figure 3.13: The method used to bend the copper tube

Two holes were made on the container for the inlet and the outlet section for the collector. Other than that, a few other holes were marked and drilled on the aluminum plate to attach the copper tube on it later to make sure the plate and the tube will be in contact with each other. This is to allow efficient heat transfer from the plate to the copper tube. Then, cable ties were inserted into the holes before the plate were assembled into the container. The copper tube were then added carefully enough not to damage the coated aluminum plate.

Figure 3.14: The copper were attached to the aluminum plate by using cable ties.

3.4.3 Heat Exchanger Tank

The heat exchanger tank was begun with the coiling of the copper tube so that it can be fit inside the tank. For the first step, a long copper tube was cut into a certain measurement that is needed. Then, one end of the copper was clipped close to allow sand to be filled into the hollow copper tube before the copper were coiled. After sand had filled the copper tube and no empty space were ensuring to be in the copper, the other end of the copper tube was clipped. This is to avoid kinks and leaks on the copper tube to occur in the bending process. A PVC pipe with the desired diameter for the coil were then clamped to a fix table before the copper tube were clamped on the pipe. After the coiling procedure ends at the desired measurement, both ends of the copper tube were cut and the sand were discarded from the tube by vibrating the tube and by inserting air from the air compressor into the tube.

Figure 3.15: The winded copper coil ready to be installed into the tank

Before the copper coil were installed into the tank, a holes were drilled at both sides of the tank to act as the inlet and outlet for the coil. The tank was then insulated with rubber foam to minimize the amount of heat that will be escaping the tank.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Flow and heat computer aided simulation

All the components for the heating mechanism for the SPMD, which are the heat exchanger tank, and the solar collector were then assembled where piping were connected with each inlet and outlet. The system was also assisted with a pump to avoid backflow and allow the heat transfer fluid to circulate the closed loop system in one flow.

Figure 4.1: The completed system of the solar heating system for SPMD

Other than that, a simulation were done based on the testing results to compared and identify the velocity, temperature flow, and the pressure drop heat transfer fluid in the copper tubing inside the solar collector by using computer aided design and simulation NX 10.0. As for the dimensioning and number of turns for the serpentine-shaped copper tube were the same as the fabricated design.

