Experimental investigation on fresh water production using air gap membrane distillation

Mohamad Hafizuddin bin Roslan, Rubina Bahar, Irfan Hilmy

Abstract--- ***Fresh waters are one of essential element to human being. Since five years ago, certain area in Selangor, Malaysia, facing insufficient water supply due to the lack of fresh water resources and the increase of maintenances cost. To overcome this problem, other alternatives in producing fresh water should be implemented. As a suggestion, freshwater production using membrane distillation could be utilized. Membrane distillation with solar heat as a main power source is a good solution for this problem. This mechanism not only could help in producing enough fresh water supplies, but also could help reducing the use of non-renewable energy. Heating mechanism using solar panel was utilized. However, to use this mechanism, study about the way to confine the heat, and the mechanism compatibility should be done first. To achieve those requirements, the overall system of fresh water production should be evaluated first. The performance of the current system has been evaluated. From the result, it can be seen the potential and feasibility of this system to produce the fresh water.***

Keywords: Solar heater; Membrane distillation; Heat transfer.

1. INTRODUCTION

Water is a vital element in everybody's daily life. Certain areas in Selangor like Klang valley have been reported experiencing lack of water supply [1]. This problem may arise due to lack of water resources and the increase of fresh water production and maintenances cost. In this paper, the idea to produce fresh water by utilizing solar heat has been developed. This renewable energy alternative is predicted could reduce the cost and help the campaign to produce a better environment.

Solar heat is one of the application from the solar energy, where the solar heat is absorbed using a collector that thermally increase the water temperature. The system is commonly used in Japan, China, India, and Europe in order to produce hot water for daily and industry application. There are several types of collector that are being used in this system such as: flat plate, evacuated tube, integral collector storage, and thermo siphon. Each collector has their own type of material and mechanism to absorb heat energy from solar radiation. In this paper, flat plate is the one that being used due to the availability and cost.

In fresh water production, membrane distillation technique is getting its popularity due to the low heat energy requirement. This technique produces fresh water by filtering the water waste or dirty water through polymer membrane. This kind of membranes are hydrophobic that only allow water vapor to pass through. The vapor movement is induced by water temperature from high to low temperature. Next, the vapor that passes through the membrane are condensed and become distilled water. The solar heat will supply heat to the membrane distillation system that will produce temperature difference for the vapor movement.

There are several types of process being used to produce fresh water such as: reverse osmosis, ultra filtration, nano-filtration, and multi-stage filtration. However, most of those processes are energy intensive that made membrane distillation a viable option. For example, reverse osmosis need a huge pressure that leads to a high energy usage. Meanwhile, membrane distillation only needs ambient pressure and low grade heat to convert water to vapor by evaporation and induced the temperature difference by using solar heat. There are no other types of energy needed. Moreover, using this process, the water output can be ensured completely safe for the daily usages.

The objectives of this research were: (1) to investigate the feasibility of using solar heat in fresh water production, (2) to study how Air Gap Membrane Distillation (AGMD) process can be utilized in a solar heat system to produce fresh water and (3) to evaluate the performances of overall fresh water production system.

2. AIR GAP MEMBRANE DISTILLATION

Direct Contact Membrane Distillation (DCMD) is one type of MD configurations that usually being used. This is due to the less complicated in structure, process operation and design. The configuration is called direct contact since it has a liquid phase that contact directly with both side of the membranes.

In a DCMD, water vapor is passed through hydrophobic porous membrane from feeder side. On the other side, the cold water flow directly to condense the vapor. The vapor diffusion path is depending on the membrane's thickness. The fresh water produced in DCMD is pure and it is suitable for medical, pharmaceutical, and semi-conductor sectors. The highest DCMD permeate recorded is 145.8 kg/m2.h using distilled water as a feeder [2]. The condensation process within the pores can be avoided by using suitable temperature differences.

AGMD types of membrane distillation system were utilized as shown in Figure 1[3]. In AGMD, there are

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additional air gap between the membrane and the condensation surfaces. In this case, impermeable film was used as the membrane.

