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Parametric Study of Passive Solar Regenerator for Liquid Desiccant based Air Conditioning System

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Abstract

Challenges like rising green house gas emissions, pollution and energy scarcity have forced us to look for alternative technologies in various technological fields. Alternative air conditioning technologies, which can use renewable energy sources are being investigated. Liquid desiccant based air conditioning is one such promising alternative which can run on solar thermal energy or waste heat. In this work, an indoor test set up for testing a novel solar passive regenerator with 1 m2 net area was prepared. The device, which has no internal electrical power consumption, can use solar thermal energy for regeneration of liquid desiccant. This device would not lead to dust contamination of liquid desiccant (LD) unlike other solar collector cum regenerators reported in literature.

A basin heater was provided for simulating solar radiation and LD temperature in basin could be controlled with the help of a temperature controller, which switched the heater on and off as required. The performance of the device in terms of water condensation rate and potential latent cooling rate were evaluated. The device has potential to provide 180 W latent cooling with solar COP up to 0.202 at 892 W/m2 solar irradiance and 8.3 km/h wind velocity. The performance is expected to improve at higher wind velocities, by reducing re-evaporation of water and improving cooling of glass cover.

***Index Terms*—Air Conditioning, Dehumidification, Liquid Desiccant, Renewable Energy, Solar Thermal Energy**

I. INTRODUCTION

CLIMATE change concerns and depleting fossil fuel reserves have motivated the researchers to look for alternative sources of energy like solar energy [1]. Air conditioning is a major consumer of electricity and its use is sharply increasing due to population and economic growth in emerging nations of the world. Alternative air conditioning technologies, which can use renewable sources of energy, need to be developed to reduce dependence on electrical energy [2]. Liquid desiccant based air conditioning system is one such promising alternative technology.

Liquid desiccants (LDs) are aqueous solutions of various salts, which are environmentally benign chemicals. Liquid desiccants can dehumidify air and provide latent cooling. LD becomes dilute by absorbing moisture from air and need to be regenerated or concentrated by removing water from it [3]. The heat energy for regeneration of LD can come from some waste heat source or solar thermal energy. Liquid desiccant based air conditioning systems have potential to provide high COP, but it faces challenges like corrosion problem and complexity of system [4]-[5].

Liquid desiccant can be regenerated using conventional solar collectors like solar water heater and solar air heater. Such system would need additional heat exchangers, pumps and piping [6]. Such systems have low COP and cost and complexity are high. Some researchers have investigated on collector cum LD regenerator (C/R), which is simpler, and potentially more efficient device [7], [8], [9], [10], [11]. Some of the problems associated with C/R are dust contamination of LD due to exposure to outdoor air and dependence of regeneration rate on ambient temperature and humidity. This work aims to demonstrate and test a simple and passive device for regeneration of LD, which is free from above limitations. The device aims to consume minimal or zero electrical energy, and has low initial and maintenance costs. An indoor test rig is developed for testing this device, where controlled heating can be provided to simulate various solar irradiance values. The potential and COP of the solar passive regenerator for latent cooling is evaluated.

II. EXPERIMENTAL SET UP

A. Solar Passive Regenerator

Solar still is one of the simplest solar collectors used for desalination of saline water. When solar radiation falls on this device, around 90% of it passes through glass cover and heats the basin which is lined with high absorptivity paint. Saline water filled in basin gets heated up and the partial pressure of water at its surface rises. Water starts evaporating into air and rises up. Hot and humid air comes in contact with glass cover, which is at low temperature due to heat loss to winds and sky. Water vapor condenses over the inner surface of glass. The solar passive regenerator works on same principle, but LD is filled in basin in place of water. Water vapor pressure at LD surface is lower as compared to water at the same temperature due to presence of salt.

A solar still with 1 m^2 net area made from fiber reinforced plastic (FRP) was purchased from market. The device did not have any insulation over it. When this device is used for liquid desiccant regeneration, working temperatures higher than those encountered in water desalination are expected due to boiling point elevation. Mineral glass fiber blanket backed by 1" thick PUF insulation are used as bottom insulation. The device is encased in a wooden box (Fig. 1). In actual application, the device should be integrated with the roof of a building with required insulation. Side and bottom losses are expected to be very low in that case due to little exposure to winds. Present prototype also has quite low heat losses as seen from surface temperatures measured during experiments and thus represents the performance of actual device that would be used in field.

B. *Indoor Test Rig and Philosophy of Experiments*

In earlier work [11], the device was tested outdoors and enhanced cooling of glass was also investigated. Due to dependence on weather, it was difficult to characterize the device. So, an indoor test facility is developed in present work. The solar radiation is simulated with an electrical heater integrated with a 1 mm thick aluminum plate. The plate is put in contact with the basin. It was thus possible to eliminate need for costly solar simulator. The input heat energy from heater can be used to solar energy input to the device are applying correction for absorptivity of basin and transmissivity of glass.