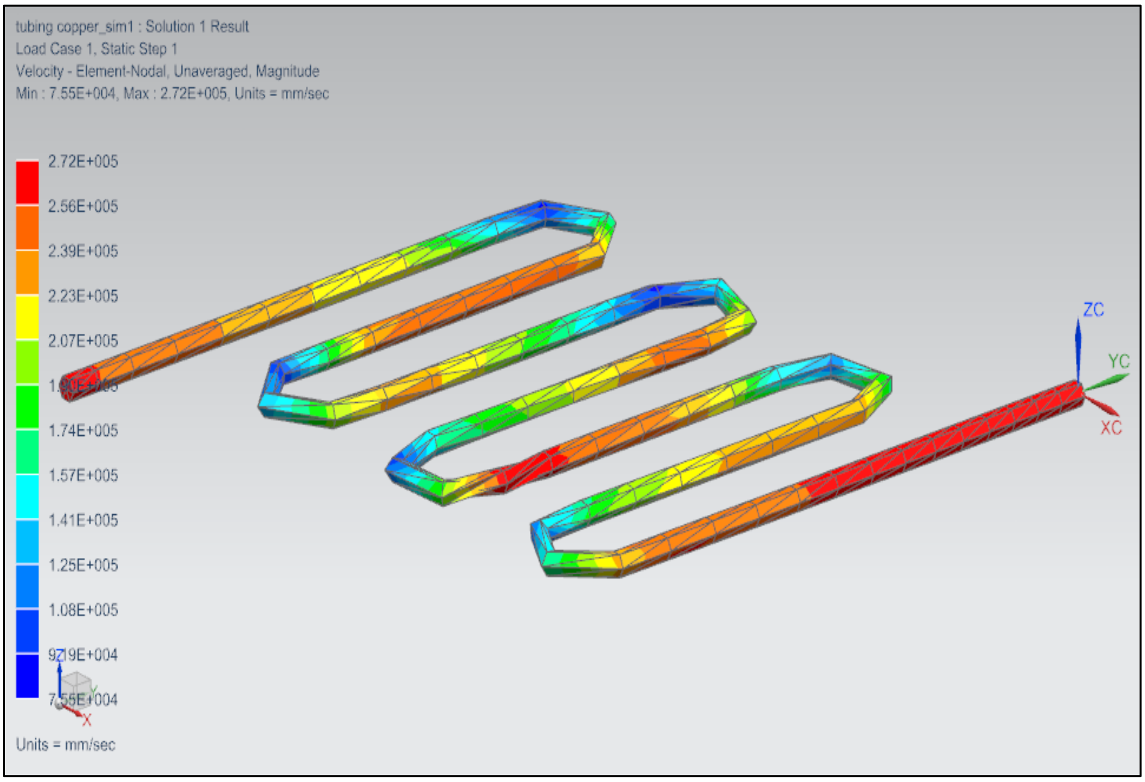


Figure 4.2: The fluid velocity of the simulation

As for the first simulation result, it is based on the velocity of the fluid inside the coil. The simulation showed that the velocity of the fluid when it is entering the tube at a volume flow of 1000 Liter per hour. The result shows that the velocity of the fluid at the inlet are the fastest compared to the other component in the tube. The simulation showed that the velocity started to decrease and were the lowest when the fluid past through the serpentine sections. Like a river, the fluid will lose their momentum after the obstacles. The viscosity of the fluid affects the fluid to imitate the shape the tube and when it reaches the curve, the streamline will be thinner to wall of the tube. The velocity normalized when it passed after the curve due to the centripetal force exist due to the pressure difference at the inside and outside walls of the tube.

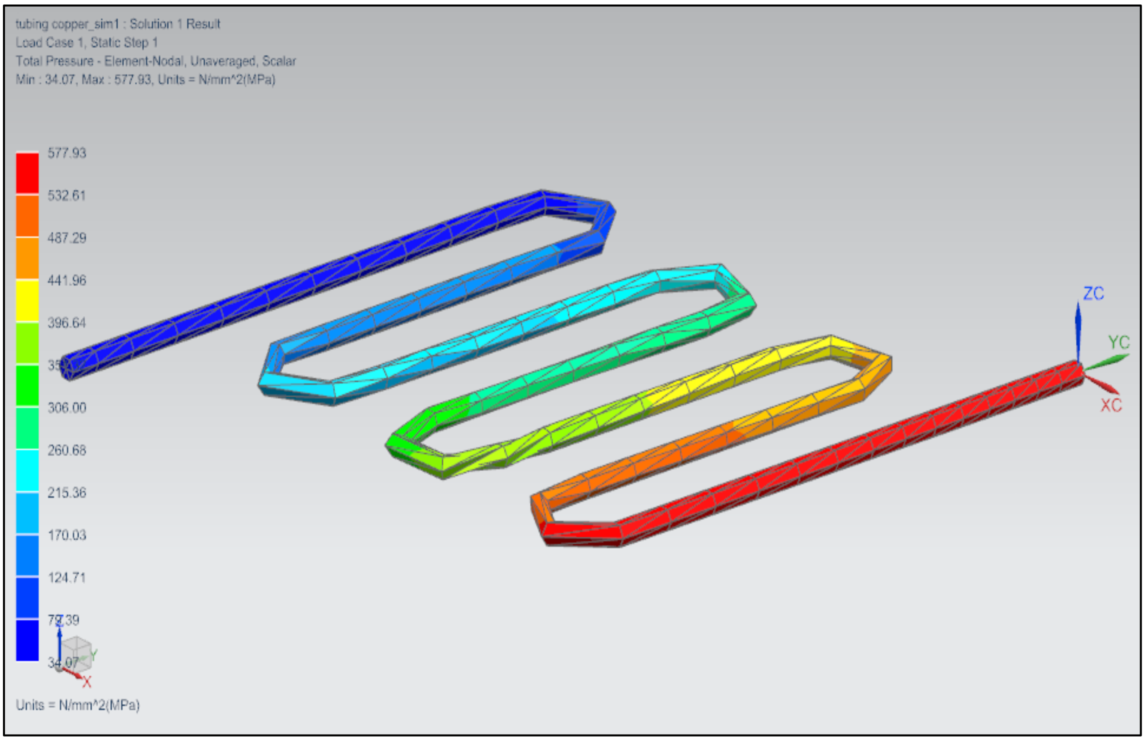


Figure 4.3: The total pressure of the simulation

The total pressure of the simulation shows that serpentine shape will give pressure drop from the inlet to outlet of the tube. This is may be due to the frictional force between the fluid and the wall of the tube that could cause resistance to the flow of the fluid. The pressure drop also was affected by the friction loss when the fluid passes through curves. Excessive pressure drop will lead to poor system performance and excessive energy consumption is needed for the circulating pump.