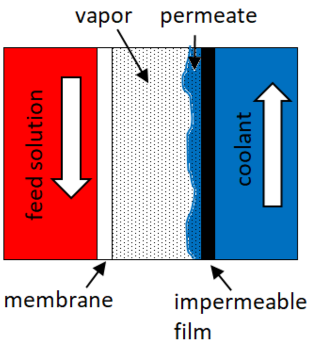

Fig. 1: AGMD configuration

Similar with DCMD, it was driven by temperature differences that lead to pressure differences. The polluted water evaporated at the feed solution side then passed through the membrane and being condensed at the cooled surface of the permeable film. Then, the water produced from the condensation process will flow through gap to the tank provided. This configuration allowed higher temperature differences to be applied across the membrane which can compensate greater transfer resistance. There will be low quantity of heat lost from the feed chamber because of the air existence between the cold and the hot chamber (feed chamber). Around 15.5% of MD experiments were using AGMD mechanism in the process [4]. This phenomenon is due to the versatility of AGMD and AGMD also has a good perspective in futures. On top of that, AGMD also has been scale up to the pilot plant size of experiment although their permeate flux is less than DCMD.

In fresh water production, membrane distillation technique is getting popular due to the low heat energy requirement. This technique produces fresh water by filtering the waste water or dirty water through polymer membrane. This kind of membranes are hydrophobic that only allow water vapor to flow. The vapor movement is induced by water temperature from high to low temperature. Next, the vapor that pass through the membrane were condensed and become distilled water. The solar heat will supply heat to the membrane distillation system that will produce temperature difference for the vapor movement. This mechanism uses renewable energy which is solar heat as main energy supply in this case.

There are several types of process generally being used to produce fresh water such as reverse osmosis, ultra filtration, nano-filtration, and multi-stage filtration. However, most of these processes are energy intensive that made membrane distillation as the most feasible option for this project. For example, reverse osmosis need huge pressure that leads to high energy usage. While, membrane distillation only needs ambient pressure and low grade heat to convert water to vapor by evaporation and induced the temperature difference by using solar heat. There are no other kind of energy needed. While, the membrane itself only allowed the water vapor that pass through it and no others. It can ensure that water is completely safe for the daily usages.

3. METHODOLOGY

The MD rig material uses polycarbonate and for the flat-plate use metal. Besides that, to complete this rig, there are other equipment that is needed to run the experiments which are solar collector, two water pumps, and pipes. Figure 2 shows the mechanism of the experiment, starting from the feed water and the cold water circulated following the arrow direction. Those circulations were induced by water pump. Next, when the feed water in the hot chamber started to evaporate, the vapor will go through the membrane and being condensed at the cool flat-plate. The air gap spaces will avoid the flat plat absorb heat from hot chamber while cold chamber is always circulated to reduces the temperature of the flat plat. All the condensed water will now drop from the air gap ramp to the fresh water container.

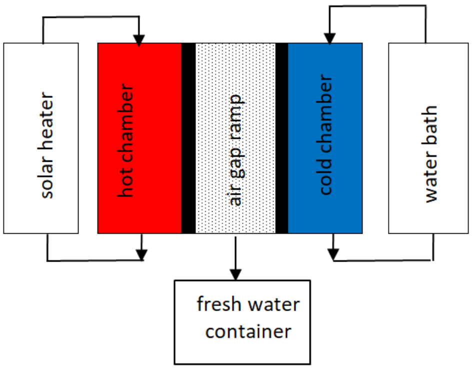

Fig.2: Flow of the experiment

The primary energy source for the MD rig is the solar heat collected by means of solar collector. The heat then transferred to water and was flow to the MD rig as feed solutions. The solar collector that have been used is model Summer CX 180 L[5].

This solar collector maximum temperature is 90 ºC. It will work well with the water evaporation application. The solar collector also has more than 85% efficiency [6] so it will be enough temperature to the MD rig to have temperature differences. Before went to full experiment using the MD rig, the temperature of water produced by the solar heater had been tested. The configuration of the solar panel is shown in Figure 3.

