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# Feasibility analysis of solar combi-system for simultaneous production of pure drinking water via membrane distillation and domestic hot water for single-family villa: pilot plant setup in Dubai

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## ABSTRACT

This paper presents the feasibility study of installation of a solar-driven integrated MD desalination system for simultaneous production of pure drinking water and solar domestic hot water in United Arab Emirates (UAE) for a single-family villa comprising of 4–5 persons. In order to satisfy the current and future demand of water for domestic purposes, the desalination of seawater is considered to be one of the most effective and strategic technique in UAE. The stress on the underground water aquifers, rapid industrial growth, and increase in urban population in UAE results in the tremendous increase in fresh water demand during the past few decades. Since the local municipalities also provide the desalinated fresh water to the people but they mostly rely on bottled water for drinking purpose. In this paper, the pilot setup plant is designed, commissioned, and installed on site in UAE using air gap membrane distillation desalination process to fulfill the demand of 15–25 L/d of pure drinking water and 250 L/d of domestic hot water for a single-family villa. Experimental analyses have been performed on this setup during summer on flat plate solar collectors having different aperture areas (Experiments have been performed for aperture area of 11.9 $m^2$ in this research study for feasibility purpose). The average hot-side temperature ranges from 50 to 70°C and average cold-side temperature of 35°C.

*Keywords:* Air gap membrane distillation; Solar domestic hot water; Desalination; Flat plate collector; Bottled water

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## 1. Water scarcity problem in United Arab Emirates—an overview

Water plays a significant role in sustaining the life of a human being. Water purification and management plays a key role in societies as it covers not only the basic need of human for consumption, but also for other survival purposes like agriculture, industrial, and domestic needs. Our earth has 325 million cubic miles of water availability and comprises 71% of earth's surface. Out of this percentage, 97.5% of the

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earth's water is salt water and only 2.5% is available as fresh water which humans utilize. Only 1% of this 2.5% of fresh water is accessible to human beings which they can utilize for drinking and other domestic purposes, as rest is frozen in ice caps or it exists as moisture in the soil. In the Middle East and North African (MENA) region, United Arab Emirates (UAE) 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 in increase in the water demand. The long-term average precipitation rate in UAE is 78 mm per year as compared to United States (715 mm per year) and 1,274 mm per year for Korea [2]. So the countries like UAE which experiences 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 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 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 the best strategy. According to International Desalination Association (IDA), the total number of desalination plants installed worldwide over 170 countries is 15,988 (as of 30 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 the 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 use the bottled water for drinking purpose which is supplied to the end users typically in five gallon containers. Although the desalinated water has been supplied to the end user, its main use would be for the domestic purpose i.e. for cleaning, bathing etc. About 1.2 billion liters 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.

## 2. Literature review and comparative studies

Membrane distillation (MD) is a promising desalination technology offering advantages of robustness, scalability, and improved environmental performance as compared to established methods [6]. In this technique, the driving force for desalination is the difference in vapor pressure of water across the hydrophobic membrane, which allows water vapor 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 vapor 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 industry as well as in industrial applications. An industrial research has been carried out on solar driven MD system to produce pure water through a recent technique of air gap membrane distillation (AGMD) [7].

Kullab et al [6] studied the system consisting of an air gap membrane distillation (AGMD) unit integrated with non-concentrating solar thermal collectors. Scale-up of the MD unit was obtained from an AGMD test facility and trials were conducted with various feedstock, total dissolved solids (TDS) levels, temperatures, and flow rates. Laboratory data obtained from these and other studies demonstrate that MD unit performance is relatively insensitive to the variations in feedstock qualities (e.g. pH, TDS levels).

Kullab and Martin [8] performed experimental analysis on MD-based water treatment laboratory setup. The analysis was 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 MD unit capable to produce 1–2 $m^3$/d of purified drinking water. District heating supply line was employed for heating, whereas municipal water was used for cooling purpose.