The water removal rate from LD (regeneration rate of LD) and COP of the regenerator depend on solar radiation intensity and wind speed. At a given value of solar irradiance, the system would achieve equilibrium (heat gain is equal to heat utilized for evaporation of water plus heat losses to ambient) at some temperature. In experiments, the temperature of LD in the basin was controlled with the help of a temperature controller. This device controls the temperature by switching the heater on and off as required. Air from a fan with 700 mm diameter was used to simulate wind. The fan was put at 45^o angle to the device, simulating winds from south-west if the sloping surface is facing the south.

III. Experimentation and Instrumentation

Aqueous solution of calcium chloride with 33% concentration was used in experiments. LD in the regenerator was initially at ambient temperature. Temperature equal to 70, 75, 80 and 85^{o}C were set on temperature controller in four different experiments. When the set temperature was achieved, the controller starts the heater switching off and on as required to maintain the set temperature. An overshoot up to 3^{o}C and undershoot of 1^{o}C was seen in this process. Ambient temperature was around 37^{o}C in these experiments. Average velocity of air over the device was 2.3 m/s.

System comes to steady state as LD reaches the set temperature. Even though condensation starts by this time, it takes some time to fill water in channels and then come out of it. Experiment period was considered from the point when condensed water started coming out of the device. Experiments were conducted for 5 h with readings like condensate quantity and surface temperatures taken every half an hour. Condensate collected in every half an hour was measured with the help of a weighing machine with accuracy of 0.2 g for mass. The condensate was put back into the device to maintain the same concentration during the experiment.

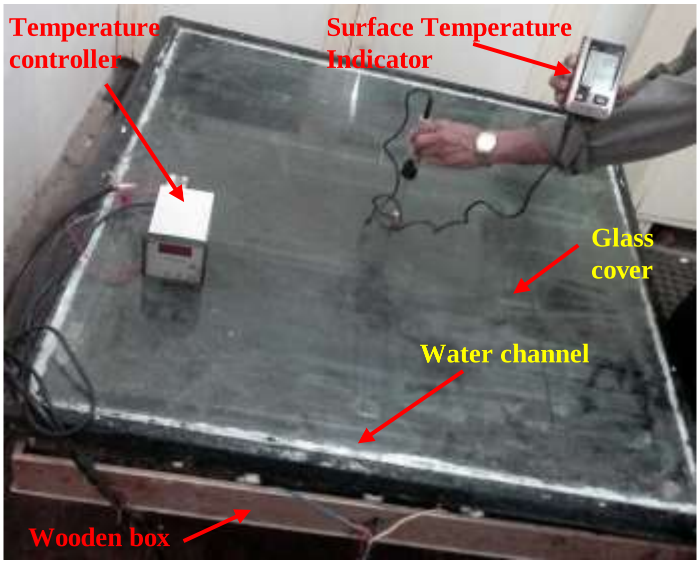

Fig. 1. Solar passive regenerator with instrumentation. The regenerator cover glass and wooden box in which the basin is put are seen. Temperature controller is used to control temperature of LD in basin. Temperatures of glass and sides were measured with surface thermocouple connected with indicator.

Total energy consumed during the period of experiment was read from cumulative reading of energy meter whose least count is 0.1 kWh. Average values of five hours steady state period is reported. A K-type surface thermocouple was used to measure glass and casing surface temperatures. These temperatures in conjunction with ambient temperature are used to find heat losses in form of convection and radiation from these surfaces.

IV. Results and Discussion

The experimental observation and calculated performance parameters are given in Table I. It is seen that temperature at which the device comes to steady state increases with increase in irrandiance. Irrandiace value is calculated by dividing actual heating rate with 0.81, which is multiplication of transmissivity of glass and absorptivity of basin, each equal to 0.9. The temperature at various places in device at various solar irrandiance values are graphically presented in Fig. 2. T_{amb} is ambient temperature, T_b is base temperature and T_g is glass temperature. $m_{w.con}$ is condensation rate of water, Q_c is cooling rate and COP_s is solar COP. These three are explained later in this section.

Higher temperature of device results in higher heat transfer rates from a solar collector to ambient. Heat loss from bottom and side surfaces are not desirable. On the other hand, , in contrast to other solar collectors, higher heat dissipation from glass is desirable. It is seen from graph that rise in glass temperature with rise in global solar irradiance is not as rapid that of LD. So, at higher irradiance, heat transfer rate from LD to glass is higher. Evaporation of water vapor from LD pool and condensation on inner surface of glass is the dominant mode of heat transfer here. So, obviously water evaporation and condensation (regeneration) rate increases with increase in solar irradiance. This is graphically presented in Fig. 3.

The regenerated LD from solar regenerator can be used in air dehumidifier of liquid desiccant air dehumidification system for absorption of moisture from air. Water absorption rate in dehumidifier should be equal to regeneration rate in regenerator. So, dehumidification rate would be equal to regeneration rate. The water removal rate in regenerator can be converted to latent cooling rate by multiplying water removal rate by the latent heat of vaporization. Here, the latent heat of vaporization is taken equal to 2418 kJ/kg K, the value at 30°C. The heat of absorption and desorption are neglected in calculations.