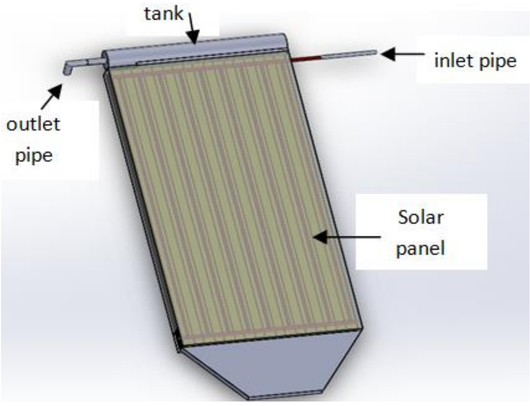

Fig. 3: Solar panel configuration

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The experiment were performed with configuration as shown in Figure 4. There were two variables controlled independently: (1) quality of input water and (2) input temperature. Then the outputs of this experiment (volume and quality of output) were recorded and analyzed.

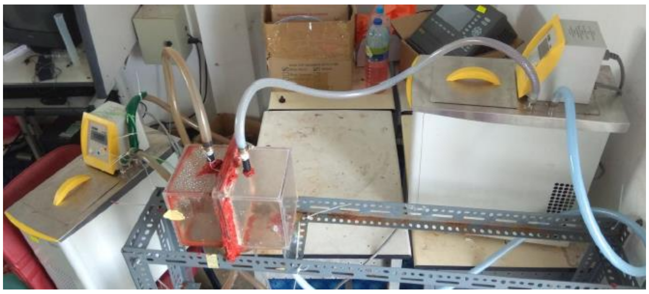

Fig. 4: Membrane rig experiment configuration

For the first variable, quality of input was varied by four different Total Dissolved Solid (TDS) in PPM unit. The input feed water was prepared by assuming the volume of water in the circulation tank was eight liters. Using formulae as shown in Equation 1, TDS could be calculated[7].

$$TDS = \frac{Vs}{Vsn} \times 10^6 \quad (1)$$

where,

TDS = total dissolved solid.
Vs = volume of solute
Vsn = volume of solution

The input feed water that have been used were 7.000 ppm, 8.500 ppm, 10.000 ppm, and 30.000 ppm prepared by using 56 gram, 68 gram, 80 gram and 360 gram of salt respectively. For each quantity, the experiments were repeated three times to take the average. For this experiment, the input temperature had been kept constant at 60 ^oC.

Furthermore, for the second variable which was the temperature of the input feed water, there were three different temperature had been used. The temperature were 50^O, 60^O, 70^O Celsius, this temperature were selected due to the result from analysis of output temperature of solar heater previously. All those temperatures above also had been tested three times to produce the average.

For both experiments, there were constants being utilized: (1) flow rate of hot chamber = 2.1 L/m, (2) Flow rate of cold chamber = 15 L/m, (3) Temperature of cold chamber = 5 ^oC and (4) Volume feed water = 8 liters

Duration for experiment was one hour and another hour was needed to ensure the circulation machine achieved the desired temperature)

4. RESULT AND DISCUSSION

Figure 5 shows the data recorded during month of February 2017. The highest temperature measured at the output location was 68°C the highest and 51°C the lowest. These measurements have been carried out inside IIUM Campus. The ranges in the result show that this area is suitable to apply MD mechanism to acquire fresh water. The temperatures were high enough and consistent to produce temperature different in MD process since the process was induced by temperature differences. The range of temperature 50^O- 70^O C will be implemented to study their output behavior.