Banat and Simandl [9] performed experimental analysis for desalinating water using AGMD technique and membranes of different porosities and different materials (Polyvinylidene fluoride and Polytetrafluoroethylene). During the experimental analysis, the hot-side temperature, cold-side flow rate, and feed concentration were investigated. The obtained results showed that the mass flux was steady over time and was affected slightly by an increase in salt concentration. Permeated quality was also affected when membrane wetting occurred. There was an exponential increase in the permeate flux rate with increase in hot-side temperature, whereas the cold-side flow rate had a negligible effect on permeate flux.

Numerical analysis and experimental studies have also been performed for desalinating water using MD technique. For desalination, an experimental and simulation work was conducted on AGMD semi-commercial system as a part of EU MEDESOL project.

The main motive of this study was to evaluate the AGMD performance with saline water (35 g/l of NaCl) and to establish an operational database for simulation of three- stage AGMD system. Without heat recovery, the specific thermal energy consumption was calculated as 950 $kWh_t/m^3$, whereas with heat recovery the specific thermal energy consumption was 850 $kW_t/m^3$ [10].

So keeping in view all the above-mentioned studies and motivation, a pilot plant setup has been planned to install capable to fulfill the drinking and domestic hot water needs for a single-family villa in Dubai.

## 3. Research objective

As mentioned earlier, UAE consumes significant amounts of bottled water per capita resulting in 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 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/d of pure drinking water and 250 L/d 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 MD-based water purifier with Solar Domestic Hot Water (SDHW) 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 MD operational parameters. Fig. 1 shows the prototype of the solar combi-system designed to carry out the research.

## 4. 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 AGMD technique because of its advantages on other membranous desalination techniques as it has low conduction losses, low temperature polarization effect, and internal heat recovery.

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. So three circuits have been designed:

(1) Solar thermal heating circuit
(2) SDHW circuit
(3) MD circuit

The experimental facility was constructed and commissioned at CSEM-UAE, now RAK Research and Innovation Center.

## 5. Why MD technique?

The process of MD is a novel process and unique method of water purification and this process can easily be adapted for the purification of water at small-scale application, as it has more advantages over other water purification techniques like reverse osmosis (RO) technique. The small-scale RO purification plants that are used in households waste a lot of water due to their low recovery ratio and continuous operation. MD operates in batch mode with recirculation of

