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Research Article

Cogeneration of Desalinated Water and Domestic Hot Water using Membrane Distillation Technique for a Family Villa in the Gulf Region

Muhammad Asim*

Department of Energy Engineering, School of Engineering,
University of Management & Technology, C-II Johar Town,
Lahore 54700, Pakistan

Abstract: Tremendous increase in fresh water demand in United Arab Emirates (UAE) over the past few decades, because of rapid industrial growth and increase of urban population, has led to increased stress on underground water aquifers. In order to cater the current and future water requirement for domestic use in UAE, desalination of seawater is considered to be one of the most effective and strategic technique. Therefore, we studied simultaneous production of quality drinking water and solar domestic hot water for a single family villa in UAE resided by 4 to 5 persons. A pilot plant setup was designed, commissioned and installed on site using Air Gap Membrane Distillation desalination process to fulfill the demand of 15-25 L/day of drinking water and 250 L/day of hot water for domestic use. Experimental analyses were performed during a summer season on flat plate solar collectors having different aperture areas; experiments were performed for aperture area of 11.85 m^2 for feasibility purpose. The average hot side temperature of membrane distillation circuit ranges from 50°C - 70°C whereas the average cold side temperature is 35°C. The experimental results show that for 10 hours operation of pilot plant, 16 Ls of total volume of distillate has been collected. The specific flow rate of water has been kept low to get higher temperatures and as a result. The total solar yield was 31.3 kWh out of which the membrane distillation energy usage was 41.3% and the domestic hot water energy usage came out to be 18%. The energy consumption per L of water was found to be 0.804 kWh/L. Some of the energy was lost due to long length of piping, which can be avoided by more effective insulation.

Keywords: Air gap membrane distillation, solar domestic hot water, desalination, flat plate collector, aperture area

1. INTRODUCTION

Water plays a pivotal role in sustaining human life. Earth has 325 million cubic miles of water availability and comprises of 71% of earth's surface. Out of this, 97.5% of the earth's water is salt water and only 2.5% is fresh water which is suitable for human consumption. Only 1% of the total 2.5% of fresh water is accessible to human beings which they can be utilized for drinking and other domestic purposes, as rest of the fresh water is frozen in icecaps or exists as moisture in the soil.

In Middle East and North African (MENA) region, United Arab Emirates is one of the affluent countries experiencing the rapid increase in the population during the past few decades. UAE is one of the leading countries in per capita consumption of the bottled water which is about 153 L per person per year [1]. The rapid industrialization results into increase in the water demand. The long term average precipitation rate in UAE is 78mm per year as compared to United States 715mm per year and 1274mm per year for Korea [2].So the countries like UAE which experiences the high temperature and low rainfall rates triggers the unprecedented water demand every year due to rapid industrial growth.

Giving the overview of water demands, it should be noted that according to Italian Trade Commission (ITC), the domestic household water consumption in UAE is about 24% and only 9% is utilized by the industrial sector. The agricultural sector consumes the major portion of water which

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*Email: muhammad.asim@umt.edu.pk

is about 67% [2]. UAE is amongst the top countries where the per capita domestic water consumption is very high i-e, about 550 L per day per person. The global average of domestic water consumption is 250 L per day per person. So UAE consumes more than twice the domestic water consumption [3]. In 2050, there will be serious shortfall of the per capita availability of water in the region by half since the region has already have stressed up aquifers, low precipitation rates and extremely hot weather.

To fulfill the demand of drinking water, domestic water and to safeguard the ground water resources the sea water desalination has been adopted as best strategy. According to International Desalination Association (IDA), the total number of desalination plants installed worldwide over 170 countries is 15988 (as of 30th June 2011) and have a total production capacity of 66.5 million cubic meters of water per day [4]. The Gulf Cooperation Council (GCC) countries account almost 41% of total global desalination output of water. Currently there are 70 water desalination plants that have been installed in UAE [3]. People in UAE mostly rely and uses the bottled water for drinking purpose which is supplied to the end-users typically in 5 gallon containers. Although the desalinated water has been supplied to the end user, but its main use would be for the domestic purpose i-e, for cleaning, bathing etc. About 1.2 billion L of bottled water consumed in UAE per year out of which 60% are ‘’home office delivery’’ in bulk supplies [5]. As the demand for drinking water increases rapidly due to consumption of more and more bottled water, many companies follow the simple marketing strategy of demineralization of already desalted water, mineralizing again, packaging, and supply of bottled drinkable water to households or offices. So the complete bottling process adds up additional consumption of energy on treatment of water, bottle packaging, and also leads towards the unsustainability of environment due to involvement of logistics and huge pile up of bottled plastic waste.

Membrane distillation (MD) is a promising desalination technology offering advantages of robustness, scalability, and improved environmental performance as compared to established methods [8]. In this technique the driving force for desalination is the difference in vapour pressure of water across the hydrophobic membrane, which allows water vapour to pass but not allowing the liquid water to pass through this membrane. The difference in vapor pressure is created by heating the source water, thereby elevating its vapour pressure.

In many areas around the world, desalination has been adopted as a valuable option and sometimes a necessity to overcome water shortages and to fulfill the need of drinking water. Several thermal and physical desalination technologies are well established in order to desalinate water for its use in industrial as well as in industrial applications. An industrial research has been carried out on solar driven membrane distillation system to produce pure water through a recent technique of Air gap membrane distillation (AGMD) [9].

