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# Desalination of seawater using solar, ambient energy and waste heat from air conditioning

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**ABSTRACT**

Desalination is considered one of the most suitable areas for the utilization of solar energy, as there are many places in the world where abundant supply of solar energy is available and also there is a great demand for fresh water. An integrated solar heat pump desalination system has been developed at the National University of Singapore. The system also offers the opportunity of water heating and drying utilizing solar, ambient energy and waste heat from air conditioning system, which is conventionally dumped into the environment causing global warming. Desalination is carried out by making use of a single effect of Multi-Effect Distillation (MED) system. Within the desalination chamber, both flashing and evaporation of saline water take place. The maximum Coefficient of Performance (COP) of the heat pump system was around 5.8. In the integrated system, the maximum fresh water production rate was 9.6 l $h^{-1}$ and a Performance Ratio (PR) of 1.2. For only desalination, the system has the potential to produce a maximum of 30 l $h^{-1}$ of fresh water.

*Keywords:* Solar energy; Ambient energy; Waste heat; Heat pump; Desalination

## 1. Introduction

The shortage of fresh water affects many developing countries of the world, particularly in Asia, where more than half of the world's population live. Even developed countries like Australia also have severe water shortage. Due to the scarcity of fresh water resources, as only around 0.77% of earth's available water is fresh water, efforts were made to explore other sources, such as, seawater and brackish water. Through the process of desalination, water shortages have been alleviated in many places [1]. However, as desalination technologies are getting cost effective and more efficient, energy costs are rising due to an increase in demand and a shortage of oil supply. As desalination processes are energy-intensive, the costs of desalinated water depend on the cost of fuel. The use of fossil fuels also brings environmental problems, not being limited to global warming but also air pollution, ozone depletion, acid precipitation etc. Effective utilization of renewable energy sources (RES) is a viable means to reduce the reliance on traditional non-RES for desalination processes. The use of RES will reduce the environment pollution as well as the cost of desalination.

The low temperature thermal requirement of a heat pump makes it an excellent match for the use of solar

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energy [2]. The combination of solar energy and heat pump system can bring about various low temperature thermal applications for domestic and industrial use, such as desalination, water heating, solar drying, space cooling, space heating and refrigeration. Unlike conventional solar water heaters, solar heat pump systems offer opportunity to collect low-grade energy resources from the surroundings as well as solar energy and make use of it for domestic and industrial applications. Additionally, waste heat available at the condenser section of an air conditioning plant can be utilized for useful purposes.

A combination of solar energy and heat pump can improve the quality of the energy available and shows potential for different applications. The evaporator-collector used in such system can absorb both solar and ambient energy [3–5] due to low operating temperature. Hawlader et al. [6], Lu et al. [7] and Chyng [8] used solar assisted heat pump (SAHP) to produce hot water. The Coefficient of Performance (COP) of the system reached as high as 9 for refrigerant R134a. Huang and Lee [9] studied the long term performance of SAHP water heater. Grossman [10] conducted experiments with a solar heat pump system to provide cooling, dehumidification and air-conditioning. In 2003, Hawlader et al. [11,12] conducted series of experiments on a SAHP system for the application in water heating, drying and desalination. At the National University of Singapore, SAHP systems for integrated application [6] as well as desalination [13] were built for the evaluation of performance under the metrological condition of Singapore for various thermal applications. This paper includes the performance of a single effect desalination system using renewable energy resources and waste heat from air conditioner.

## 2. The SAHP system

A solar heat pump desalination system has been developed, which enables collection of solar energy and ambient energy besides using waste heat from air conditioning system. The schematic diagram of the test facility is shown in Fig. 1. The renewable energy is harnessed by three different type of collectors: (1) Solar Evaporator Collector, which captures energy from irradiation and ambient, (2) Liquid Solar Collector for pre-heating water for Desalination, and (3) Photovoltaic system for running pump and blower.