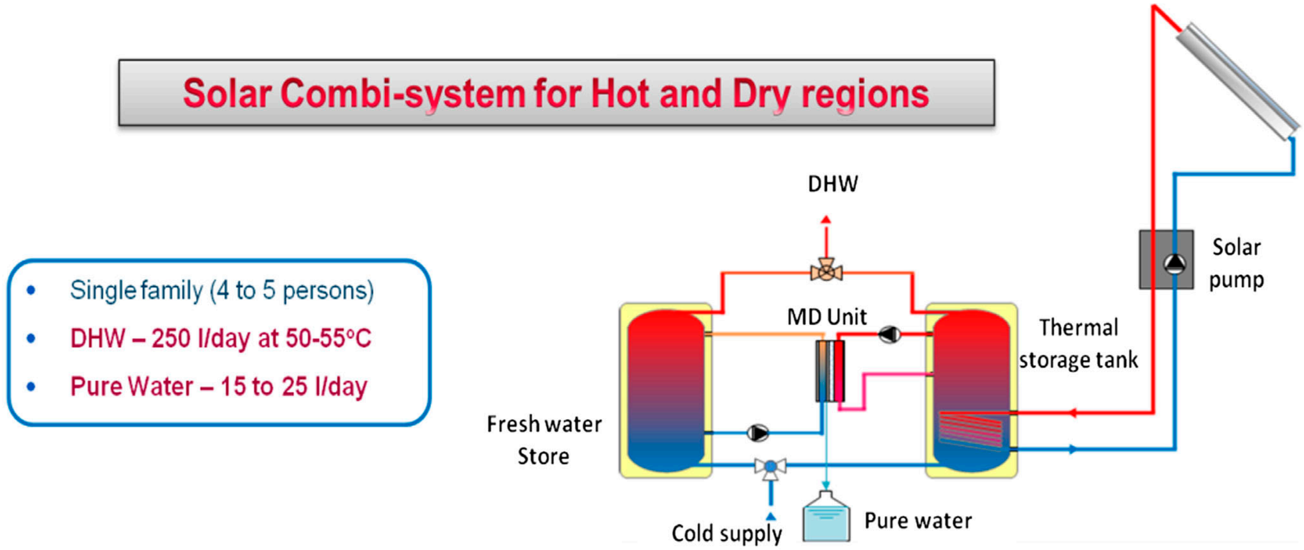


Fig. 1. Prototype of solar combi-system for hot and dry regions.

feed water due to its superior quality of handling changes in feed parameters. In this research study, the AGMD 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 the form of vapor to pass through the microporous 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. Hot-side temperature below 90˚C is the suitable operating temperature and this process is also very beneficial for recovering the heat from cold-side. Fig. 2 shows the basic process of AGMD [11].

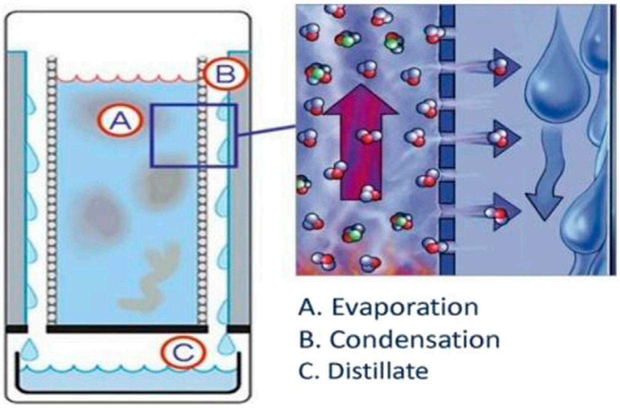


Fig. 2. AGMD technique (image on right-hand side courtesy of Scarab development AB).

## 6. MD module

As mentioned earlier, the MD process is a combined thermal-driven membrane separation process in which the microporous hydrophobic membrane separates the pure water from the bulk feed water. The MD module that is being used in this experimental setup has the following properties.

(1) Hydrophobic Polytetrafluoroethylene (PTFE) Membrane.
(2) Pore size is 0.2 μm; thickness is 280 μm.
(3) 80% porosity and membrane area 0.2 $m^2$.

The AGMD module consists of 2.4-cm gap between the two condensing plates made of aluminum behind which the cooling channels in serpentine shape are located. 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 comes in from the bottom of the cassette and flows out from the top. An 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. Overall module design is identical to the unit presented in Khan and Martin [12]. The sketch of the MD module is shown in Fig. 3.

The above explanation can be summarized through description of flows in three channels:

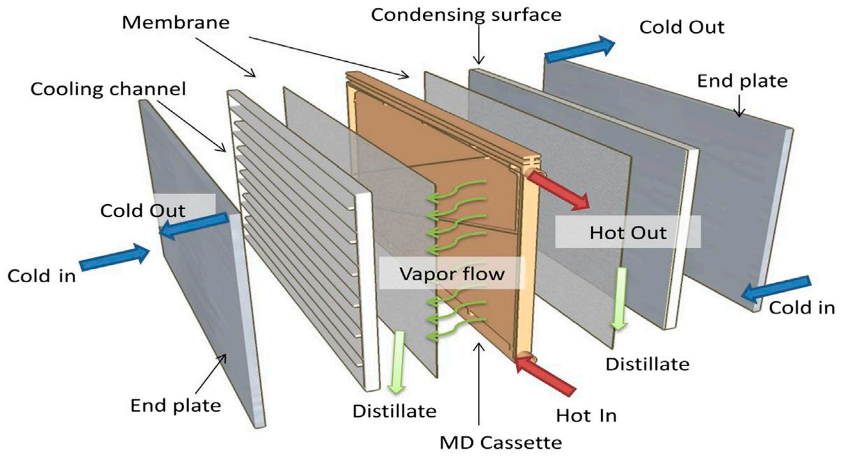


Fig. 3. Sketch of a MD module.

