A Solar Energy Hybrid Desalination System Using Humidification–Dehumidification Process integrated with RO unit Evacuated tube solar water heater and solar air heater

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Abstract- An experimental investigation of hybrid desalination system using Humidification–Dehumidification process integrated with RO unit, evacuated tube solar water heater (SWH) and solar air heater (SAH). The humidifier unit is based on a cellulose paper as a packing material to increase the mass and heat transfer. A modified design of dehumidifier is used in HDH process to condensate water vapor and improve the performance of the unit. The system is based on the idea of open-water and open -air cycles. The SWH and SAH are integrated with the desalination unit to increase the rate of evaporation. The results showed that, the productivity of the unit strongly depends on the water temperature at humidifier inlet and Ro unit inlet. In addition, the optimal ratio of cold water at dehumidifier inlet to hot water at humidifier inlet (C/H) is obtained. The results show that a maximum productivity of (14.25 L/hr.) is obtained when C/H =2, inlet water mass flow rate to the humidifier (2 kg/min), Using SAH with (5 m/s) humidifier inlet air velocity, and 95 °C at humidifier inlet. The productivity obtained from the HDH system while operating full day is 56.6 L/ workday and maximum Ro unit productivity is 55 L/hr. was obtained at 45 °C RO unit Feed Water, the productivity obtained from the Ro unit while operating full day is 416 L/ workday was obtained at average 40 °C RO unit Feed Water. Hybrid system provides 472 L/day as a Sumption of Condensate water and Ro unit productivity.

Keywords-- Humidification; Dehumidification; Distillation; System; Reverse Osmosis.

i. INTRODUCTION

The availability of drinking water is reducing day by day, whereas the requirement of drinking water is in-creasing rapidly. All over the world, access to potable water to the people is narrowing down day by day [1]. Most of the human diseases are due to polluted or non-purified water resources. Even today, developed countries and developing countries face a huge water scarcity because of unplanned mechanism and pollution created by artificial activities [2]. The shortage of drinking water is expected to be the biggest problem of the world in this century due to unsustainable consumption rates and population growth. Pollution of freshwater resources (rivers, lakes, and underground water) by industrial wastes has heightened the problem [3]. The total amount of global water re-serves is about 1.4 billion cubic kilometers. Oceans constitute about 97.5% of the total amount, and the remaining 2.5% fresh water is present in the atmosphere, polar ice, and ground water. This means that only about 0.014% is directly available to human beings and other organisms [4]. Desalination of sea and/or brackish water is an important alternative, since the only unlimited source of water is the ocean. Besides the problem of water shortage, process energy constitutes another problem area. Desalination processes require significant amount of energy. It was estimated that the production of 1 million cubic meter of water per day re- quires 10 million tons of oil per year [5] . Due to high cost of conventional energy sources, environmentally harmful, renewable energy sources (particularly solar energy) have gained more attraction since their use in desalination plants. This will save conventional energy for other applications, reduce environmental pollution, and provide free, continuous, and low maintenance energy source [4].

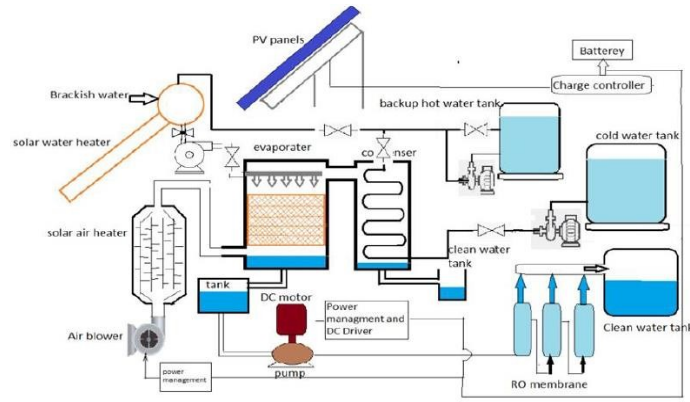
Different types of water desalination processes have been developed. Mainly desalination processes can be classified into the following two categories: phase change (thermal processes) and single phase (membrane processes). In the phase change process, a thermal energy source, such as fossil fuels, nuclear energy or solar energy may be used to evaporate water, which is condensed to provide fresh water. The phase change desalination processes described here include, solar distiller, Multi-Stage Flash (MSF) distillation, Multi-Effect (ME) distillation, Vapor Compression (VC) distillation, and Freezing distillation, In the single-phase processes membranes are used in two commercially important desalination processes, Reverse Osmosis (RO) distillation and Electro Dialysis (ED) distillation [10]. The HDH process is based on the fact that air can be mixed with quantities of vapor. Air ability to carry water vapor increases by increasing its temperature. For example, 1 kg of dry air can carry 0.5 kg of vapor and about (2814 kJ) when its temperature increases from 30° to 80° as reported in [5]. When air flow is in contact with salt water, air extracts a certain quantity of vapor at the expense of the sensible heat of salt water (providing cooling) [7]. On the other hand, the distilled water is recovered by maintaining humid air at contact with cooling surface, causing the condensation of a part of the vapor mixed with the air. The condensation occurs in another heat exchanger in which salt water is preheated by latent heat recovery [9]. A solar air heater, a solar water heater, a humidifier (evaporator), a dehumidifier (condenser), a RO unit, a solar panel, and a storage tank make up the HDH desalination system [8].