In the heat pump cycle, as shown in Fig. 1, the refrigerant (R134a) vapour enters the variable speed compressor inlet at a lower pressure and it is compressed to a high pressure and temperature. The superheated vapours first enters the condenser coil in the desalination chamber, where it releases sensible and latent heat, and evaporate feed water in the desalination chamber. Subsequently, the refrigerant flows through coil immersed in water of a condenser tank and then passes through the air-cooled condenser to ensure complete condensation. In this system, the recovered heat in the water-cooled condenser and air-cooled condenser are used for thermal applications, such as, water heating and clothes drying. The saturated/sub-cooled liquid refrigerant

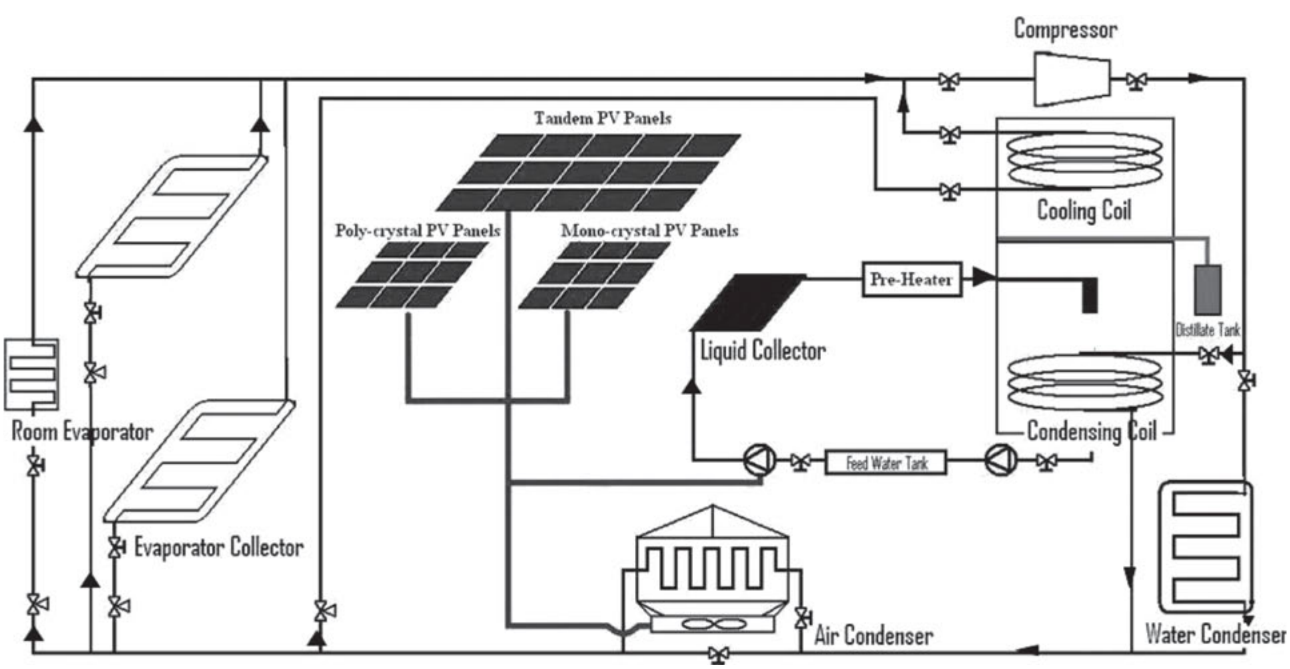


Fig. 1. Schematic diagram of SAHP system.

from the condensers will then be split into three separate branches. Each branch leads the refrigerant to a separate evaporator component. Refrigerant mass flow rate in each branch is regulated by the thermostatic expansion valve before entering the evaporator components.

In the evaporator-collector, absorber plate gained energy from solar irradiation, ambient air and the latent heat due to condensation of water vapour present in the air. Energy gained by the collector plates are then transferred to the refrigerant in the serpentine tubes. In the room evaporator, refrigerant vaporizes by receiving thermal energy from room air, while the room air is cooled by releasing heat to the cold refrigerant flowing through the evaporator cooling coil. Lastly, refrigerant flowing through the cooling coil in the desalination chamber will vaporize after gaining latent energy released during film condensation of water vapour on the horizontal cooling coil. The mass flow rate of refrigerant in each evaporator is regulated to ensure refrigerant vapour at the exit of each evaporator is in a saturated or slightly superheated state. The three streams of refrigerant vapour are then mixed together before entering the compressor inlet, where the refrigerant vapour is compressed to raise its pressure and temperature before it is released to the condensers and the cycle will continue.