Kullab et al. [8] performed experimental analysis on MD-based water treatment laboratory setup. The analysis were performed via laboratory testing, system simulations of thermodynamic performance, and economic evaluations on laboratory setup deployed at Idbacken Cogeneration Facility (Nykoping, Sweden) with a five-module membrane distillation unit capable to produce 1-2 m^3/day of purified drinking water. District heating supply line was employed for heating whereas municipal water was used for cooling purpose.

The objective of this study was to evaluate the AGMD performance with saline water and to establish an operational database for simulation of three stage AGMD system. Without heat recovery, the specific thermal energy consumption was calculated as 950KWh_t/m^3 whereas with heat recovery the specific thermal energy consumption was 850 KW_t/m^3 [12]. So, keeping in view all the above mentioned studies and motivation, a pilot plant setup has been planned to install capable to fulfil the drinking and domestic hot water needs for a single family villa in Dubai.

As mentioned earlier, UAE consumes a lot of bottled water per capita resulting into unsustainability and high energy demand. So a sustainable solution is presented in this research paper for the simultaneous production of pure drinking water in order to replace the consumption of bottled water and domestic hot water by designing a Solar Combi system for hot and arid regions like UAE. The designing of this system involves the co-generation of pure water and hot

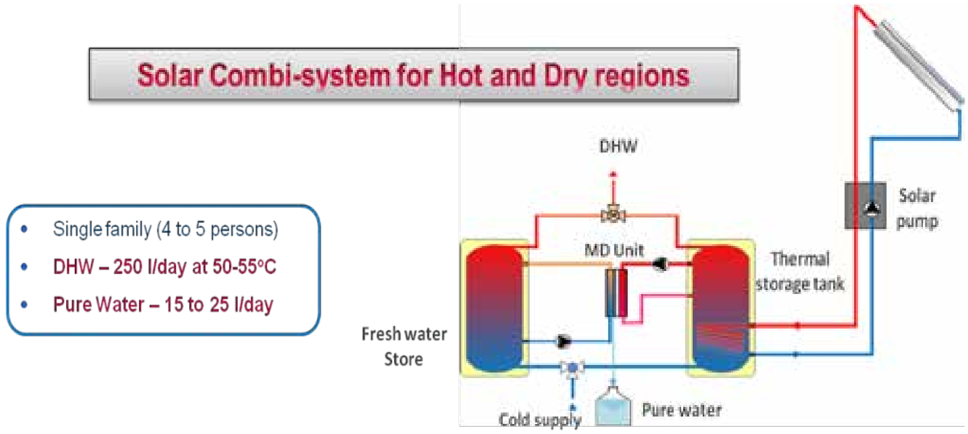

Fig. 1. Prototype design of plant setup [13].

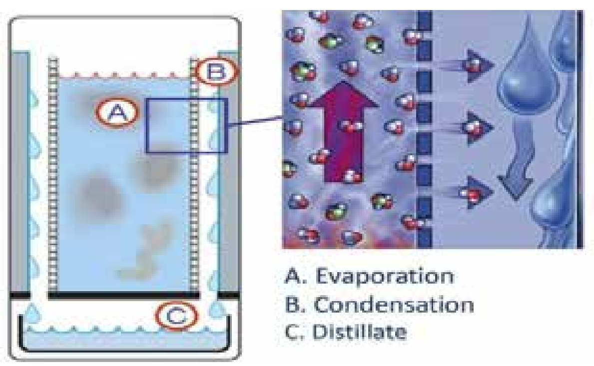

Fig. 2. Air Gap Membrane Distillation Technique [13].

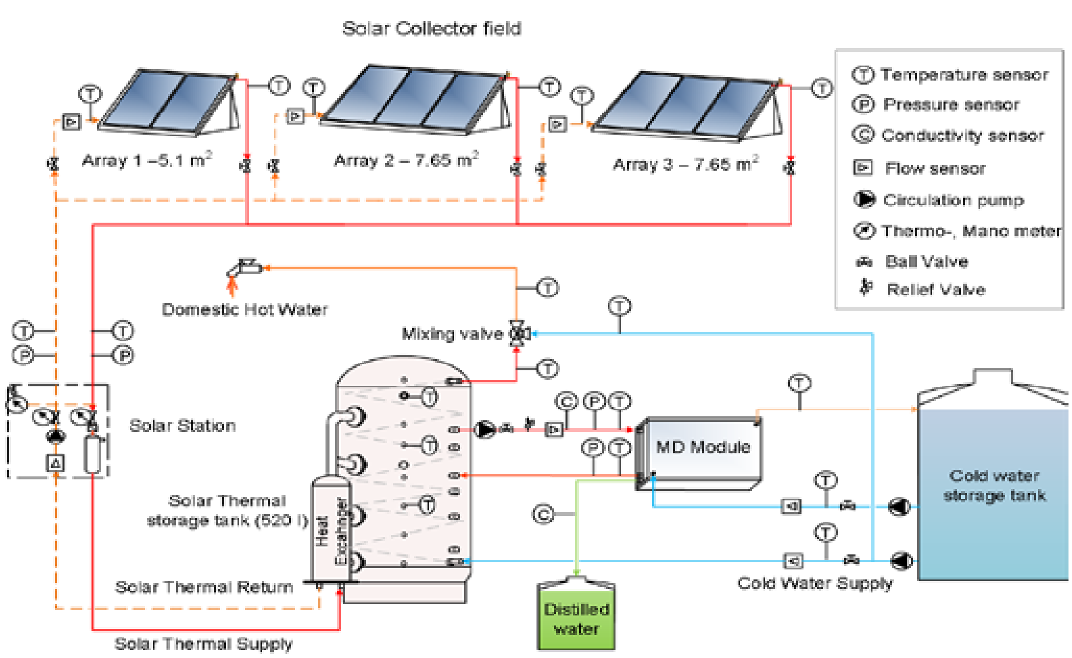

Fig. 3. Integrated SDHW-MD Onsite Setup [13]