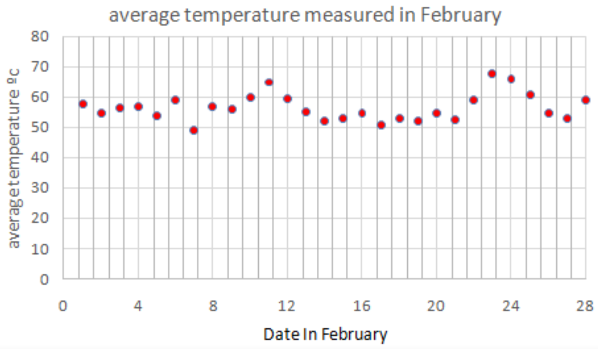

Fig. 5: Temperature of the output during (Feb. 2017)

4.1. Variable of total dissolved solid (TDS) input

As shown in Figure 6, the output volume keeps decreasing respectively with the increase of TDS of the input. At feed input, TDS 7,000 ppm producing 60 ml of fresh water in one hour. While, for input 30,000 ppm the output produced was only 20 ml. It shows that 66.67% of output decreased when the feed water TDS was increased from 7,000 to 3,000 ppm.

Permeated flux had been calculated using Equation 2 as follow:

$$Mf = \frac{Vo}{Am \times Texp} \quad (2)$$

where,

Mf = permeated flux in (kg/(m^2.hr))
Vo = volume of output (L)
Am = area of membrane (m²)
Texp = duration of experiment (hour)

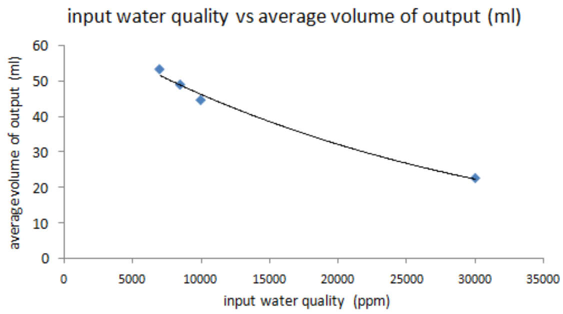

Fig. 6: Graph of feed water TDS vs output in volume

Permeated fluxes that have been calculated were displayed in graph on Figure 7. The graph also shows that the permeated flux is keep decreasing as the TDS of the feed water increase.

Permeate flux decreases with an increase in the feed concentration. This phenomenon can be attributed to the reduction of the driving force due to decrease of the vapor pressure of the feed solution and exponential increase of viscosity of the feed with increasing concentration.

The contribution of concentration polarization effects was also known, nevertheless, this was very small in comparison

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with temperature polarization effects. As it is well known, MD can handle feed solutions at high concentrations without suffering the large drop in permeability observed in other pressure-driven membrane processes and can be preferentially employed whenever elevated permeate recovery factors or high retentive concentrations are requested.

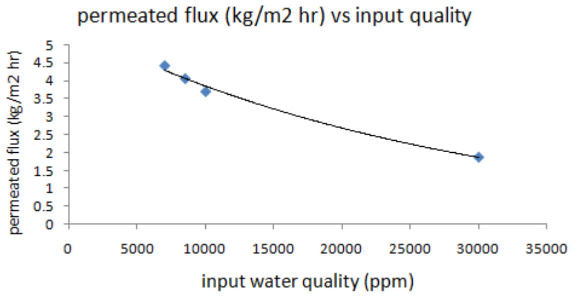

Fig. 7: Graph of permeated flux for different quality of feed water TDS

Furthermore, using the Equation 1 that been used to calculated the input TDS, the output TDS was calculated. The result is displayed in Figure 8. The graph showed that the outputs is linearly increasing with feed water TDS. Although the highest TDS of the output is 20 ppm, it is still considerably safe for human usage.

Moreover, from Figure 8, the rejection factor can be calculated. The result is shown in Figure 9. From the rejection factor, the percentage of dissolved solid that have been removed and how well our membranes distillation works can be determined. The rejection factor of the outputs was calculated using Equation (3).

$$Rf = \frac{TDS\ in - TDSout}{TDSout} \quad (3)$$

where, Rf = rejection factor

TDS in = total dissolved solid in input solution in (PPM)

TDS out = total dissolved solid in output solution (PMM)

The result of rejection factor have been represented in Figure 9, all the outputs were noticed to have more 0.99 rejection factor which means that the membrane distillation process could remove more than 99 percent of impurities.