The water distillation unit consists of a glazed liquid solar collector, an electrical heater, and a distillation chamber. A condenser coil is located at the bottom of the chamber to evaporate water, and a cooling coil is located at the top section of the chamber to condense vapors, as stated earlier. These coils are connected to the condenser and evaporator section of the heat pump.

The distillation chamber is operated under vacuum condition, which helps water to saturate at a lower temperature. Upon entering the distillation chamber feed water undergoes thermodynamic flashing. Saturated water is then evaporated further by condenser coils of the heat pump system. Vapors from flashing and evaporation are then condensed by a cooling coil located in the top section of the chamber and collected in a tray connected to a tank, thus producing fresh water.

## 3. Results and discussion

### *3.1. Meteorological condition in Singapore*

Singapore is located at latitude 1°22′N and longitude 103°55′. There is hardly any seasonal variation of the meteorological conditions in Singapore. Figs. 2 and 3 show the values of solar radiation, wind speed, ambient temperature, and relative humidity of Singapore on a typical day in January 2010. It can be seen that the temperature varies between 27.5°C and 32.5°C, where the maximum radiation was about 700 W m$^{-2}$. Wind speed varies from around 1–7 m s$^{-1}$, with relative humidity between 65% and 90%, and solar radiation varies from 300 to more than 700 W m$^{-2}$ for the duration of the experiment. The maximum hourly value of global solar irradiation in Singapore is about 1000 W m$^{-2}$.

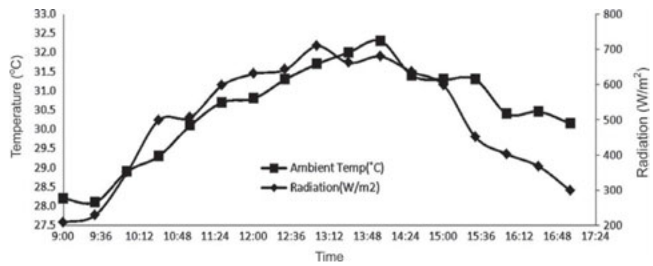


Fig. 2. Variation of solar radiation and ambient temperature with time.

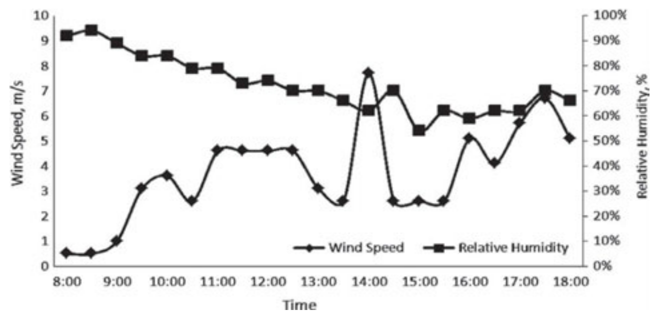


Fig. 3. Variation of relative humidity and wind speed with time.

### *3.2. Production of fresh water*

The desalination is carried out by using a single effect MED technique. As shown in Fig. 4, desalination rate increases with the increase in irradiation and then, as time passes, it attains a steady value of 9.6 kg h$^{-1}$.

Fig. 5 shows an increase of distillate production rate with the increase solar irradiation as more irradiation leads to an increased energy absorption in solar collectors and, hence, improved performance.

