INVESTIGATION OF POLARIZATION IN MEMBRANE DISTILLATION (MD) PROCESS AND ITS ENERGY EFFICIENT SOLUTION FOR FRESHWATER PRODUCTION IN MALAYSIAN HOUSEHOLDS

Project Ending Report for

Fundamental Research Grant Scheme Project-**FRGS 14-0118-0359**

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Abstract

Recent water scarcity in Malaysia has raised an issue about the abundant supply of freshwater in the country. A water purification method like Membrane Distillation (MD) can be a wonderful solution to be utilized to deal with this immediate unpredictable water scarcity issues. MD is an ambient pressure process which works mostly below a temperature of 80 Degree Celsius, hence very much suitable to harvest solar/ waste energy. However, MD system has a limitation of restricted production due to temperature and concentration polarization on the membrane surface. This work aims to deal with fundamental investigation on Polarization in MD process to make it a more effective freshwater supply system for Malaysian households. It has been observed that using smaller sized multiple chambers in the process can enhance the production of fresh water compared to a bigger sized chamber with a single large membrane. Association of solar heat into the MD module can contribute to further energy savings in the process and make it economical and feasible for water treatment in hot tropical climate. It was observed for using multi stage, a distilled water flux of 8.5 liter/m^{2}h has been obtained. Using a solar heater also helped to minimize the specific energy demand from electric supply. Overall, the multi-stage MD system is a possible option to be implemented in Malaysian household to mitigate the freshwater scarcity.

Keywords: Multi Stage Membrane Distillation, Solar energy, Pure Distillate, Wastewater treatment.

1. Introduction:

The current water scarcity condition due to the sudden dry season put us in a place where we have to re-think about the freshwater supply issue to the Malaysian household. The Malaysian people are in need of small scale water supply unit that can produce freshwater with available household wastewater and low grade energy. Membrane Distillation (MD) process is an ideal solution for such requirement. It works on the principle of partial pressure difference. It is rather an evaporative process where only a hot fluid (impure water in this case) evaporates due to difference in partial pressure (maintained by a coolant flow or coolant plate). The vapor generated from the hot fluid passes through hydrophobic membrane pores and later condenses in the coolant or on the cold plate and the ultimate product is pure distilled water. The membrane is responsible for maintaining the vapor-liquid interface. The process is quick and do not require heavy installations. Because of the low grade energy requirement, it is an excellent option for the household to provide freshwater supply during the dry seasons, as household waste water can be retreated into potable water instantly. However, when the hot fluid passes over the membrane, due to continued evaporation on membrane surface the concentration is increased near the evaporating layer and the temperature drops in the same zone. Hence there is a difference in the concentration and temperature near the evaporating surface compared to the bulk flow region. These differences are termed as concentration and temperature polarization respectively. Since more concentrated solution requires higher energy to evaporate(in the liquid-vapor interface, i.e. the membrane surface), due to drop in temperature there is a chance of forming "stall" zones where little evaporation occurs, which is a result of polarization on the evaporating surface. Hence, it is necessary to investigate the polarization in details and ways to control it to aid the total distillate production. By applying multi-stages instead of a large single module, the fluid is compelled to mix at the entry and exit of each module thus bringing the polarization to a lower level, thus increasing the overall production[1]. In addition to this, there is enough possibility to associate the process with the waste/solar heat source and making it an effective energy efficient freshwater supply system for Malaysian households.

The following figure [Figure 1] explains how the MD process works. The vapor generates from the hot feed and travels through membrane pores. The membrane-liquid interface is the main region where the polarization occurs. If the feed flow is allowed to mix better by implementing many small modules instead of a large undisturbed membrane surface, the polarization effect is expected to be smaller than the large membrane. Thus, within the same range of energy input, the produced distillate will increase due to better mixing of fluid and hence the system will become more energy efficient.

