PERFORMANCE OF OPEN TYPE SOLAR THERMAL LIQUID DESICCANT REGENERATOR UNDER DIFFERENT OPERATING CONDITIONS

Summary

A strong liquid desiccant is effective for dehumidifying outdoor air in an air dehumidifier unit of an open type sorption air conditioning technology and can be made strong again or regenerated by evaporating the water absorbed from the outdoor air using solar thermal energy in its solar regenerator unit. In this air condition technology, the exact same amount of mass of water absorbed by the desiccant solution in the dehumidifier must be rejected back to the ambient air through boiling for cyclic operation. This is challenging since solar energy and climate condition fluctuates throughout the day and several environmental and operational parameters also effective in making the desiccant strong again. This paper presents effects of operational and environmental conditions like solar regenerator absorber size; glazing gap and presence or absence of glazing; initial desiccant concentration; humidity and temperature of ambient on regeneration of solutions of lithium and calcium chlorides using a standalone solar thermal regenerator based on experimentally gathered data.

Keyword: Liquid desiccant regenerator, Calcium chloride, Lithium chloride, Solar thermal water evaporation, Solar energy, Sorption air-conditioning technology.
Field of application for the findings: Solar air conditioning and refrigeration

Addressed audience: Conference

Results and discussion: Diurnal performance of the 4.0 m^2 (SR-A) and 1.47 m^2 (SR-B) open type solar thermal liquid desiccant regenerators were calculated in terms of hourly and diurnal concentration increase, evaporated mass of water and solar regenerator efficiency. Diurnal performance of a solar regenerator is affected by environmental and operational conditions. In this study, variables such as irradiance, temperature & humidity ratio of ambient air, glazing gap, SR size or area, initial concentration of desiccant at inlet to the solar regenerator and inlet temperature of solution are selected for identifying their effect on the regenerator performance. Impact of presence or absence of glass cover was also studied. To evaluate diurnal open air solar regenerators' performance, a fixed quantity of desiccant brine was kept in the solution tank before beginning the experiment at 9 pm. Then the solution was continuously circulated from the tank for spread over the absorber surface and back to the tank using a small electric pump from 9 am up to 4 pm (Tafesse et al. 2014; 2016). The main data such as ambient air (DBT & WBT), solution and surfaces temperatures of the absorber were measured using RTDs and thermocouple wires. The irradiance was measured by a Pyranometer. These data were gathered every ten seconds using an Agilent data logger.

a) Solar regenerator (SR-A)

b) Solar regenerator (SR-B)

Figure 1. The experimental solar thermal brine regenerators

The critical intensive thermodynamic properties of the solution or solution density and its corresponding temperature in the tank were manually measured every 30 minutes using a portable digital densitometer and bulb thermometer. All of the instruments used for gathering data were calibrate at ice point and boiling point of water and as per the guideline of the instrument manufacturers. Degree of uncertainties of measuring instruments and calculated performance indicating results parameters were estimated using the general uncertainty principle suggested by Dunn, (2006). The appropriate thermodynamics, and heat transfer & mass transfer relations were used for data reductions.