water for domestic applications. Keeping in view the scope of present work, a pilot plant has been setup and the benchmark is the production of 15-25 L/day of pure drinking water and 250 L/day of domestic hot water in a single family villa comprising of 4-5 persons.

The main research objective of this paper is to investigate the feasibility of integrating the Membrane Distillation based water purifier with solar domestic hot water for in house pure water drinking purpose. Experimental analysis has been performed on the integrated system with different configurations of flat plate solar collector arrays and with different membrane distillation (MD) operational parameters. Fig. 1 shows the prototype of the solar combi system designed to carry out the research.

2. RESEARCH APPROACH AND METHODOLOGY

In order to implement the research approach and to integrate (MD) system with solar domestic hot water system (DHW), we will use Air Gap Membrane Distillation Technique (AGMD).

The first phase of research approach is to design the whole system in order that involves all the important components that are required to perform the experimental analysis like flat plate solar collectors, pumps, sensors, copper piping, insulation etc that fulfills the benchmark production of 15-25 L/day of pure drinking water and 250 L/day of domestic hot water. Moreover, in order to obtain the maximum annual solar fraction, the analysis has also been performed for the proper orientation and placement of the flat plate solar collectors. The first phase of research approach is to design the whole system in order that involves all the important components that are required to perform the experimental analysis like flat plate solar collectors, pumps, sensors, copper piping, insulation etc. that fulfills the benchmark production of 15–25 L/d of pure drinking water and 250 L/d of domestic hot water. Moreover, in order to obtain the maximum annual solar fraction, the analysis has also been performed for the proper orientation and placement of the flat plate solar collectors.

Why Membrane Distillation Technique?

The process of membrane distillation (MD) is a novel process and unique method of water purification MD operates in batch mode with recirculation of feed water due to its superior quality of handling changes in feed parameters. In this research study, the Air Gap Membrane Distillation has been used as it is well suited for small scale application and for this pilot scale setup

The difference in partial pressure serves as the driving force and allows the water in form of vapors to pass through the micro porous hydrophobic membrane ensuring the high quality of purified water. One of the most important reasons of using this technique is that the whole system operates below the atmospheric pressure. Fig. 2 shows the basic process of air gap membrane distillation [6].

3. MEMBRANE DISTILLATION MODULE

As mentioned earlier, the MD process is a combined thermal driven membrane separation process in which the micro porous hydrophobic membrane separates the pure water from the bulk feed water. The membrane distillation module that is being used in this experimental setup is of hydrophobic poly tetra fluoro ethylene (PTFE) material with 0.2 µm pore size and 280 µm thickness.

The AGMD module consists of two condensing plates made of aluminum metal behind which the cooling channels are located in serpentine shape. Two membranes each of surface area 0.1 m^2 are thermally welded on to the cassette which is to be fitted in a module. The hot water from the feed enters from the bottom of the cassette and exits from the top. The air gap of approximately 5 mm is maintained on both sides of the membranes. When the water is filled in the membranes, they bulge out reducing this gap up to 1 mm. The above explanation can be summarized through description of flows in three channels.

Hot Channel, where the hot feed water enters the cassette in contact with the membrane, vapors are generated and passes through the membrane

Air Gap, a stagnant air gap is maintained between the outer membrane surface and condensation plates allow the vapors to condense and collected in a distillate channel at the bottom

Cold Channel, where the cold fluid flows in contact with the other side of the condensation

Fig 4(a). Installation of flat collector plates [13].

Fig 4(b). Orientation, placement & angle orientation of collectors [13].

Fig 4(c). Stratified thermal storage tank with piping circuits [13].

Fig 4(d). Cold water storage tank (municipal water supply) [13].

Fig. 5. MD system with solar station.