It is seen that at 892 W/m^2 solar irrandiance, the device can provide latent cooling rate of 180 W. So, for 1 kW of latent cooling, slightly higher than 5 m^2 collector area would be required. When potential cooling rate is divided by solar energy input, one gets efficiency of the solar regenerator, also called solar COP (COP_S). The solar COP of the given device ranged between 0.184 and 0.202 for global solar irrandiance range of 556 to 892 W/m^2 with reducing incremental rise (Fig. 4).

TABLE I
OBSERVATIONS AND RESULTS

T_{set} °C	I_g W/m^2	T_{amb} °C	T_b °C	T_g °C	$m_{w.con}$ ml/h	Q_c W	COP_S
70	556	36.9	39.4	46.4	152	102	0.184
75	724	36.4	39.6	49.1	210	141	0.194
80	892	36.9	40.8	51.0	268	180	0.202

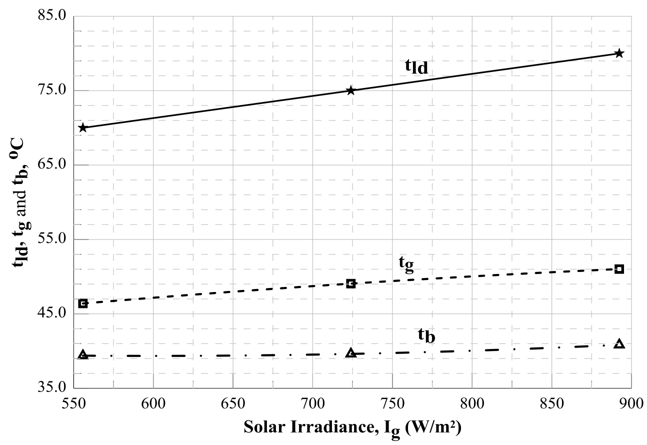

Fig. 2. Variation of LD temperature (t_{ld}), glass temperature (t_g) and base temperature (t_b) with global solar irradiance (I_g).

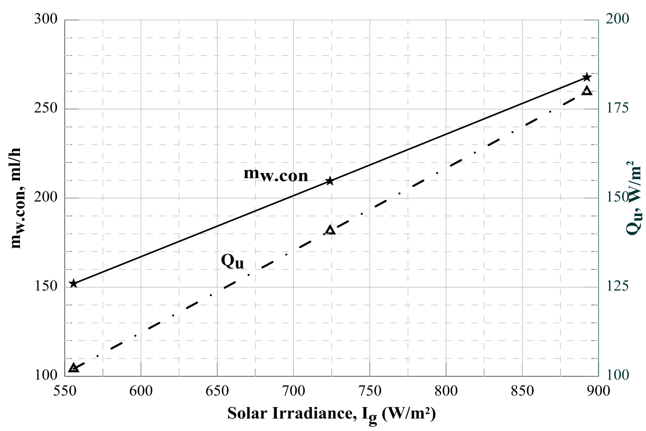

Fig. 3. Variation of mass of water condensed ($m_{w.con}$), and cooling rate (Q_c) with global solar irradiance (I_g).

When LD temperature was set at 65°C, evaporation and condensation rates were very low. Due to this, very small amount of water could reach the collection channel and no water could come out of the device. This means that all heat supplied was lost. Actually, at low condensation rates, significant amount of heat exchange may occur between LD and water droplets on inner surface of glass due to long exposure time. The performance of the device would be very poor at low solar irradiance values due to above phenomenon. The losses from sides are very low due to low convection heat transfer coefficients, low temperature difference and small surface area.

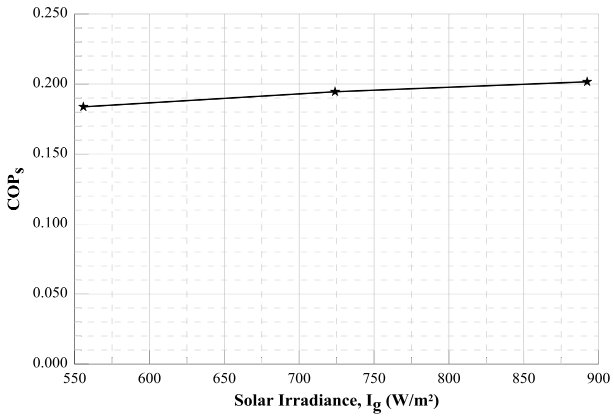

Fig. 4. Variation of solar COP (COP_s) with global solar irradiance (I_g).

V. Conclusions and Future Work

A solar passive regenerator with zero internal electrical power consumption was fabricated. The device with net area of 1 m^2 was tested at various simulated solar irradiance values and constant wind speed of 8.3 km/h. Experiments showed that this device can provide latent cooling rate up to 180 W at 892 W/m^2 global solar irradiance. The solar COP was in the range of 0.184 to 0.202 for irradiance range of 556 to 892 W/m^2. It was found that re-evaporation of water from inner surface of glass could be an important loss, particularly when regeneration rates are low.

The set up may be used in future for performance evaluation at more values of solar irradiance. The effect of wind speed on performance should also be evaluated by using various fan speeds. Reduction of re-evaporation of condensed water and better cooling of glass can help improve performance of the device further. Rigorous heat and mass transfer analysis need to be performed to pin-point the sources of losses.

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