1. Hot channel, where the hot feed water enters the cassette in contact with the membrane, vapors are generated and pass through the membrane.
2. Air gap, a stagnant air gap is maintained between the outer membrane surface and condensation plates allow the vapors to condense and are collected in a distillate channel at the bottom.
3. Cold channel, where the cold fluid flows in contact with the other side of the condensation plates and absorbs the latent heat of condensed vapors.

## 7. Why SDHW?

There is availability of high solar insolation in MENA region due to which it is very useful and helpful to use solar DHW in this region. The typical SDHW systems that are installed in MENA region are designed for 60–70% of annual solar fraction [13] 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 backup 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 the solar fraction. The system has been designed at high solar fraction because of the two main concerns:

1. 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.
2. Backup electric heaters are also used to kill the Legionella bacteria by heating up to 60°C which makes the SDHW systems inefficient [13].

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.

## 8. Experimental design and analysis of SDHW-MD integrated system

### *8.1. 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 MD circuit for the production of pure drinking water that includes MD module, distillate storage, and feed water storage tank. These three circuits have been combined to form a solar-driven MD 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. 4 and the details of the three circuits have also been elaborated.

### 8.1.1. Solar thermal circuit

The most important part of this circuit are the solar collectors and they have been divided into three different combinations 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 2.55 $m^2$ and a total of eight collectors have been installed having total absorber area of 20.5 $m^2$. The first array has an area of 5.1 $m^2$ and the second and third array each has absorber area of 7.65 $m^2$. 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 (520 L). 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.

### 8.1.2. SDHW circuit

The SDHW circuit consists of hot water storage tank, a solenoid valve, and a three-way manual mixing valve to adjust the temperature during the collection of domestic hot water and to control the flow rate so as to get the desired volume of the domestic hot water (250 L/d) which is the benchmark figure.