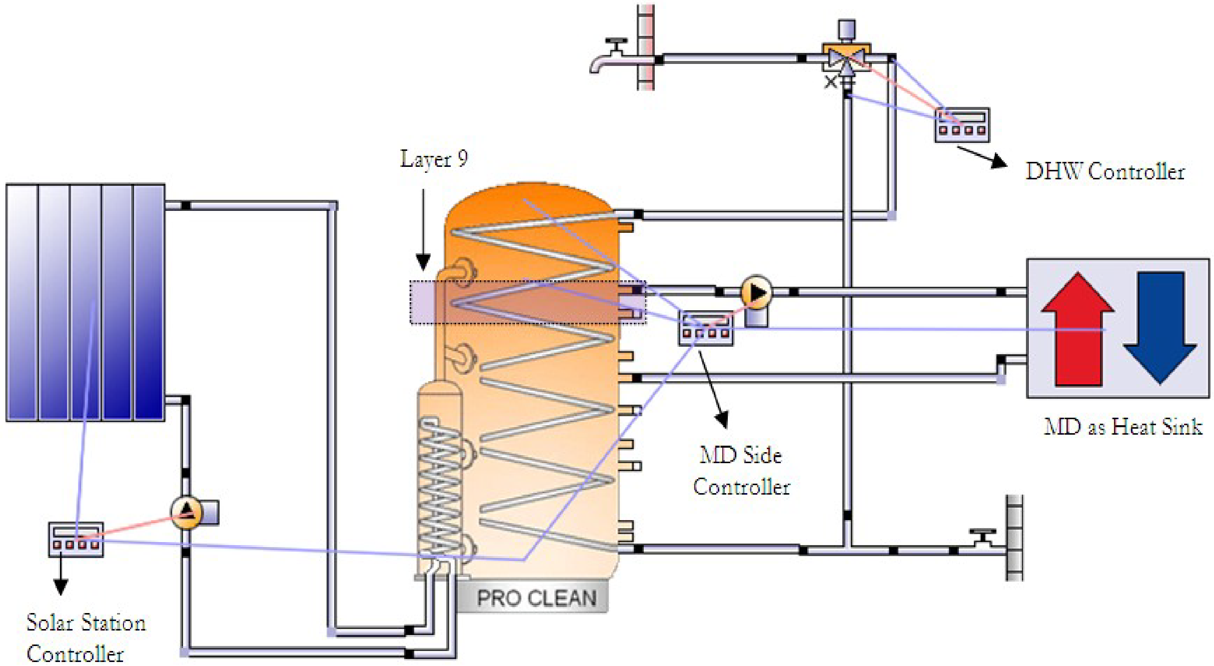

Fig. 6. PolySun simulation model SDHW-MD system [13].

Fig. 7. Flat plate collector array aperture area 11.85 m^2 [13].

plates and absorbs the latent heat of condensed vapors.

4. WHY SOLAR DOMESTIC HOT WATER SYSTEM?

There is availability of high solar insolation in MENA region due to which it is very useful and helpful to use solar domestic hot water system in this region. The typical Solar Domestic Hot Water (SDHW) systems that are installed in MENA region are designed for 60-70% of annual solar fraction [7] and backup electric heating is used to gain energy for heating the water for the rest of the time.

Now it would be obvious that the backup electric heating is required during winter season not in the summer as there is sufficient solar insolation available to gain the required temperature of hot water. But in UAE, the requirement of back up heating is more in summer than in winter. The solar insolation in UAE throughout the year is sufficient enough to provide the heat for producing water at least with 90% of solar fraction. The system has been designed at high solar fraction because of the two main concerns

Flat plate collectors have to cope with the high stagnation temperatures during summer time. The system remains idle during summer time and the demand is fulfilled with the backup heaters.

Back up electric heaters are also used to kill the Legionella bacteria by heating up to 60°C which makes the SDHW systems inefficient[7].

So the proposed integration of MD with SDHW system would be an ideal option to enhance annual solar fraction. In summer, the extra heat could be utilized for pure water production. Based on the local conditions, the concept of the solar Combi system could be utilized in UAE region.

5. EXPERIMENTAL DESIGN & ANALYSIS OF SDHW-MD INTEGRATED SYSTEM

5.1. Design of Pilot Plant Field Setup

As mentioned earlier in the methodology, the design of the system is majorly based on three circuits. The first circuit is the solar thermal circuit containing solar thermal collectors, solar station and thermal storage tank. The second circuit is the domestic hot water circuit and includes the domestic hot water storage tank, mixing valves and cold water supply tank. The final circuit is the membrane distillation circuit for the production of pure drinking water that includes membrane distillation module, distillate storage and feed water storage tank. These three circuits have been combined to form a solar driven membrane distillation desalination system. Moreover temperature, pressure, conductivity and flow sensors have also been installed in order to take the exact readings for experimental evaluation. The experimental setup of the SDHW-MD pilot plant has been shown in Fig. 3.

5.1.1. Solar Thermal Circuit

The most important part of this circuit are the solar collectors and they have been divided into three different combination or arrays so as to perform as many experiments as possible by making different arrays of the collectors. The collector arrays have been arranged so as to form three parallel arrays. Each collector has an absorber area of 2.55m^2 and a total of 8 collectors have been installed having total absorber area of 20.5m^2. The energy from different arrays of solar collectors have been transferred to thermal storage tank from where the hot water is being utilized for the production of domestic hot water and as feed water in MD.

The solar circuit has been pressurized by switching on the solar station pump which also circulates the water in solar collector circuit and thermal storage tank. Inline flow meters have been installed so as to monitor and adjust the inflow of water. The flow rate of the water has been adjusted and the water in the solar collectors is being heated by the available solar radiation. The temperature sensors measure the inlet and outlet temperature of the water through each collector array. The thermal energy from the collectors is transferred to the stratified thermal storage tank. This thermal storage tank also contains the spiral corrugated steel piping through water cold water passes for the production of domestic hot water. Moreover, the hot water in the tank also act as feed to the MD hot side.