The system works on the principle of a open water–open air circuit which is basically consists of three paths as follow. The first path is SAH Which raises the air temperature greatly, which is then further heated to higher level by the second path SWH by high temperature water vapor used in the humidifier. The SWH heats sea water, which is then pumped into the humidifier which presents the second path. In the humidifier, heated sea water and air come into contact by backing materials. As the dehumidifier and humidifier are linked together, humidified air goes through the dehumidifier. Cold water which presents the third path travels through a cooling coil which is surrounded by humidified air. The water vapor then condenses on the dehumidifier's surfaces, resulting in fresh water. Water was collected at the bottom of the well. The HDH unit's condenser and evaporator have been created and tested to increase the HDH's performance. Condenser is a cylindrical shell air-water heat exchanger with corrugated fins and copper coil. The evaporator, on the other hand, is a rectangular cross-sectional shell with a small entrance for changing packing material. By employing a vacuum tube solar collector, the sequence of experiments and computations for the influence of the feed water temperature (ranging from 65 to 95 °C) on the evaporator are repeated with C/H = 2 (Ratio of cold-water Dehumidifier inlet to hot water Humidifier inlet) with different speed of blower range 3: 5 m/s. SPC of RO unit has decreased due to using hot brine rejected from the humidifier.

ii. Experimental Setup

Recently, constructing a high productive desalination unit with low power consumption has been a challenge. Along with that, this study aimed to discuss a new hybrid desalination unit merging two common techniques of high freshwater production: humidification-dehumidification (HDH), and reverse osmosis (RO). The solar (PV) systems were used to power the hybrid HDH-RO unit as illustrated in Figs.1-(a) and 1-(b). From previous work the freshwater production rate of HDH desalination technology is highly dependent on the temperature of the air and water entering to the humidifier as well as the water–air flow ratio. The reverse osmosis (RO) membrane process is widely used in seawater desalination as it is characterized by easy operation in the long term as well as low energy consumption. While it is still highly required to reduce the energy consumption rates of the RO process and make it an available technology for most of the global region.

(a)



(b)

Fig. 1 (a) hybrid system set up , (b) the schematic diagram of the experimental set up

System depends on PV Panels to supply the system with required power to achieve high performance of PV Panel, it is needed to be cooled to a specific range of temperatures, this is achieved by using part of brackish which is used for main process of desalination. This cause brackish water gets heated to a few degrees which makes sure that PV Panels achieve higher efficiency and increase the overall system efficiency by increasing inlet water temperature to the HDH system. This water is then pumped to solar water heater which heat the brackish water up to approximately boiling temperature (90:98 °C). The hot water then is pumped using 0.5 hp pump through piping system, this water enters the humidifier from the top and is sprayed through set of nozzles which convert it onto steam, at the same time air is forced by blower onto solar air heater which heat the air which help in improving air capability to carry more steam, this air entering the humidifier from the bottom. Inside the humidifier the air is moving from bottom to the top due to density difference and steam moves from the top to the bottom due to gravity force, as the humidifier contains backing material inside it which plays an important role in humidification process, as it increases the surface area of contact between the steam and the hot air which increase the rate of humidification. As a result, the humidifier is almost a saturated air and the water at the bottom is considered as a rejected water (Brine) (represent Ro unit inlet water at temperature range (40-45) ℃). The second stage of the system is done at dehumidifier, as humidifier and dehumidifier have a connection from the top, the saturated air is entering the dehumidifier from the top, at the same time cold water is fed to the dehumidifier from the bottom but it has its own path through the coil inside the dehumidifier, this coil has the effective role on purification process and it presents the contact aera between the cold water and hot saturated air and where the heat transfer occurs and water is condensate and this present the pure water from the HDH system. Due to heat transfer through the dehumidifier cold water gain heat and this hot water is recirculated to the solar water heater. The productivity of the HDH system is considered low because of low evaporation and condensation as in HDH system. The modification to increase the productivity is using Reverse osmosis system with the outlet hot water from the humidifier. Hot water is pumped to the RO unit, RO is considered as a filter as water pass through a membrane which works on separating the salt and dissolved particles from the water, this increasing the productivity by produce additional amount of pure water on the other hand the rest of water entering the RO unit is rejected. Using Ro unit with HDH is also has a great advantage as it reduces the amount of power required to RO unit.