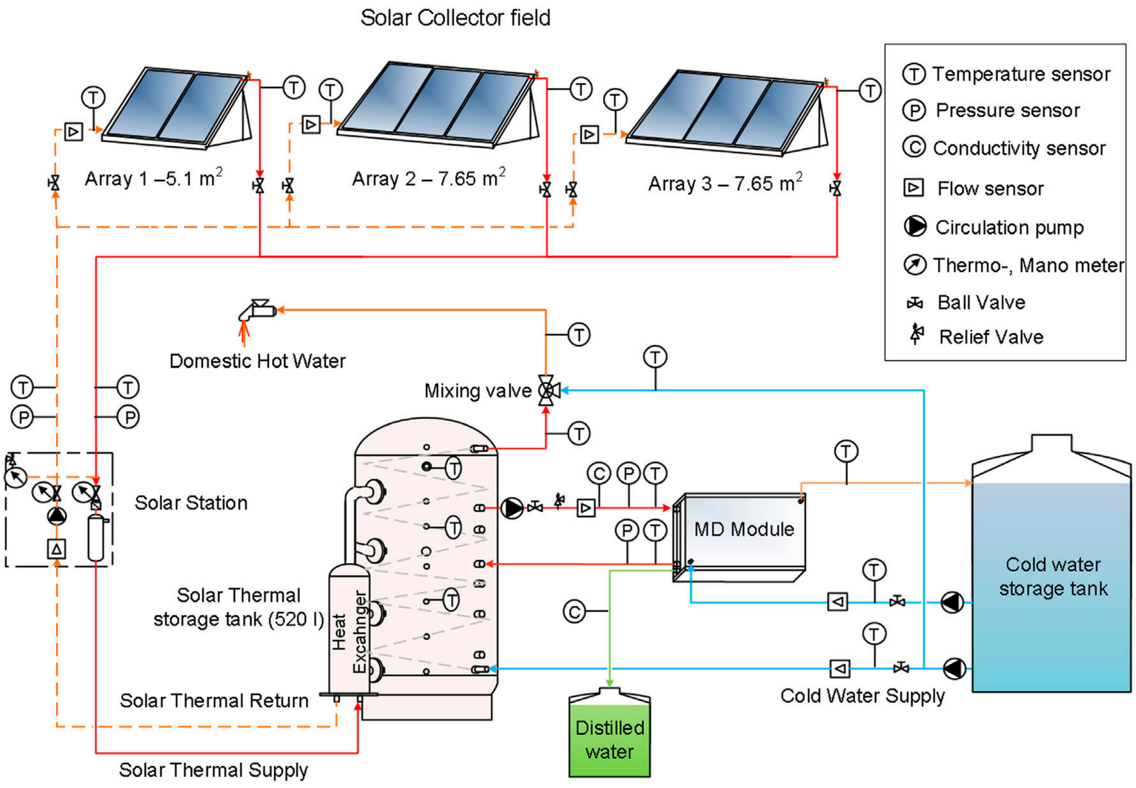


Fig. 4. SDHW-MD experimental plant design.

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 intervals.

### 8.1.3. MD circuit

MD 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 is pumped into 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 the incoming and outgoing lines. Conductivity meter is also installed in order to monitor the feed water conductivity and distillate flux conductivity.

The MD circuit has been integrated with thermal storage system in order to purify the water. The hot-water feed pump circulates the water from the thermal storage tank to the feed of MD hot side at high temperatures and the return line is also provided, so that the hot water, after exchanging the heat with cold water, returns back to the lower temperature zone in thermal storage tank. By doing so, we are actually recovering the heat as we are sending the water back to the tank at low temperature and reducing the thermal energy demand for MD system.

## 9. 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 Fig. 5(a). The flat plate collector faces south at a tilt angle of 35˚ in order to maximize the solar yield in winter (Fig. 5(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 50 mm thickness having density of 35–40 $kg/m^3$.

The solar station circuit was connected to stratified solar thermal storage tank (Fig. 5(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. 5(d)), whereas copper piping with same insulation was used to connect the DHW system to thermal storage tank (Fig. 6).

## 10. Standard operating procedure for plant start-up

The standard procedure for plant start-up for the circuits is discussed in detail as:

### 10.1. Solar thermal circuit

1. The thermal storage tank temperature should be checked for initial reading. The temperature should lie between 70 and 85˚C (Depending on previous day charging).
2. Now start the solar loop filling pump making sure that the valves of the desired collector array are open. Check the pressure in the solar circuit which should lie between 2.5 and 3 bar. If, in case, the pressure exceeds 3 bar, a drain valve has been provided in the circuit to release the pressure manually in order to bring the pressure within the permissible operating range.
3. Fill the storage tank with municipal tap water and pressurize the storage tank till 0.5 bar. Make sure that during filling, MD hot in and return line valves are closed to avoid the excess pressure in MD circuit that might lead to membrane damage.
4. Switch ON the solar station pump and set it to automatic mode.

### 10.2. MD circuit

1. Before switching the MD circuit ON, check the water level in cold-water storage tank. It should be well above in order to start the MD