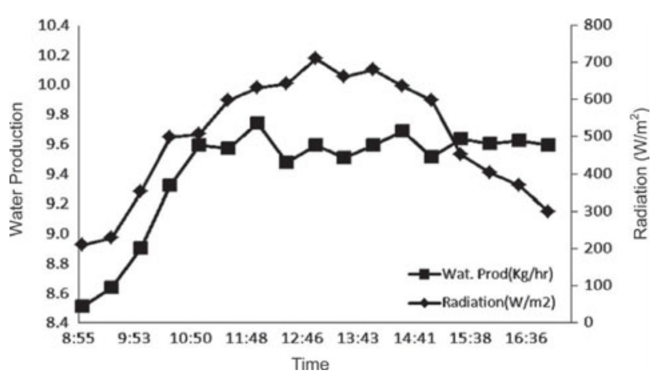


Fig. 4. Variation of water production and solar radiation with time.

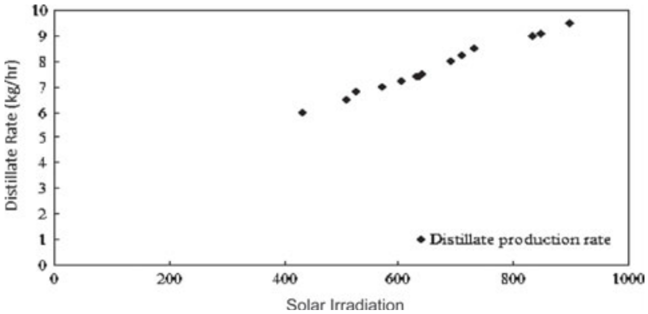


Fig. 5. Variation of distillation rate with solar irradiation.

### 3.3. Variation of coefficient of performance

COP is defined as the amount of energy rejected by the refrigerant in condensers over the energy input to the compressor. In the integrated heat pump system, three evaporators, connected in parallel, can increase the system cooling and heating COP significantly. One of the evaporators performs as solar collector, which absorbs energy from solar irradiation and ambient air; another evaporator performs as air conditioner and absorbs heat from a room, which means space cooling, while the third evaporator is located at the top of the distillation chamber. The energy from these three heat sources, plus the energy added to compressor, is used in condenser side for thermal applications. The overall COP is represented in Fig. 6. The maximum of COP is 5.9.

### 3.4. Variation of performance ratio

Performance Ratio (PR) is defined as the amount of distillate produced per 2326 kJ of heat input. A liquid solar collector was used to preheat feed water and an electrical heater was used as a booster should there be not enough solar radiation to heat the water. With higher solar radiation, the liquid solar collector will absorb more heat, thus increasing the temperature of feed water entering the chamber and increase the value of PR, as observed in Fig. 7.

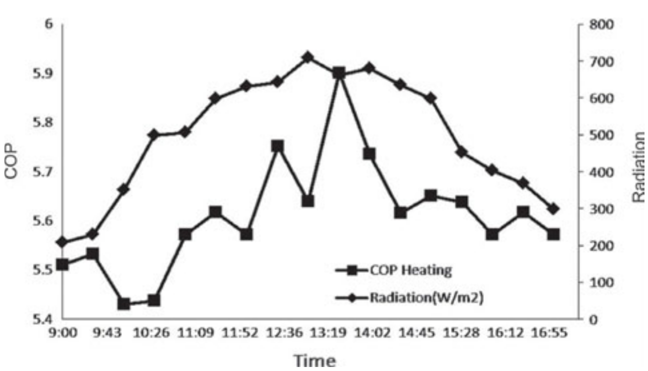


Fig. 6. Variation of COP and solar radiation with time.

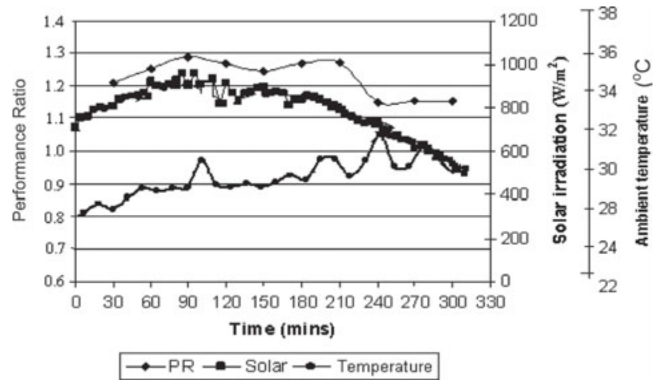


Fig. 7. Variation of performance ratio, solar irradiation and ambient temperature with time.