iii. Results and Discussions

All results are obtained when C/H = 2 (Ratio of cold-water Dehumidifier inlet to hot water Humidifier inlet), inlet water mass flow rate to the humidifier is (2 kg/min), Using Solar Air heater with various air velocities (air is forced by blower onto solar air heater) and cellulous 5 mm as the packing material in the evaporator.

3.1 Effect of using Solar Air Heater (SAH) on Unit Productivity

Fig. 2 shows the effect using SAH on the unit productivity at different operating condition. For constant water flow rate, the productivity of the unit increases by using SAH at high range of Humidifier Inlet temperature (85-95) ℃, Due to using Air solar heater which raises air temperature, as a result, the capability of humidifier inlet air to carry vapor is increased which plays an important role at condensation processes and increase unit productivity. As shown in Fig. 2. below through the range of Humidifier Inlet temperature (85-95) ℃ using blower to provide air at evaporator inlet at 5 m/s. The productivity without SAH at 95 ℃ is about 12 L/hr. but with SAH the productivity has increased to 14 L/hr. by 16.7 percentage.

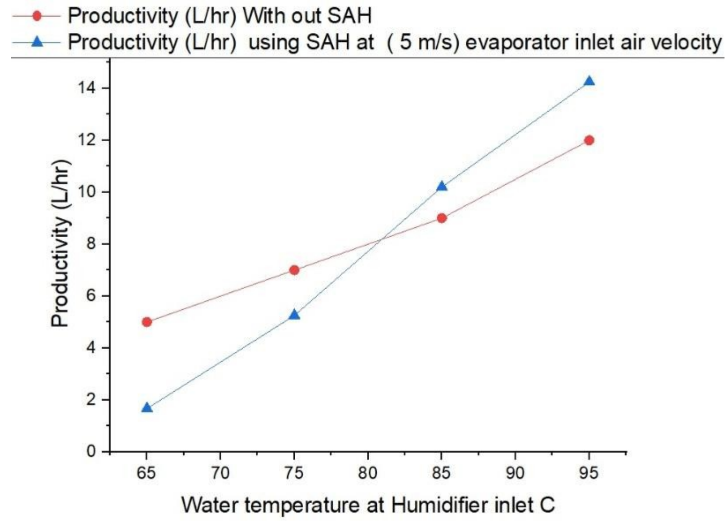
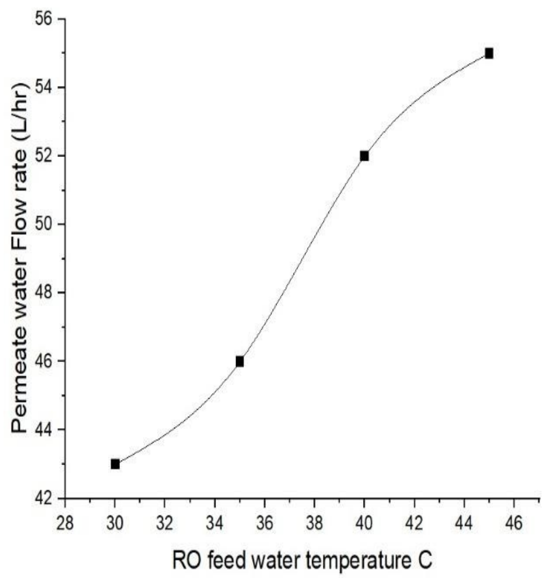