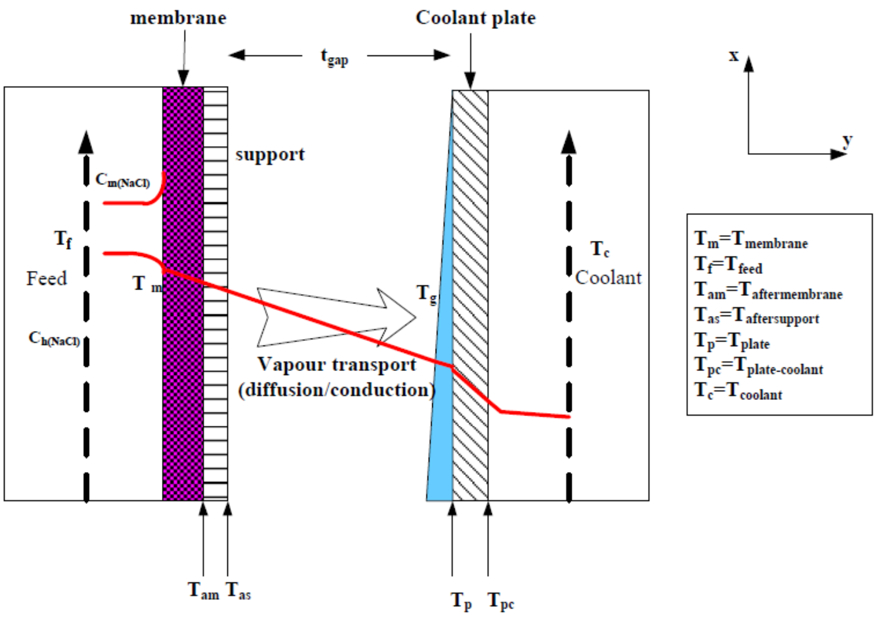


Figure 1: Working Principle of Air Gap Membrane Distillation(AGMD) Process[2]

The objectives of the project are listed as

1. To investigate the overall performance of an AGMD unit.

2. To study the effect of Multi-staging and choose an optimized multi-staging system by linking it to the polarization phenomena in multi-stages.

3. To study different available free energy sources

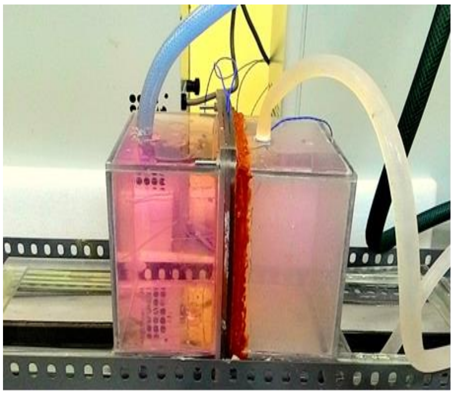
2. Methodology:

The methodology has been divided in 3 major portions according to the objective(s) stated.

i) Investigation of the overall performance of an AGMD unit:

To investigate the polarization inside an MD module, first an experimental MD module has been built. The hydrophobic membrane was placed inside hot fluid (wastewater) module chamber with establishment of hot and cold liquid flow system, temperature and power consumption measurement system. The coolant plate used was a channelled one to have higher condensation area. Then, the system's performance has been evaluated based upon the parameters like hot and cold side temperature, and entry angle of the flow. Based on the performance, the multi-staging has been designed and developed. Figure 2 shows the setup.

(a)The overall setup



(b)The membrane module

ii) Development of Multi-stage rig to observe its effect on Polarization:

A multistage MD rig has been build as mlti-staging in MD has shown significant improvement in production. Figure 3 shows the Multi-stage setup

Figure 3. Multistage MD setup

iii) Study and association of available renewable energy sources

A Solar heater was associated with the multi-stage MD setup. Figure 4 shows the solar heater. It has a maximum capacity of 180 L and can store and supply hot water till 72 hours even on a cloudy day.

Figure 4. The solar collector

3. Results and Discussion:

i). Performance Evaluation of the single stage

Table 1 and Figure 5 shows the ultimate improvement of the system performance. A highest of 84% increase in production has been found at 55°C feed temperature for the angled inlet. While using the finned plate the production increased significantly.