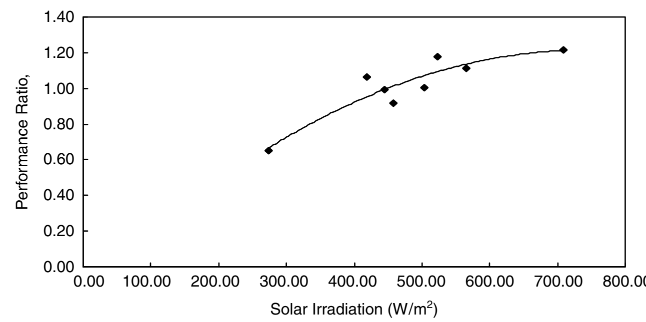


Fig. 8. Variation of PR with solar irradiation (30 Hz experiments).

PR varied between 1.1 and 1.3. The highest recorded PR is around 1.3. As shown in Fig. 8, PR increases as solar irradiation increases. As solar irradiation increases, there would be more energy available at the liquid solar collectors. As a result less electrical energy input is needed by the pre-heater for heating the water to desired temperature. The overall effect is the increase in PR due to increase in distillate production and more effective energy usage.

### 3.5. Desalination by flashing and evaporation

As the Desalination chamber was under vacuum condition, when the preheated feed water enters the chamber, it undergoes flashing followed by evaporation. As shown in Fig. 9, around 25% was obtained by flashing and rest 75% contributed by the condenser coil of the heat pump. The experimentally obtained distillate production results were also compared with the theoretically calculated values [14] to check the validity of the results, as shown in Fig. 9. Here, experimental results concur with theoretical ones, showing validity of the model.

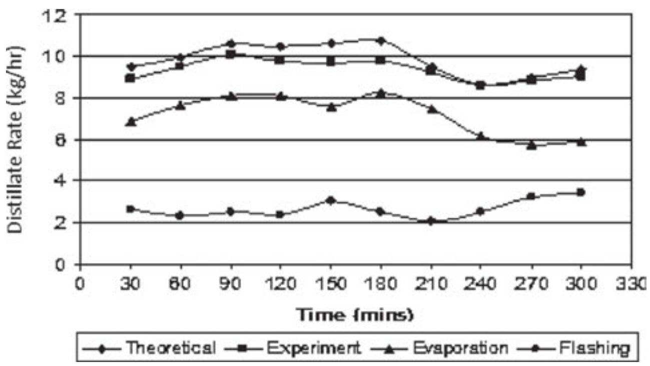


Fig. 9. Distillate production rates as a function of time.

### 3.6. Desalination potential

In the integrated SAHP system, a single effect desalination has been used along with water heating and drying. If the system is used entirely for desalination, the maximum possible production is represented in Fig. 10 and it is observed that the water production rate can be as high as 30 kg $h^{-1}$.

### 3.7. Performance enhancement due to incorporation of liquid solar collector

In the desalination chamber, a liquid solar collector was incorporated to preheat the inlet water. The efficiency of the liquid solar collector is shown in Fig. 11. It can be seen that at a relatively stable solar radiation, the collector efficiency is also stable. The collector, 2 $m^2$ in area, has an efficiency in the range of 50–60%.

Fig. 12 shows liquid solar collector efficiency as a function of inlet water temperature and solar radiation. The $F_R(\tau\alpha)$ value is shown to be at 0.51. The slope of the line gives a value for $F_R U_L$ close to 2.94 W $m^{-2}$, and a value of $U_L$ = 5.76 W $m^{-2}$ K.