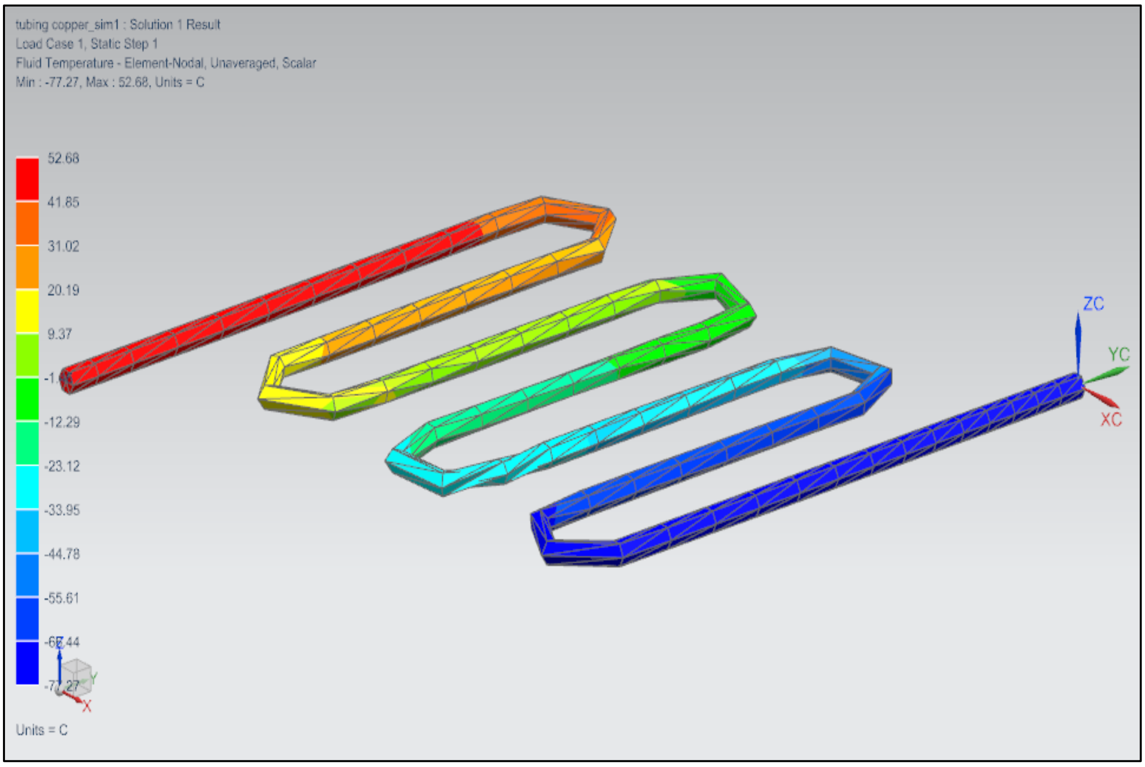


Figure 4.4: The temperature of fluid of the simulation

The temperature of the fluid was increasing as it approaches the outlet were resulted to be grater that the inlet fluid temperature. This is due to the solar collector's behavior and performance by gaining heat from the solar radiation and the copper tube transferred the heat gained efficiently. The pressure drop also affects the temperature of the fluid since the slower the fluid runs in the tube, the greater heat could be gain from the trapped irradiation heat in the collector and through the conductive heat receive from the absorbing plate under the copper tube.