5.1.2. Solar Domestic Hot Water Circuit (Sdhw Circuit)

The solar domestic hot water circuit consists of a hot water storage tank, a solenoid valve and a three-way manual mixing valve to adjust temperature during the collection of domestic hot

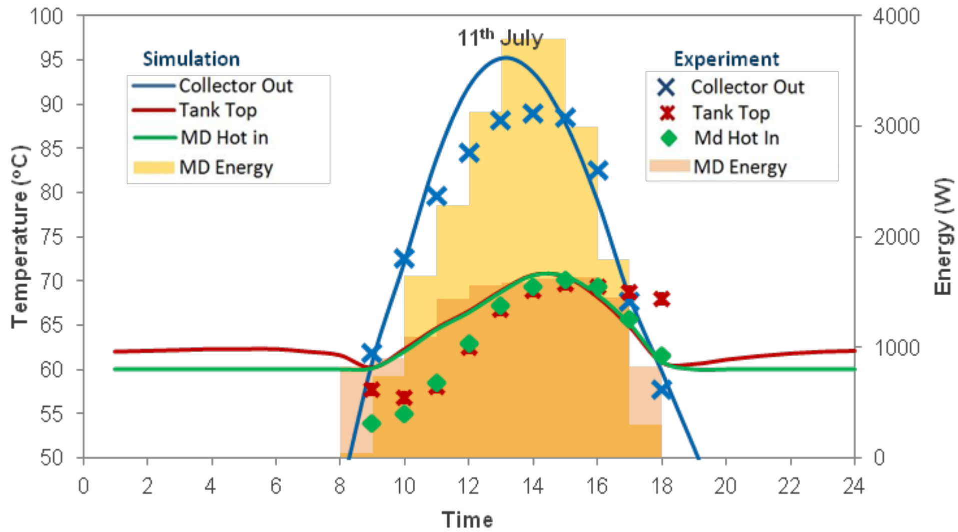

Fig. 8. MD Temperature and energy profile.

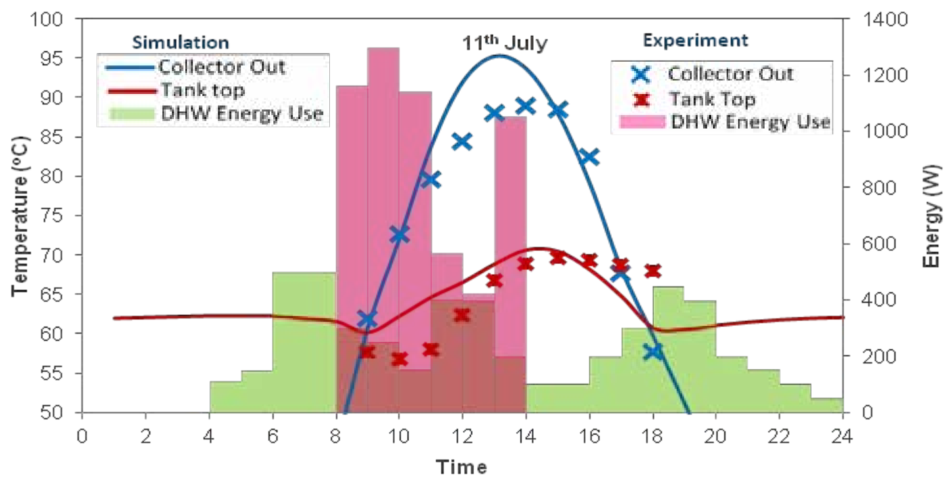

Fig. 9. DHW temperature and energy profile.

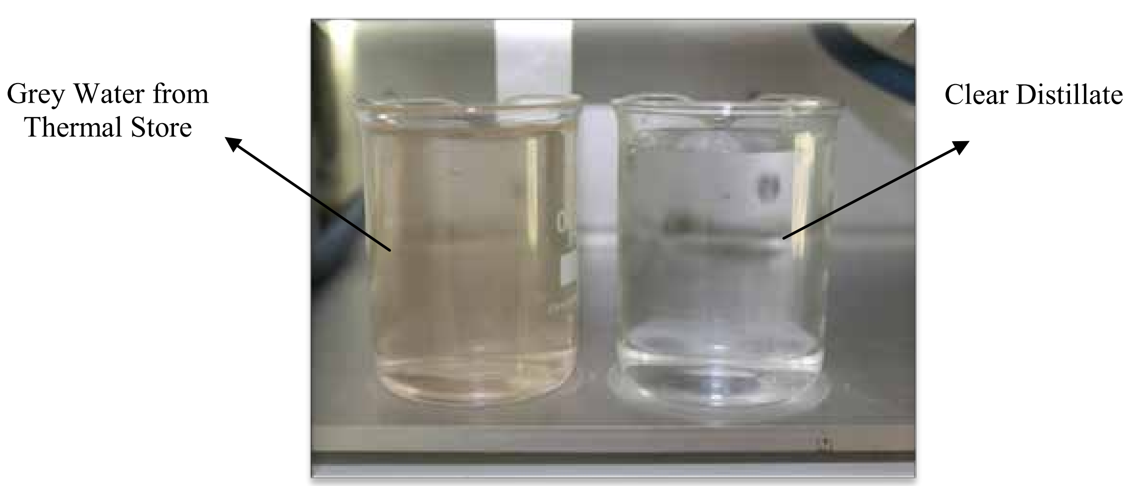

Fig. 10. Samples of grey water and clear distillate.

water and to control flow rate so as to get the desired volume of domestic hot water (250 L/day), which is the benchmark figure.