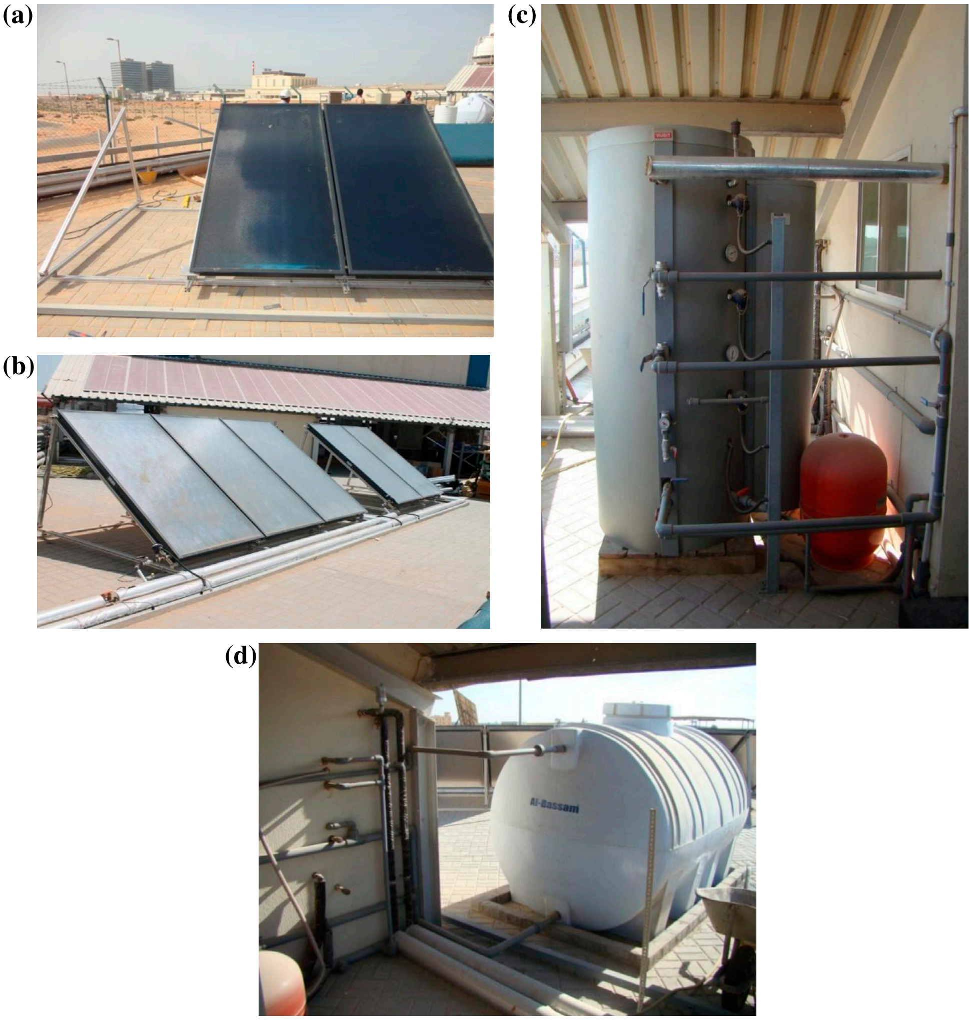


Fig. 5. (a) Installation of flat plate collector plates, (b) orientation, placement and angle orientation of collectors, (c) stratified thermal storage tank with piping circuits, and (d) cold water storage tank (municipal water supply).

cold-side pump. Adjust the desired flow rate on which we want to perform the experimental analysis and set the cold-side pump in automatic mode.

(2) Open the MD inlet and return line valves that were closed during the filling of storage tank. Then switch ON the MD hot-side pump.
(3) Set the desired hot-side flow rate on which we want to perform the experiments. Make sure that the circuit is air free before starting the pump.
(4) Now start the main DHW pump by adjusting the hot-side flow rate of 3 L/min. The temperature should be monitored in order to get the hot water at desired temperature i.e. 45–55°C.

### 10.3. Distillate collection

(1) Clean the distillate tank thoroughly.
(2) Tare and check the weight balance and then check the weight of the total distillate collected in the container.

## 11. 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

Fig. 6. MD system with solar station.

model has also been established on PolySun. It is important to simulate the model and then perform the experimental analysis, then compare these simulated readings and experimentally taken readings and then compare them to find the results. The complete procedure is mentioned below.

### 11.1. 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 system, 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. 7.

### 11.2. Experimental performance on flat plate collector—aperture area 11.85 $m^2$

Experiment has been performed on flat plate collector having the aperture area of 11.85 $m^2$ (5 collectors) shown in Fig. 8 and with low specific flow rates in order to achieve the higher collector outlet temperature.