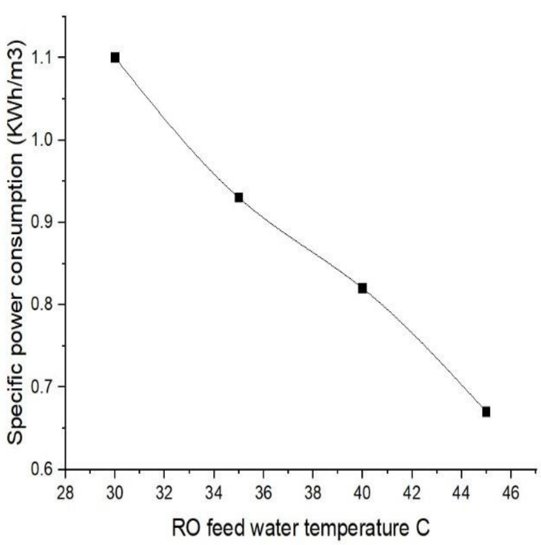
Fig. 2 Effect of using Solar Air Heater (SAH) on Unit Productivity

3.2 RO Unit Productivity

The effect of RO unit inlet water temperature on the performance, productivity and power consumption are experimentally tested. As mentioned before we used evaporator outlet water as an input to RO unit since its high temperature range which play an important role to unit performance as result of raise of water feed temperature the viscosity of water will decrease so shear stress due to water movement in RO membrane will decrease which decrease specific power consumption and increase unit productivity, this is shown in Fig. 2 (a) Ro productivity at various temperature as RO feed water temperature has increased from 40 to 45 ℃ the productivity has increased by 8 percentage, and Fig. 2-(b) shows that as RO feed water temperature has increased from 40 to 45 ℃ the power consumption has decreased by 33 percentage.



(a)



(b)

Fig. 3 (a) Ro productivity at various temperature, (b) RO Specific power consumption

3.3 Effect of RO feed water temperature on Unit Productivity

Fig. 3 shows the effect of RO feed water temperature on the unit productivity at different periods of time. For constant water flow rate, the productivity of the unit increases by increasing feed water temperature. The figure shows the effect of increasing feed water temperature on permeate water flow rate, as feed water temperature has increased by 5 ℃, the productivity has increased by 8 percentage.

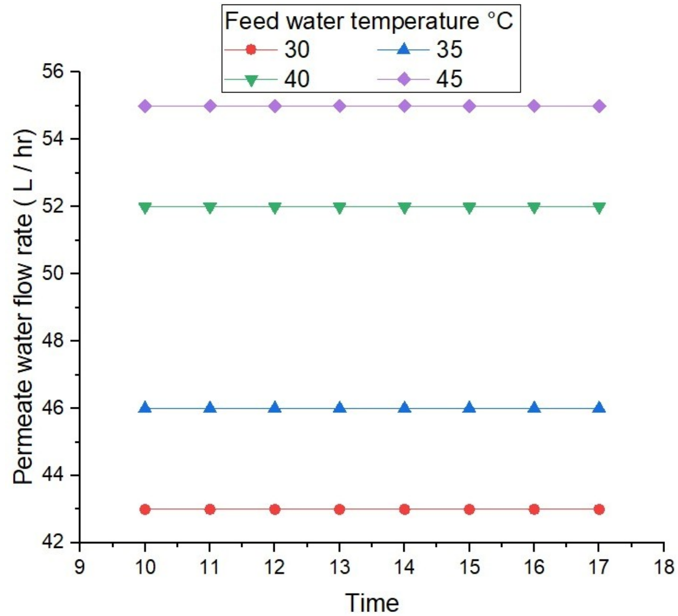


Fig. 3 Ro productivity at different periods of time with various temperature range.

3.4 Hybrid system productivity

Fig. 4 shows the effect of changing $Twhi$ on the overall Hybrid system Using Humidification–Dehumidification Process integrated with RO unit and solar air heater, and maximum productivity is about 70 L/hr. at 95 ℃.