The domestic hot water circuit is connected to thermal storage tank through copper piping and poly-isocyanurate is used to insulate the copper piping to minimize the heat losses. The cold water is supplied from the cold water storage tank through a pump .and the hot water is fed into the circuit from the top layer of thermal storage tank. The cold side flow rate is set at 3 L/min and the mixing valve is manually controlled so as to mix the hot and cold water in order to obtain the desired temperature of 45-55°C for domestic hot water. Once this temperature has been maintained, the valve position is fixed and domestic hot water is being collected at regular interval.

5.1.3. Membrane Distillation Circuit

Membrane distillation circuit contains the MD module which is connected to the cold water storage tank and hot water storage tank for the inflow of hot and cold water into the module cassette. The hot water for s pumped in MD from thermal storage tank and the cold water from municipal water supply. For precise evaluation, different temperature, pressure and flow sensors have been installed in incoming and outgoing lines. Conductivity meter is also installed in order to monitor the feed water conductivity and distillate flux conductivity.

The membrane distillation circuit has been integrated with thermal storage system in order to purify the water. The hot water feed pump circulate the water from the thermal storage tank to the feed of MD hot side at high temperatures and the return line is also provide so that the hot water, after exchanging the heat with cold water, returns back to the lower temperature zone in thermal storage tank.

6. INSTALLATION AND COMMISSIONING OF SDHW-MD INTEGRATED SYSTEM

The installation and commissioning phase starts with the first step of installing the flat plate collector frames. The frames were adjusted and cut into suitable lengths according to dimensional details of the solar collectors. The installation of the frames and complete installations is shown in the Fig. 4(a). The flat plate collector faces south at tilt angle of 35° in order to maximize the solar yield in winter (Fig. 4(b)). After the installation of the flat plate solar collectors, the second step was to lay the copper piping The piping connect different arrangements of solar arrays with solar station as mentioned in design phase. In order to avoid the heat losses, insulation is very important. For this purpose, the whole copper piping was insulated with Poly-Isocyanurate insulation of 50mm thickness having density of 35-40 kg/m^3.

The solar station circuit was connected to stratified solar thermal storage tank (Fig. 4(c)) so as to circulate the water in collector loop. The thermal storage tank was then connected to MD system and SDHW system in order to draw the hot water for simultaneous production of hot water and drinking water. Chlorinated Polyvinyl Chloride (CPVC) piping was used to connect the MD system with thermal storage tank and with the cold water storage tank (Fig. 4(d)) whereas copper piping with same insulation was used to connect the domestic hot water system to thermal storage tank.

7. EXPERIMENTAL APPROACH

As mentioned earlier, different collector arrays combination with different absorber areas have been performed. From feasibility point of view, the complete analysis has been performed on flat plate collector having aperture area of 11.85 m^2. A simulation model has also been established on PolySun. It is important to simulate the model and then performed the experimental analysis and then compare these simulated readings and experimentally taken reading and then compare them to finds the results. The complete procedure is mentioned below.

7.1. Polysun Simulation Model

A system model has been created in PolySun software in order to replicate the experimental installation. In built system, components have been selected for solar thermal circuit and exact experimental specifications have been provided like pipe length, diameters, insulation thickness, solar station controller settings etc. Solar pump has been controlled similar to the experimental unit and switches ON when the collector outlet temperature difference and the tank lower layer temperature is greater than 6°C and switches OFF when the temperature difference is less than 4°C. Although there are no in-built components for MD

Table 1. Simulation and experimental data: FPC aperture area 11.85 m^2.

Parameter	Value	Remarks
Specific Flow Rate	11.2 l/h/m^2	Kept low to achieve high temperatures
	Simulation Data	
Solar Yield	31.3 kWh	12 Hours
MD Energy Use	20.0 kWh	64% of total solar yield
DHW Energy Use	5.85 kWh	18.5% of total solar yield
% of losses	17.5%	Long pipe lengths – more losses
	Experimental Data	
Distillate Collected	16 L	10 Hours of Operation
MD Energy Use	12.92 kWh	0.804 kWh/l
DHW Energy Use	5.63 kWh	Not withdrawn according to DHW profile DHW profile
	Estimated Values	
Extra Available Energy	7.3 kWh	$Total_{Sim}$ – $Total_{Exp}$
Estimated $V_{Dist.}$	25 L	36% more production

system, so an energy sink with specific demand profile has been replicated in place of MD. Therefore, in addition to solar station controller, two more controllers have been used in the model. One for MD circuit and another for the DHW circuit. The model is shown in Fig. 6.

7.2. Experimental Performance on Flat Plate Collector

Experiment has been performed on flat plate collector having the aperture area of 11.85 m^2 shown in Fig. 8 and with low specific flow rates in order to achieve the higher collector outlet temper

Table 1 shows the energy consumption estimates from simulation and experimental data that has been performed on the plant. From the simulation it is important to note that 64% of the total solar yield could be used by MD whereas only 18.5% for DHW production. Assuming the same solar yield for the experiments, only 41% of the total solar yield has been utilized by MD and 18% for the DHW production. The losses have been observed due to low flow rate and long pipe distances between the solar collector arrays and thermal storage tank. For practical purpose, these losses could be avoided with proper insulation thickness and by installing the thermal storage near to the collector. Therefore, assuming simulation results as real case scenario, 23% extra amount of energy could actually be used for MD and hence more production of pure water could be obtained. It has been estimated that 36% more pure water production could be achieved with same operational hours of MD.