Table 1: Performance of the single stage setup with variation in inlet and coolant plate geometry

Feed temperature (°C)	**40**	**45**	**50**	**55**	**60**	**65**	**70**
Distillate collected using straight inlet	2.3	2.8	3.6	5.0	6.6	8.3	10.9
Distillate collected using 60° angled inlet	3.9	5.0	6.4	9.2	11.8	14.5	18.6
Performance increase (%)	**69.56**	**78.57**	**77.78**	**84.0**	**78.78**	**74.7**	**70.64**

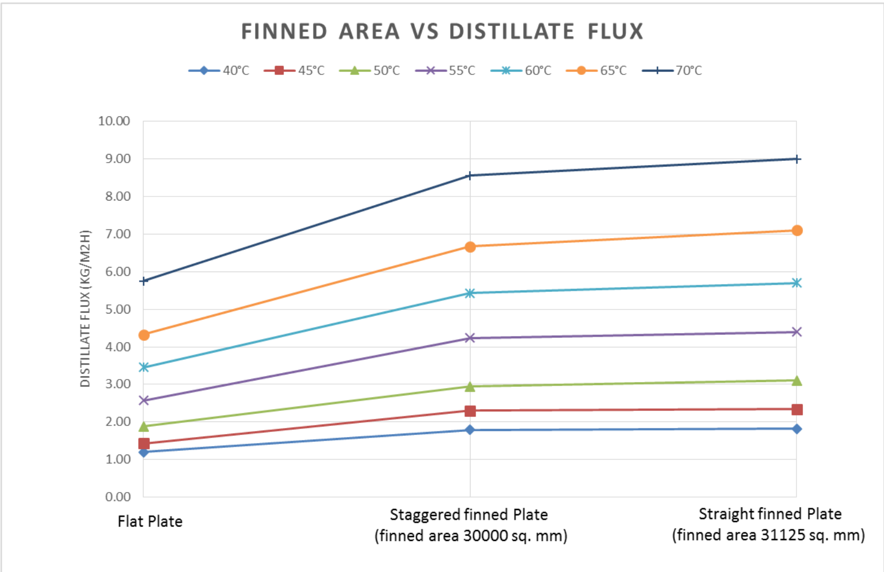


Figure 5. Performance of the single stage MD with finned plate

ii) Multistaging and improvement in production

with applying multi-staging, significant enhancement in production was observed. It is due to the fact that instead of a large membrane area in a singles stage, if multiple stages are added, it helps to destroy the polarization by re-mixing of the liquid in each stage. Figure 6(a) and (b) shows the improvement after applying multistage.

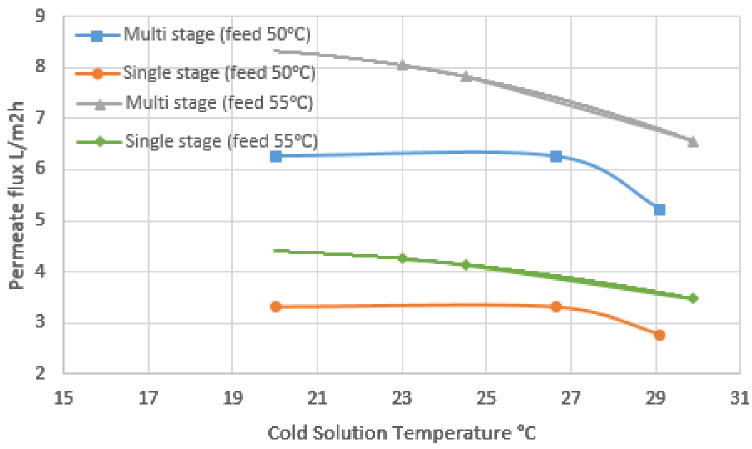


Figure 6(a). Effect of multi-staging on production increase(variation of coolant temperature)