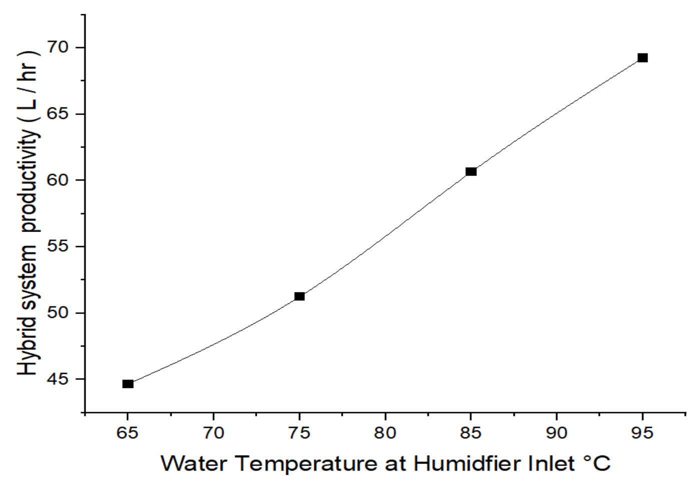
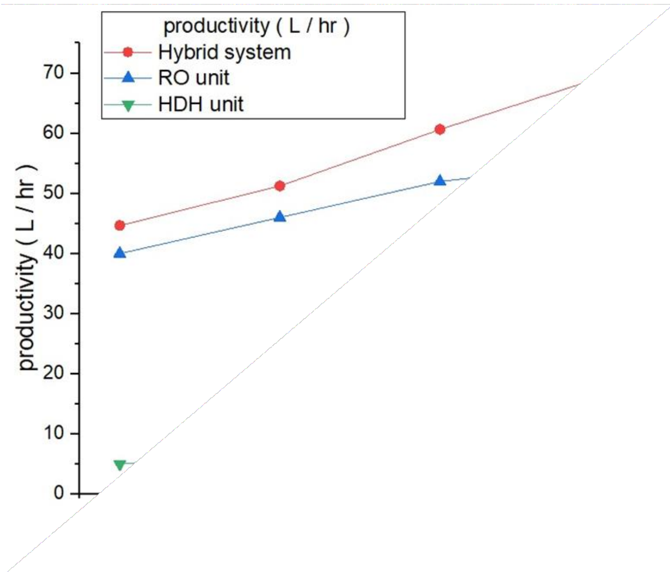


Fig. 4 Hybrid system Productivity

3.5 Hybrid system productivity Vs HDH unit Productivity

Fig. 5 shows the effect of using hybrid system on increasing the productivity of the all unit, the HDH unit productivity increases with $Twhi$ as well as RO unit productivity. So, the productivity of hybrid system is more than



HDH unit and RO unit individually. The maximum productivity is about 70 L/hr. which has increased by 550 percentage difference than HDH unit productivity and 39 percentage difference than RO unit at 95 C water temperature at humidifier inlet

4. Conclusions

Solar humidification-dehumidification desalination technology integrated with air, water solar heaters and reserve osmosis unit, powered by PV panels has been reviewed in this paper. It is found that the humidification and dehumidification desalination process HDH will be a suitable choice for fresh water as the availability of drinking water is reducing day by day, whereas the requirement of drinking water is increasing rapidly. HDH is a low temperature process where total required thermal energy is obtained from solar energy. Capacity of HDH units is between that produced by conventional methods and solar stills and HDH productivity is about 10 L/hr. with C/H = 2. More- over, HDH is distinguished by simple operation and maintenance. Solar energy is obtained from PV panels which is effective and cheap, and it requires cooling to get its high performance. PV panels help in decreasing cost per liter produced. Ro unit also helps in increasing the productivity of all system as it is fed with the hot brine outlet from the humidifier, this is due to that when the feed temperature increases by 1 degree membrane productivity increases by 2-3% as water permeability increases. Also, increasing feed water temperature decreases the viscosity of water, thus decreasing the required driving pressure across the membrane, this in turn decreases the SPC of RO plant and makes RO desalination cost- effective. The hybrid system of PV-HDH-RO has the advantage of higher productivity reach 70 L/hr. which has increased by 550 percentage difference than HDH unit productivity, and lower RO SPC reach 0.8 KWh/m^3 , effectiveness about 77 %, using SAH with 5 m/s evaporator inlet air velocity with 7% increase compared to the system without using Solar air heater.

amount of water vapor at humidifier which increases the productivity as this increases the evaporation rate at humidifier and, condensation rate at dehumidifier, but this can be achieved at high ambient temperature with high velocities of air through it and this leads to an increase in power consumption.

The results of this work:

- The hybrid HDH-RO desalination system is a good choice for freshwater production with low power consumption.
- Using air solar heater increases the ability of air to hold a huge amount of water vapor at humidifier which increases the productivity as this increases the evaporation rate at humidifier and, condensation rate at dehumidifier, but this can be achieved at high ambient temperature with high velocities of air through it and this leads to an increase in power.
- The accumulated productivity obtained from the Ro unit while operating full day is 416
- L/workday was obtained at average 40°C RO unit Feed Water (average Temperature of Evaporator Output).
- The accumulated productivity obtained from the HDH system while operating full day is 56.6 L/ workday.
- Freshwater production from the hybrid HDH-RO desalination unit is 472 L/day.

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