A plot has been developed for hourly energy consumption for MD along with collector outlet, tank top layer, MD hot in temperature in Fig. 8. From the plot, it has been observed that collector outlet temperatures from experiments show 5°C less than that of simulation. As stated above, excess energy consumption trend for MD could be observed for simulation data.

Also the trends for MD hot in and tank top temperatures show slight deviation especially during early hours of operation. This drop could be explained due to the fact that DHW has been withdrawn only during morning instead of following the withdrawal profile as shown in Fig. 9. The sudden drop in tank top temperature is due to the uncontrolled draw off of the domestic hot water. The vertical green bars show the hourly DHW energy profile from simulations in PolySun. The pink bars show the energy profile that is generated according to the experiments. The average hot water volume that was withdrawn during experiments was 273 L at an average temperature of 50°C.

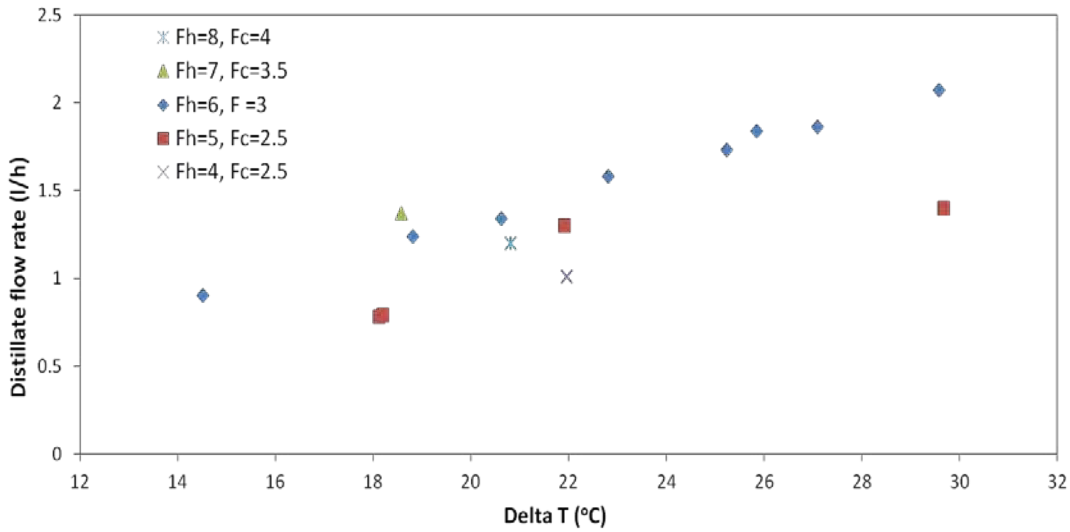

Fig. 11. Distillate flow rate vs Delta T (hot in temperature-cold in temperature).

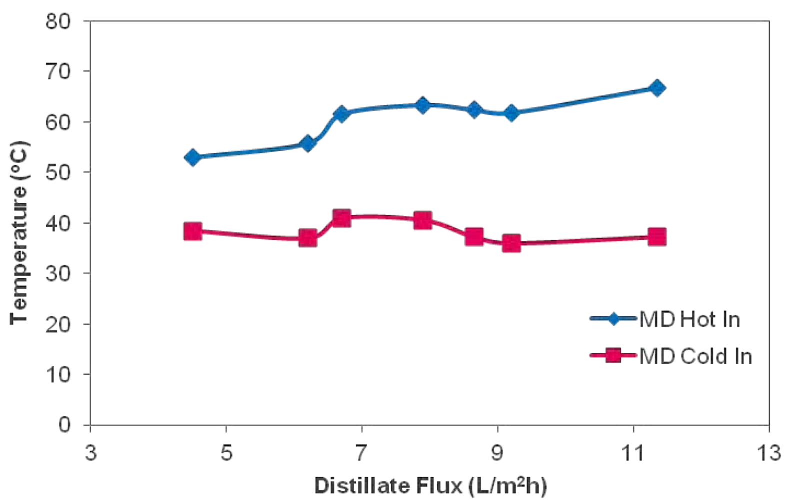

Fig. 12. MD hot and cold feed temperatures vs. distillate flux.

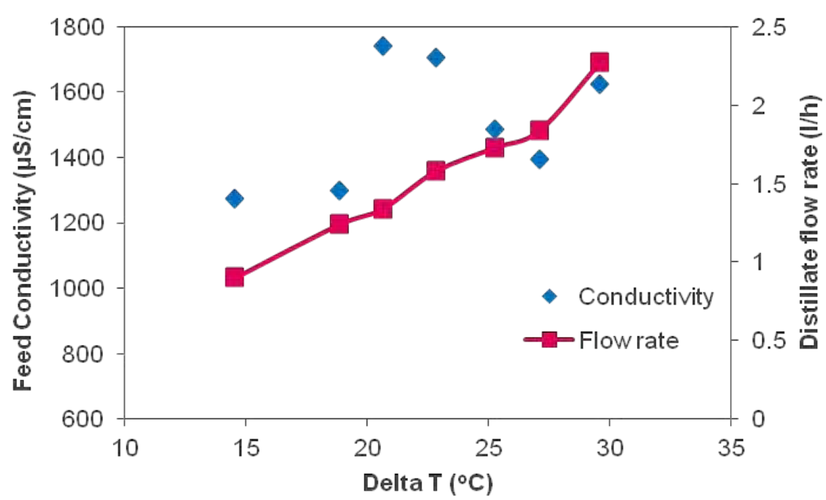

Fig. 13. Feed water conductivity vs. distillate flux.