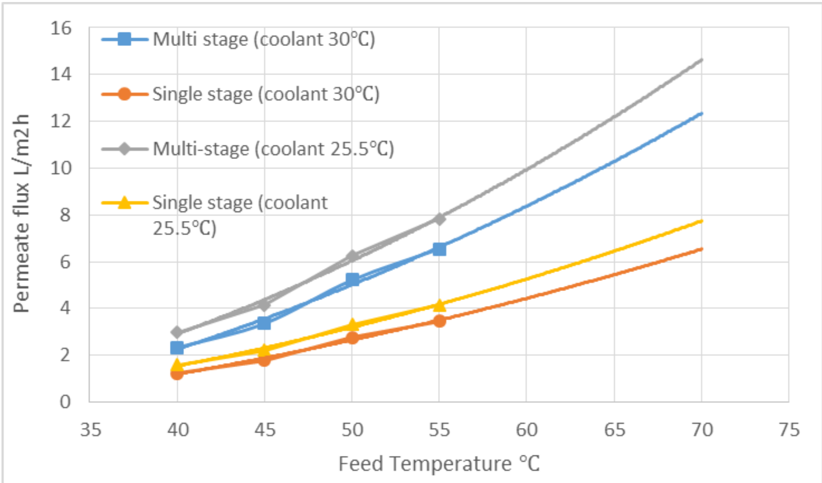


Figure 6(b). Effect of multi-staging on production increase(variation of feed temperature)

iii) Association of solar heat:

The solar heater was used to obtain the average temperature during the day time and was coupled with MD system. The results were used to obtain the water production during the day (8 hours runtime) if the membrane area was 2 m^2 which is equivalent to a small scale plant. Figure 7 shows the water production during the month of February, 2017. It is clear that with this system pure water production of 220L per day is achievable. And even in the cloudy seasons producing 90L of water is possible. Figure 8 shows the specific

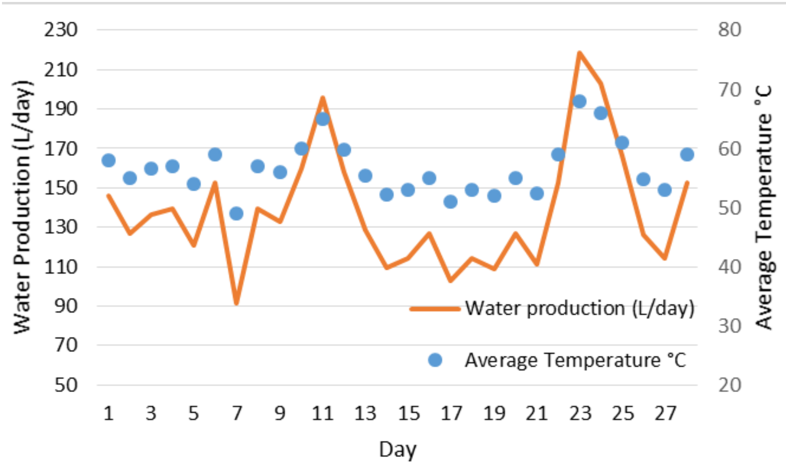


Figure 7. Expected water production during the month of February, 2017.

The specific energy consumption was also calculated and it was observed that with the implementation of solar heater, the specific energy(electricity) consumption decreased as the large amount of heating was available from the solar heater.

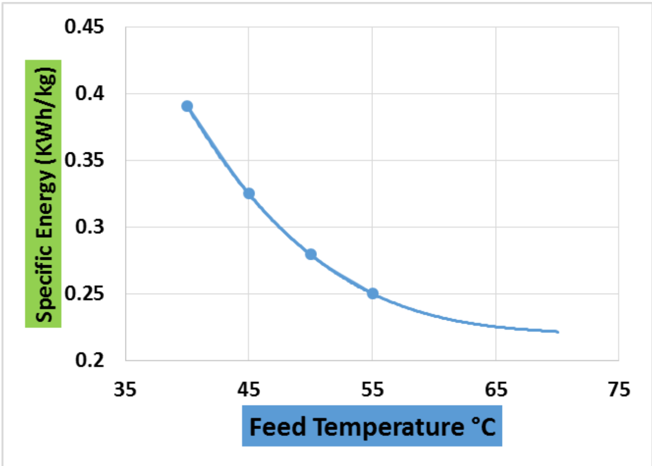


Figure 8.Specific energy consumption decrease with increased temperature after installation of solar heater