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 the same operational hours of MD.

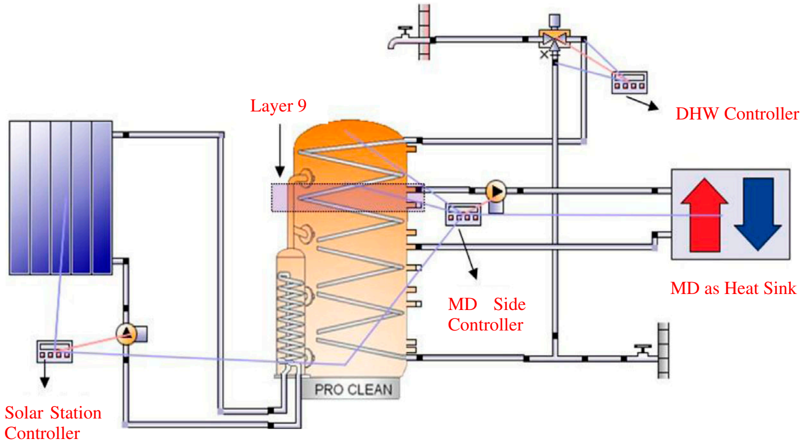


Fig. 7. PolySun simulation model SDHW-MD system.

Fig. 8. Flat plate collector array aperture area 11.85 $m^2$.

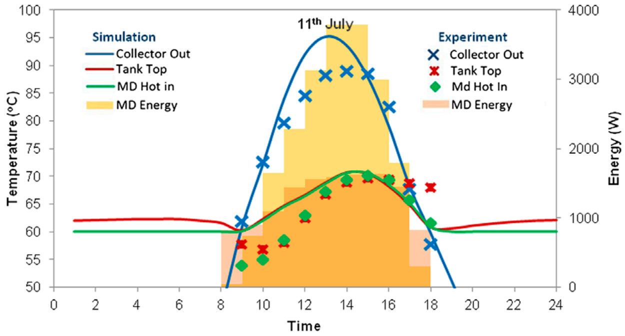


Fig. 9. MD temperature and energy profile.

A plot has been developed for hourly energy consumption for MD along with collector outlet, tank top layer, MD hot in temperature in Fig. 9. 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. 10. 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.

Proper data acquisition has been done for the whole SDHW-MD plant and the parameters were transferred from the sensors to the system through data acquisition modules. This interface is shown in Fig. 11.

### 11.3. Purification results of water through MD

Fig. 12 shows the physical result for the purification of the gray water. The municipal water or gray water from the thermal storage tank was fed into the MD unit and the conductivity of the desalinated water was obtained less than 5 μS/cm irrespective of changes in feed concentrations.

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 h |
| 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 h 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 | $\text{Total}_{\text{Sim}} - \text{Total}_{\text{Exp}}$ |
| Estimated $V_{\text{Dist.}}$ | 25 L | 36% more production |

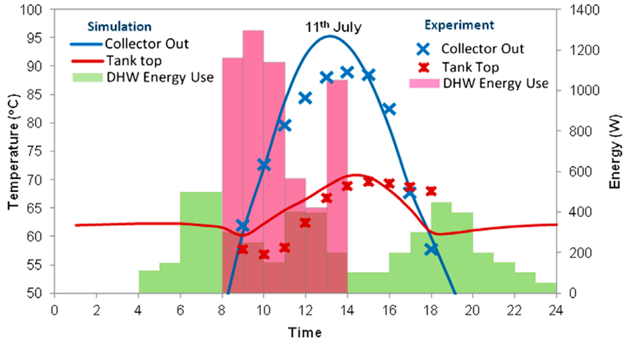
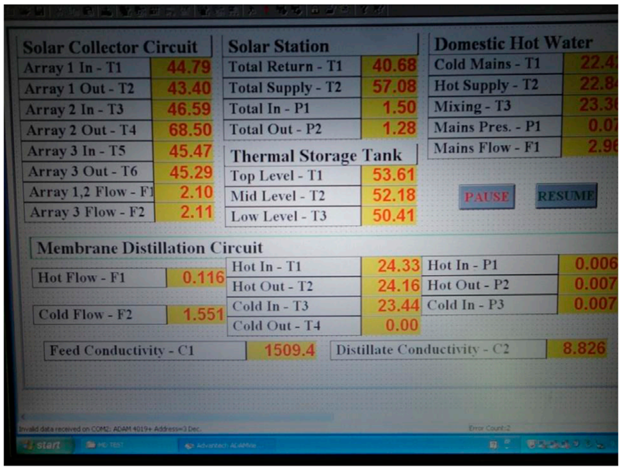