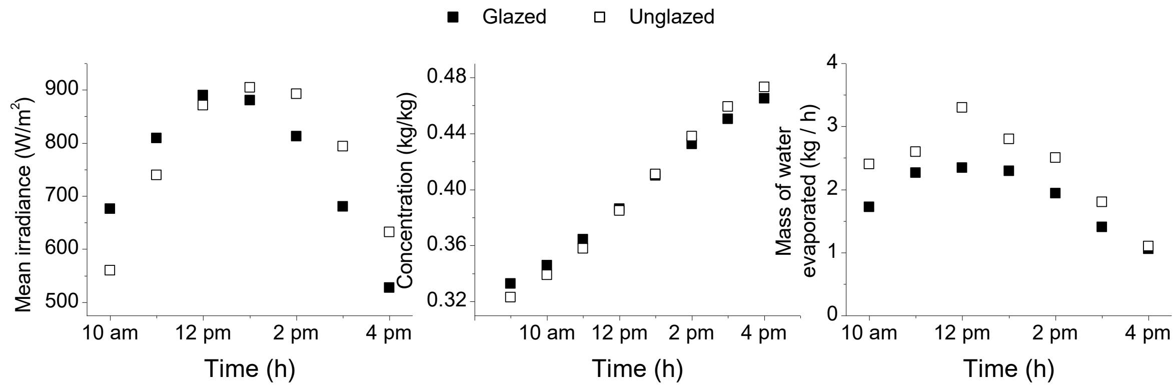

Figure 2. Diurnal regeneration performance LiCl solution using glazed and unglazed solar C/R-A

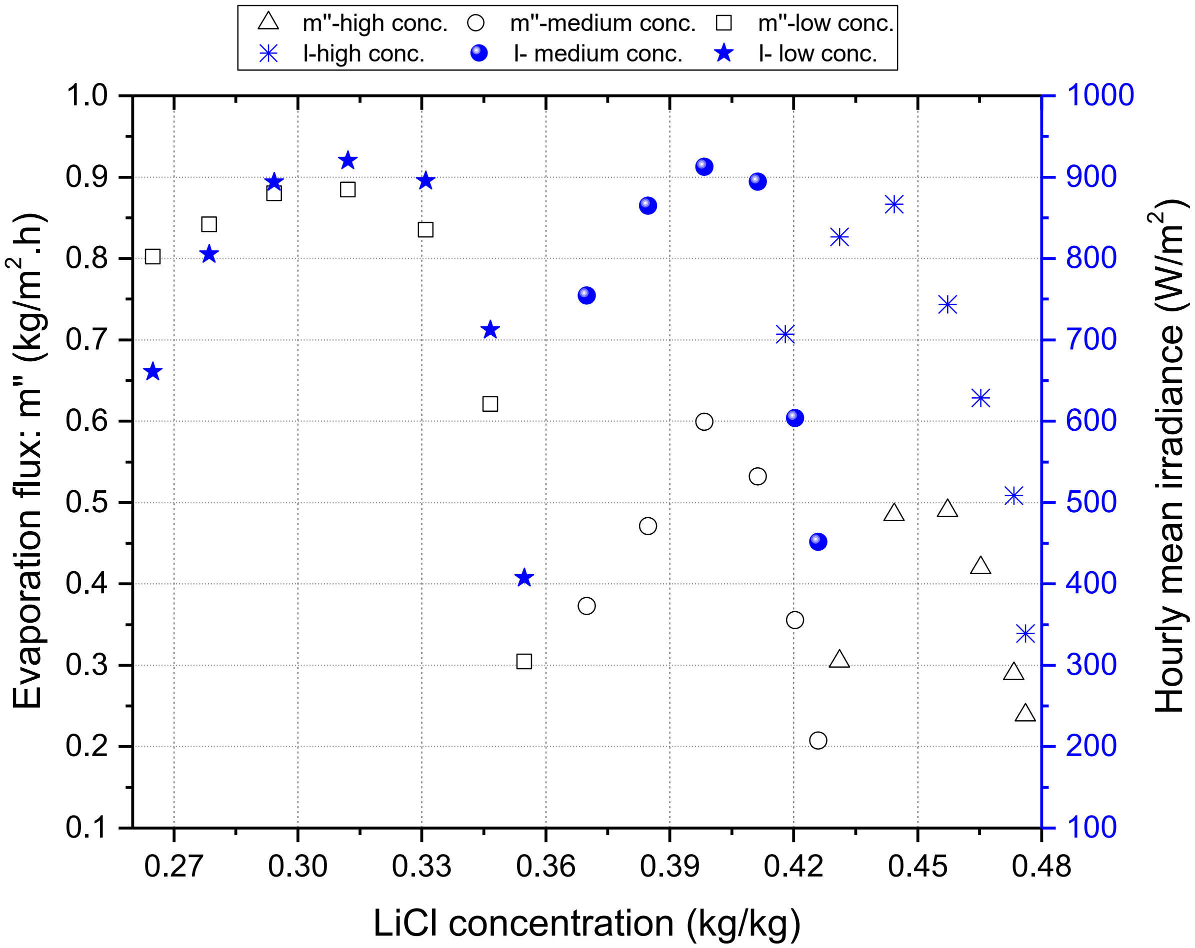

Figure 3. Diurnal evaporation flux of water from LiCl brine for low, medium and high initial concentration when using SR-B