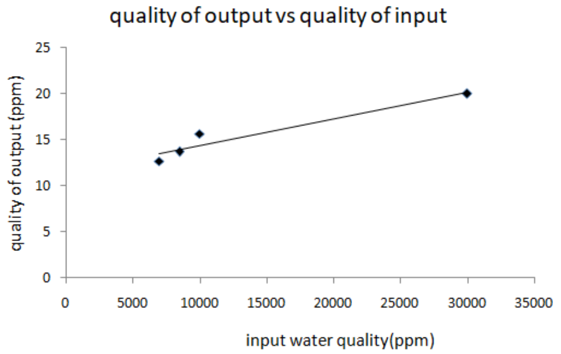

Fig. 8: Quality of output (PPM)

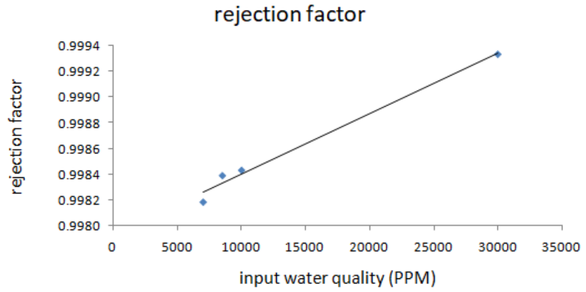

Fig. 9: rejection factor for different quality of input

4.2. Variable of feed water temperature

For the second experiment, temperature of the feed chamber had been varied. The variable temperature was chosen according to the result from previous chapter. From the graph as shown in Figure 10, it can be seen that the output volume are linearly increase when the temperature increase.

Notice that the cold chamber temperature was kept constant at 5 ^{o}C, in which the temperature differences were increasing from 45 ^{o}C to 65^{o}C. The increment of the temperature differences leads to the increase of the output volume. Furthermore, in lined with result of experiment as discussed in Sub-chapter 4.1, the volume of output then being transformed in term of permeated flux using the same formulae to see the output in wider view. The result then displayed in graph in Figure 11.

Various investigations have been carried out on the effect of the feed temperature on permeate flux in MD. In general, it is agreed upon that there is an exponential increase of the MD flux with the increase of the feed temperature. As the driving force for membrane distillation is the difference in vapor pressure across the membrane, the increase in temperature increases the vapor pressure of the feed solution, thus results an increase in the trans-membrane vapor pressure difference.

It is worth quoting that working under high feed temperatures was offered by various MD researcher, since the internal evaporation efficiency the ratio of the heat that contributes to evaporation) and the total heat exchanged from the feed to the permeate side is high. Temperature polarization effect also increases with the increase in the feed temperature.

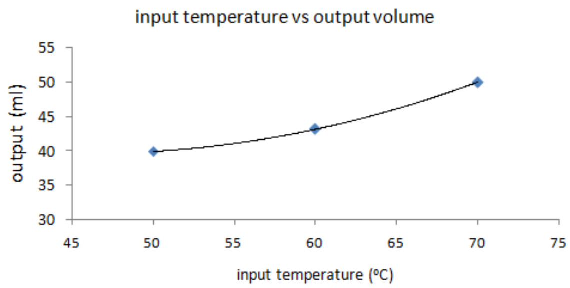

Fig. 10: Volume of output produced with different temperature of feed water

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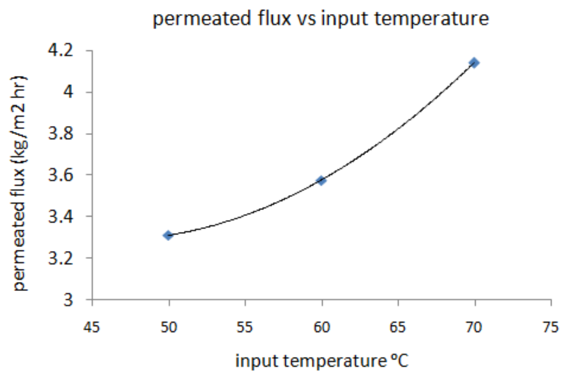

Fig. 11: Permeated flux for different input temperature

Next, using TDS method, the output was also being analyzed in term of quality perspective. From Figure 12, we can see the total dissolved solid in the output water is decreasing along with the increasing of the temperature. While, the rejection factor keep increasing linearly with the increment of the temperature shown in Figure 13. Moreover, the rejection factor also showing that all the temperature from 50 to 60 °C are more than 0.99 which also mean that this temperature could removed 99 percent of impurities in the feed water.