Fig. 10. DHW temperature and energy profile.



**Solar Collector Circuit**

| | |
|---|---|
| Array 1 In - T1 | 44.79 |
| Array 1 Out - T2 | 43.40 |
| Array 2 In - T3 | 46.59 |
| Array 2 Out - T4 | 68.50 |
| Array 3 In - T5 | 45.47 |
| Array 3 Out - T6 | 45.29 |
| Array 1,2 Flow - F1 | 2.10 |
| Array 3 Flow - F2 | 2.11 |

**Solar Station**

| | |
|---|---|
| Total Return - T1 | 40.68 |
| Total Supply - T2 | 57.08 |
| Total In - P1 | 1.50 |
| Total Out - P2 | 1.28 |

**Thermal Storage Tank**

| | |
|---|---|
| Top Level - T1 | 53.61 |
| Mid Level - T2 | 52.18 |
| Low Level - T3 | 50.41 |

**Domestic Hot Water**

| | |
|---|---|
| Cold Mains - T1 | 22.4 |
| Hot Supply - T2 | 22.8 |
| Mixing - T3 | 23.3 |
| Mains Pres. - P1 | 0.0 |
| Mains Flow - F1 | 2.9 |

**Membrane Distillation Circuit**

| | |
|---|---|
| Hot Flow - F1 | 0.116 |
| Cold Flow - F2 | 1.551 |
| Hot In - T1 | 24.33 |
| Hot Out - T2 | 24.16 |
| Cold In - T3 | 23.44 |
| Cold Out - T4 | 0.00 |
| Hot In - P1 | 0.006 |
| Hot Out - P2 | 0.007 |
| Cold In - P3 | 0.007 |
| Feed Conductivity - C1 | 1509.4 |
| Distillate Conductivity - C2 | 8.826 |

Invalid data received on COM2: ADAM 4019+ Address=3 Dec.

Error Count:2

Fig. 11. Data acquisition interface of SDHW-MD system.

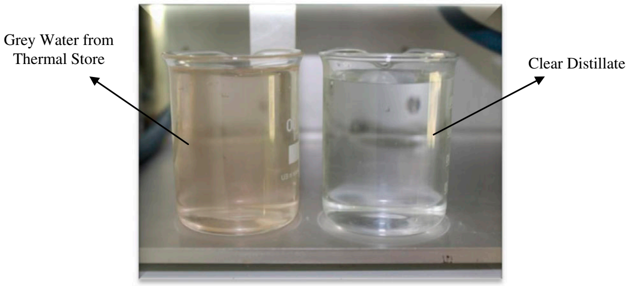


Fig. 12. Samples of gray water and clear distillate.

## 12. Results and conclusion

The results obtained by performing the analysis on flat plate collector of aperture are of 11.85 m$^2$ showing 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 4–5 persons. Moreover, it is also feasible to integrate MD system with SDHW system.

Moreover, since our benchmarks were the production of 15–25 L/d of pure drinking water and 250 L/d of domestic hot water with flat plate collector of aperture area 11.85 m$^2$ is fulfilling the demand by producing 16 L/d of pure drinking water and 273 L/d of domestic hot water at an average temperature of about 50°C.

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