4. Financial Statement:

To complete the project, about 77.51% of the budget has been utilized. Equipment purchased under the project are listed as

1. LAUDA hot and cold re-circulator bath-2

2. HEATWATT DATA LOGGER with thermocouple-32 Channel

3. SUMMER 180-C solar collector, 180 L capacity.

Table 2 gives a summary of all expenditure (collected from RMS)

Table2: Summary of Expenditure (from RMS)

Vote Code	Description	Amount	Disburse	Committed	Balance
V11000	Research Assistant	5,600.00	5,600.00	0.00	0.00
V21000	Travelling Expenses And Subsistence	7,000.00	0.00	0.00	7,000.00
V27000	Research Materials & Supplies	8,400.00	8,454.05	0.00	-54.05
V28000	Maintenance and minor repair services	0.00	0.00	0.00	0.00
V29000	Professional Services & Other Services including Printing & Hospitality, Honorarium for subjects	25,600.00	21,702.01	0.00	3,897.99
V35000	Equipment	47,400.00	36,094.00	0.00	11,306.00
V36000	MISCELLANEOUS RESEARCH ADVANCEMENT	0.00	0.00	0.00	0.00
V37000	TRAVELLING RESEARCH ADVANCEMENT	0.00	0.00	0.00	0.00
		94,000.00	**71,850.06**	**0.00**	**22,149.94**

5. Human Capital Development

Two MSc students were funded partially using the FRGS grant. One student has submitted his thesis, and the other one has committed to submit his thesis by June 2017.

Their details are

i. **Mohammad Jabed Perves Bappy**
Matric: **G1413843**
Passport No: **AG2429807**
Nationality: Bangladeshi
Status: Submitted Thesis
ii. **Istiaq Jamil Siddique**
Matric: **G1526615**
Passport No: **BN0449857**
Nationality: Bangladeshi
Status: Intended to submit thesis by June 2017.

6. Publications

Indexed:

i) M.J.P. Bappy, Rubina Bahar, S. Ibrahim and T. F. Ariff, Enhanced freshwater production using finned-plate Air Gap Membrane Distillation (AGMD),MATEC Web of Conferences, Volume 103, Pages6-14, 2017.(Scopus Indexed)

ii) Bappy M.J, Rubina Bahar. and Ariff T.F., Effect of Air Gap in the Performance of Air Gap Membrane Distillation System, ARPN Journal of Engineering and Applied Sciences, Vol. 11, No 6, (2016).(Scopus Indexed)

Conferences

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ii) M.J.P. Bappy, Rubina Bahar, T.F. Ariff , 2-Dimensional heat and mass transfer analysis on channelled coolant plate of an air gap membrane distillation (AGMD) freshwater production system, 2nd International Conference on Desalination using Membrane Technology, July 2015, Singapore.

iii) I.J. Siddique, Rubina Bahar, MAA Faizi, Shaliza Ibrahim, Wastewater treatment by Solar Air Gap Multi-Stage Membrane distillation, Accepted to be presented in 10th congress of EWRA , Greece, 9-10 July,2017.

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i) Rubina Bahar, Hawlader M.N.A. Ng K. C. and Yee J W., b Experimental study on a multi-stage air gap membrane distillation (AGMD) unit. Jurnal Teknologi, 69 (9). pp. 89-92,(2014).

ii) Hawlader M.N.A., Rubina Bahar, Ng K. C. and Stanley L. J. W, Transport analysis of an air gap membrane distillation (AGMD) process, Desalination and Water treatment, Vol.42, pp 333-346. (2012).