7.3. Purification Results Of Water Through Membrane Distillation

Fig. 10 shows the physical result for the purification of the grey water . The municipal water or grey water from the thermal storage tank was fed in to the MD unit and the conductivity of the desalinated water was obtained less than 5 μS/cm irrespective of changes in the feed concentrations.

8. DISCUSSION

In order to draw the experimental results from the integrated pilot plant, several experiments were performed on the system and the experimental results were tabulated. At different feed conductivities, the hot and cold side flow rates were experimented and the optimum conditions were found. Once the optimum flow rates have been evaluated, the plant was operated on those flow rates and collector areas were changed. Following sections provide effect of various parameters on distillate flux

8.1. Effect of Hot and Cold Flow rates on Distillate Flow

Previously, lab scale experiments were performed at CSEM to determine optimum flow conditions for the AGMD module to maximize the flux. However due to lab system limitation, it was unable to go beyond flow rates of 4 l/min on MD hot side. Therefore, several experiments are performed to determine optimum flow conditions for the single cassette module. The graph below is drawn between the distillate flow rate and the temperature difference between MD hot and cold side. So, from the Fig. 11, it is obvious that the optimum flow rate at hot side and cold side of the MD was 6 l/min and 3l/min. The cold side flow rate has been taken as half of the hot side flow based on the manufactures recommendation.

Now there is a slight deviation from the observed value at flow rates of 7 l/min on hot side. Experiments will be performed on the plant by further researchers in the future in order to find out that whether that observed deviation will fulfill the conditions or not. But for now, based on the experimental results, the optimum hot side flow rates was 6 l/min and cold side flow rate was 3 l/min. These conditions were fixed for further experimentation

8.2. Effect of Hot and Cold Side Temperature on Flux

Various researchers investigated the effect of feed temperatures on the AGMD performance. In general, the rate of evaporation increases with increase in feed temperature. Therefore, for the experiments performed, a graph has been drawn between the distillate flux and the MD hot and cold in temperatures in order to find out the effect of temperature on the distillate flux as shown in Fig. 12. As the hot in temperature increases, the distillate flux increases. Heat loss due to conduction decreases with increase in feed temperature and hence thermal efficiency could be improved. From the experimental data obtained, the thermal storage tank has been charged well in order to provide the sufficient temperature to the MD hot side (between 50 to 70^{o}C)

8.3. Effect of Feed water Conductivity

The application under consideration is to purify municipal tap waters supplied by local authorities in UAE. Therefore aqueous feed conductivities are varied between 1000 to 1800 μS/cm. As far as the conductivity of the feed water is concerned, there is no significant effect of feed water conductivity on the distillate flux. Irrespective of the increase or decrease in the conductivity, the production of the distillate flux increases due to increase in feed temperature differences. However at large conductivities (brackish or seawater), flux production would be reduced due to reduction in water vapor pressure for high concentrated non-volatile solutions. For the experiments conducted at CSEM-uae, the effect of feed conductivity on distillate flux is shown in the Fig. 13.

11. CONCLUSIONS

The results obtained by performing the analysis on flat plate collector of aperture are of 11.85 m^2 shows that the installation of solar combi system for simultaneous production of pure drinking water and domestic hot water fulfills the benchmark production in hot and dry regions like Dubai. Due to the high solar insolation, hot weather conditions and high solar fraction, this system is sufficient enough to fulfill the drinking demand and domestic hot water demand for a single family villa comprising of 4 to 5 persons. The experimental set up was operated for 10 hours at specific flow rate of 11.21 L/h/m^2. The flow rate was kept low to achieve the high temperature.

From the experimental data, the total volume of distillate that has been collected was 16 L. The total solar yield was 31.3 kWh and the membrane distillation system energy usage was 12.92 kWh as compared to 20 kWh from simulation data. The most of the energy lost takes place in pipings, bends and fittings. Moreover, the proper piping insulation is another recommendation in order to avoid the losses and for efficient energy recovery form the solar combi system. Similarly, the domestic hot water energy usage was 5.63 kWh as compared to the 5.85 kWh from simulation data. Per L energy consumption of the membrane distillation system was 0.804 kWh/l. In view all these factors, it has been concluded that it is feasible to integrate MD system with DHW system.For single family in UAE comprising of 4 to 5 members, our single cassette membrane distillation setup integrated with domestic hot water system can produce 16 l/day of pure water and 273 l/day of domestic hot water at an average temperature of about 50°C according to the experiments that has been performed on flat plate solar collectors of aperture area of 11.85m2. Since our benchmark production was 15-25 L/day of pure drinking water and 250 L/day of domestic hot water, so this integrated system can fulfil the demands. The future experiments may be performed on evacuated tube collectors using multiple cassettes for MD side in order to increase the distillate volume and domestic hot water for more than one family.

12. ACKNOWLEDGEMENTS

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