4.2 Project Planning

4.2.1 Gantt Chart for SDP 1

Table 4.1: Project Timeline Senior Design Project 1

Activities	Week													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Group members recruitment														
Title briefing from supervisor														
Discussion on the project and task distribution														
Literature survey														
Generate and analyze designs														
Select & finalize the practical design														
Material listing														
Proposal's first draft preparation														
Submission of the proposal's first draft														
Project advisor's approval of the proposal's first draft														
Prepare the presentation slides														
Present the proposal														
Improvisation of the proposal														
Submission of the final proposal														

4.2.2 Gantt Chart for SDP 2

Table 4.2: Project Timeline Senior Project Design 2

Activities	Week														
	1		3	4	5	6	7	8	9	10	11	12	13	14	15
Fabrication of Solar Thermal (bend coil)	■	■	■	■	■										
Glue insulator and spray plate				■	■										
Do coil in feed tank						■	■	■							
Do stand for solar thermal					■	■	■	■	■						
System successfully built									■	■					
Making sample and first testing										■					
Do piping from solar Thermal to Feed tank										■	■				
By using the system, evaluate the performance											■				
Test the and analyzation											■	■	■		
Record of the results obtained.											■	■	■		
Presentation														■	
Final thesis report														■	■

4.2.3 MILESTONES for SDP1

Week 1 : SDP briefing coursework and distribute group

Week 2 : Briefing about the project title "Solar Powered Membrane Distillation" and scope of work of each member from supervisor.

Week 2 to 7 : Generate new designs for solar power for heating at the feed tank. Literature survey about previous designs to decide the most practical one that can be used in our project and do the analysis based on several designs and survey for material list.

Week 7-9 : Select & finalize the practical design with the list of material and prepare the Proposal's first draft for Submission of the proposal's first draft.

Week 10 : Submit the proposal draft to supervisor.

Week 10-11 : Project advisor's approval of the proposal's first draft

Week 11-12 : Do the correction of the draft proposal by the supervisor and prepare the presentation slides.

Week 13 : Present the Project proposal to the panel.

Week 13-14 : Correction of the final proposal based on panel comments if applicable.

Week 14 : Submit the final proposal after correction to the supervisor.

4.2.4 MILESTONES for SDP2

Week 1-3 : Start fabricate the Solar Thermal and modify the feed tank. Then, do piping from solar Thermal to feed tank to connect both part.

Week 3-4 : Do insulation at the system to avoid heat loss.

Week 4-5 : The system are completely build.

Week 5 : Sample Collection from industry.

Week 5-7 : Test the untreated wastewater quality at the water sample and at the same time evaluate the performance of the system using the water sample from adjusting the flowrates and temperature to get the best performance of the Solar Power Membrane Distillation system.

Week 7-9 : Test the treated water quality and analysis of the results obtained by using theoretical analysis method.

Week 9-12 : Prepare and submit the final thesis of report.

4.3 Cost analysis

The project was funded by the Faculty of Engineering Technology (FTech) of RM1500.00 per team. So the team had priorities a list of material that needed to be used and were compulsory for the project.

4.3.1 Solar Collector and Feed Tank

No	Items/ materials	Specifications	Unit	Price per unit	total
1	Oxidized copper	- Length : 10m - Diameter : 0.375m	10m	Rm5.00	Rm 50.00
2	Stainless steel tank	- Volume: 6.28 L	1 unit	Rm 55.00	Rm 55.00
3	Bakery Tray	- Area : 0.64 m x 0.32 m	1 unit	Rm 37.00	Rm 37.00
4	Aluminum Sheet	- Area : 0.62 m x 0.32	2 unit	Rm 08.00	Rm 16.00
5	Insulator Foam	- Area : 15 inch x 15 inch	13 inch	Rm 3.67	Rm 47.71
6	Marble Tiles	- Area 0.64m x 0.32m	1 unit	Rm 79.00	Rm79.00
7	Clear Glass	- Area 0.64m x o.32m	1 unit	Rm 30.00	Rm 30.00
8	Steel Plate	- Thick : 0.005 m - Area : 0.5m x 0.5m	3 unit	Rm 12.00	Rm 36.00
9	Mid Steel Hollow	- Area 0.02 m x 0.02 m - Length 0.35 m	12 rods	Rm 04.00	Rm 48.00
TOTAL					Rm 343.71

Table 4.3: The total cost for the fabrication of the solar collector and the tank