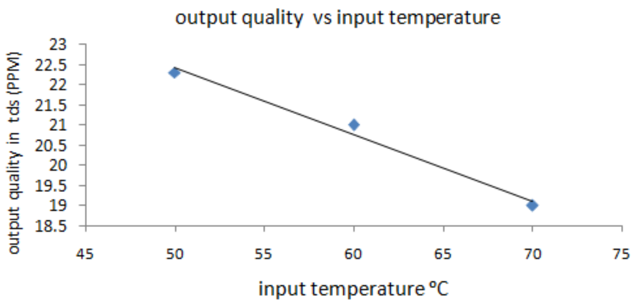

Fig. 12: Quality of output with different temperature of input

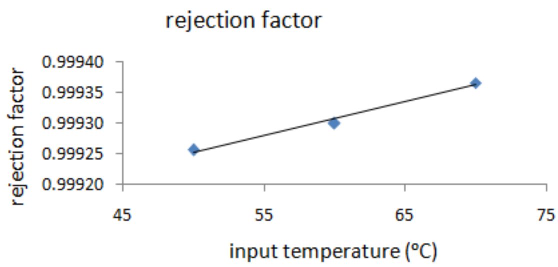

Fig. 13: Rejection factor for different temperature of feed water

4.3 Usage cost of air-gap membrane distillation

Table 1 listed the summary of usage cost calculation. Assuming that 1m² area in daily application was used, to produce one liter of fresh water equivalent with RM 0.108. This cost is far lower than domestic's prices which is RM 0.54 per liter.

Table 1: Usage cost of Distillation process

Lowest permeated flux	$4.4 \frac{kg}{m^2.hr}$
Electricity tariff from TNB	For 1st 200kWh = RM 0.218 per kWh For 2nd 100kWh = RM 0.334 per kWh For 3rd 300 kWH = RM 0.516 per kWh
Pump and water bath electricity	1.5 kW
If the MD were used for 8 hour per day for a month, the total electricity used are :	the total electricity used are : 1.5 kW x 8h x 30 day = 360 kWh.
total cost for a year	(200 kwh x0.218) +(100 x 0. 334) + (60x 0.516) = RM 107.6
Output for a year	$4.4 \frac{kg}{m^2.hr}$ x 8h x 30 day = 1056 litres
Cost of fresh water / liter	RM 107.6/1056 litres = RM 0.108

5. CONCLUSION

Finally, after going through three experiments, it can be concluded that IIUM Gombak environment are suitable for production of fresh water associated with solar heater. From the first experiment, it shows that the solar hater can produced water with average temperature more than 50° C every day which are more than enough to induce temperature differences. Those temperature differences are the one that drives the vapor to pass through the membrane and produce the fresh water.

Furthermore, from the fact quoted from Utusan online, the TDS around Lembah Klang River are less than 4,000 PPM. It's definitely shows that, water from those rivers can be used as feed water if this system be implemented in future. On top of that, from third experiment, it clearly shows that the MD rig can work well under the irradiation produced by the solar heater in IIUM Gombak surrounding. With the temperature between 50°C to 70 °C using the membrane surface less 0.0123m², the MD rig could produced more than 40 ml fresh water per hour with rejection factor more than 99 percent and also could produced water lower price market were a very good indicator to show the compatibility of this MD system to work in Gombak environment.

The main reason why the system is recommended to be implemented are the system itself provide a better environment and have the possibility to reduce the cost of fresh water production. Lastly, it is hope that MD system could be the alternative way to produce the fresh water and could be implemented in Malaysia in the future.

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