Fig. 13 shows the PRs attained from running the experiment at a particular speed of the compressor (at a frequency of 30 Hz) before and after the incorporation

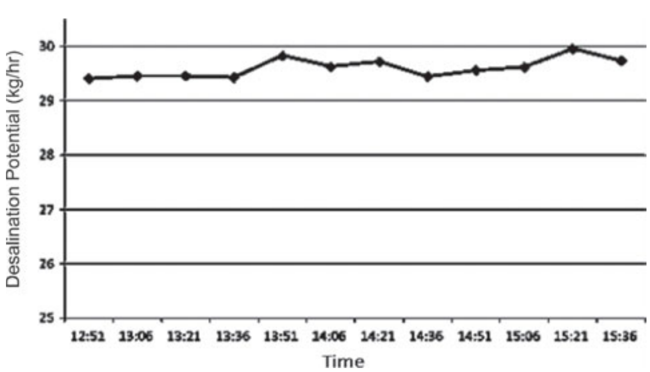


Fig. 10. Desalination potential with time [14].

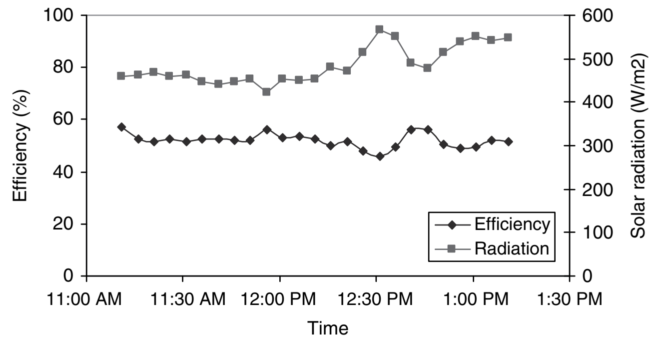


Fig. 11. Change of liquid collector efficiency and solar radiation with time.

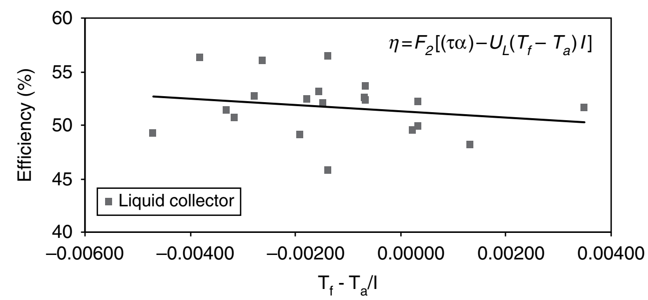


Fig. 12. Liquid solar collector efficiency as a function of water inlet temperature and solar irradiation.

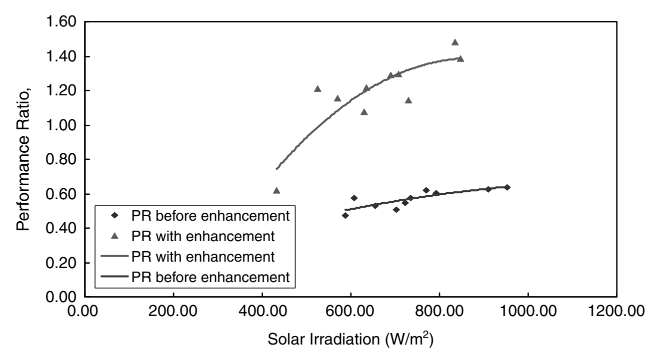


Fig. 13. Performance ratio with solar radiation.

of liquid solar collector. It shows that by adding liquid solar collector, the PR increases by about 0.6.

The enhancement of PR is mainly due to the great reduction in electrical energy input by the electric preheater. This enhancement is even more obvious when solar irradiation is high, as shown in Fig. 13. The liquid solar collector supply most of the energy and, sometime, the preheater does not need to be switched on. The distillate production is similar but electric energy input is greatly reduced.

## 4. Conclusions

A low temperature solar assisted heat pump (SAHP) has been developed to use solar and ambient energy, and waste heat from air conditioning system for desalination, water heating and drying. A single effect desalination system has been used with renewable energy resources and heat pumps for desalination purposes. For the heat pump, an average COP was around 5.5 and a PR of 1.2. The system produces about 10 kg $h^{-1}$ of fresh water, in addition to heating water and drying materials. The system has potential to produce 30 kg $h^{-1}$ of fresh water, when it is used for desalination only.

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