4.3.2 Electrical Parts

No	Items/Materials	Specifications	Unit	Price per unit	Total
1	Halogen Lamp	Power : 500 watt, 300 watt Type : Stainless steel housing	2 unit	Rm 35.00	Rm 70.00
2	Plug Socket	Type : White Housing Socket	3 unit	Rm 8.45	Rm 25.35
3	Plug Top	Current : 13 ampere Output : 5 volts	3 unit	Rm 4.90	Rm 14.70
4	Main Switch Breaker	Current : 32 Ampere Type : One pole	1 unit	Rm 25.00	Rm 25.00
5	Earth Leakage Circuit Breaker	Current : 32 Ampere Type : One Pole	1 unit	Rm 15.00	Rm 15.00
6	Miniature Circuit Breaker (MCB)	Current : 32 Ampere Outputs : 13 volt	3 unit	Rm 4.50	Rm 13.50
7	Busbar Electrical	Types : Copper	3 unit	Rm 3.00	Rm 9.00
TOTAL					Rm 172.55

Table 4.4: The total cost for the electrical wiring and parts

4.3.3 Others

No	Items/Materials	Specifications	Unit	Price per unit	Total
1	Clear rubber tube	Thick : 0.002m Length : 15m	10m	Rm 1.33	Rm 13.33
2	Valve	Diameter : 0.25 inch Type : One way Brass Ball	2 unit	Rm 3.50	Rm 7.00
3	Tube Insulator	Diameter : 0.01 m Type : Rubber tube heat resistance	4m	Rm 2.50	Rm 10.00
4	PTFE tape	Length : 50 mm	2 unit	Rm 1.50	Rm 3.00
5	Tube Clamp	Types : Stainless steel Size : Adjustable	4 unit	RM 0.50	Rm 2.00
6	Spray Paint	Colors : White, Black, Gold	6 unit	Rm 7.90	Rm 47.40
TOTAL					Rm 82.73

Table 4.5: The total cost for the other component along piping and fabrication process

4.4 Ethical Consideration

The most crucial tasks attended in this project are the evaluation of the SPMD performance and the solar collector efficiency, material purchasing, the designation and the fabrication of this project. Many test were run to make sure the product designed would give a successful outcome and can be run functionally.

Before all the steps were started, we had to be aware of the safety measure and regulations to be followed when we were using the facilities provided by the university. We had to attend lab handling training for the workshop and laboratory in order to avoid any possible incidents and injuries that could occur during the machines, tool or chemical handlings along the process of making this project into success. We were informed to wear proper PPE before entering the lab or the workshop. For example, we are compulsory to wear the safety shoes and goggles when entering workshop and wear lab coat and gloves when handling chemicals. This is important since the student might not be monitored personally by the lab instructor since of the tight schedule and the students are using the facilities regardless of time whether it was in office hours or not. Besides that, teaching engineers play a major role in providing guidance during fabrication process and any incident that has happen should directly report to the teaching engineer that in charge in the workshop to minimal the risk of students.

The tasks were divided equally among the members in the group to make sure the project could be completed in the required time. However, a good team work and respects among team members were implemented in the team and were considered important in the team. All of us have some major task and contribution in various parts such as manufacturing, fabricating, water testing and economic analysis based on our skills and knowledge.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In conclusion, the solar thermal collector for seawater heating purposes has been fabricated and designed. the potential of the solar thermal collector in maintaining and heating the desired fluid temperature in the feed tank has been identified and the performance of the solar powered membrane distillation system (SPMD) in seawater desalination was successfully evaluated hence had solved the problem that has been circulated in the environment. By designing the solar powered membrane distillation (SPMD), this project able to minimize the dependency on the electrical sources in heating the salt water. Other than that, the efficiencies rate of heat collect can be achieve maximum by 30% to 40% through the design and material that had been proposed. Finally, from SPMD also can improve the salinity of salt water from the previous recorded data.

5.2 Recommendation

The design for this solar collector had achieved the required temperature and could maintained the temperature the desired fluid in the tank successfully. However, a high amount of time had been consumed to heat the fluid in the feed tank to a required temperature. These problem could be overcome by increasing the features of the collector by adding double glazing to trap more heat in the collector or changing the design to a concentrated type of collector, which will consume a lot of costs. As heat could escape easily from the system, the piping for the system should be insulated more tightly to avoid heat loss. The system will also be easier if and automation for the monitoring system for the flow rate, pressure and the temperature change occurred in the collectors and the heat exchanger tank. Other improvement that could be made in this project is replacing the whole electrical supply for the pumps and chiller that is involved in the system to solar PV. This would allow the mobility of the system and cut the energy consumption of the SPMD from the electric grid.

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