Fig.2. shows diurnal regeneration results for LiCl solution obtained using glazed and unglazed SR-A for nearly similar incident irradiance and initial LiCl concentration in the tank. The average irradiance incidents on the glazed and unglazed regenerators (over the day) were 753.7 and 770.5 W/m^2, respectively. Total evaporated quantity of water from glazed and unglazed SR-A during the day were 13.0 kg and 16.5 kg, respectively. The performance of unglazed SR-A was better than the glazed one mainly because the glass cover reduces the amount of irradiance that could be absorbed by the plate by approximately 17.5%. Ordinary window glass of 3.0 mm thick was used as glass cover, which had high optical losses. The ratio of vapor evaporation flux to the average irradiance received over the period of experimentation for the glazed and the unglazed SR-A for regeneration of LiCl solution were 0.61 and 0.75 kg/kWh, respectively.

The quantity of water vapor evaporated from glazed and unglazed SR-A in regenerating $CaCl_2$ solution over the day were 17.0 and 15.2 kg, respectively. The average incident irradiance and the ratio of vapor flux to the average irradiance over the period of experimentation for glazed and unglazed SR-A in regenerating were 797.6 & 674.1 W/m^2 and 0.75 & 0.79 kg/kWh, respectively. It is relatively easy to regenerator $CaCl_2$ solution than LiCl solution. Operating the solar regenerator without glass is not viable in Delhi due to city is dusty. Glazing the solar regenerator helps protect the solution from dust and foreign matter contamination. Blockage of the solution distributor pipe holes was significant for unglazed solar regenerator due to foreign matter that reduces the flow of solution and also coverage area of the absorber plate, if operated without cleaning the holes every day. Hence, glazing solar regenerator with a glass having high optical efficiency is recommended. It was also observed that regeneration of calcium chloride is relatively easy compared to lithium chloride. However lithium chloride is also more recommended desiccant solution than calcium chloride from use in sorption technology. It is also reported in many literatures that desiccant concentration has recommended range for uses in sorption technologies.

For effective dehumidification of ambient air by a LiCl solution air cooling system, concentration of LiCl in brine was recommended to be 0.4 by Hawlader et al., (1993), and 0.42 by Yang & Wang (2001) and Yutong & Yang (2010) based on their experimental studied on performance of an air cooling system coupled with open-type solar regenerator that uses lithium chloride solution in concentration range between 0.33 up to 0.36. To identify the influence of desiccant mass concentration on the evaporation flux of water from the solar regenerator, three days diurnal LiCl solution regeneration test results obtained using SR-B for low, medium and high concentration are presented in Fig. 3. Three concentration ranges were selected for comparison: low concentration (26.5 to 35%), medium concentration (37 to 42.6%) and higher concentration (42.4 to 47.8%). The day average vapor flux for low, medium and higher initial concentration of desiccant were 0.81, 0.42 and 0.37 $kg/m^2.h$, respectively. The results indicate that vapor flux from low concentration solution is higher due to higher potential for mass transfer to air as expected.
The influence of humidity content of ambient air on evaporation rate of water in the month of May (hot & dry) and in October (moderate weather) was studied. Although the ambient air temperatures are much higher in May, the differential temperature of brine and ambient air were closer to each other for both months. The differential temperature of solution and air was of the order of 8-14.1 ^oC and 8.3-13^oC in October and in May, respectively. This greatertly contributes to the minimization of cooling energy needed before sending the brine to the air dehumidifier during coupling with the open type solar regenerator. As seen, humidity ratio of air in October was higher than humidity ratio of water in May. The humidity ratio of air was higher in the morning time and gradually decreases towards evening from 13.7 to 9.8 g/kg in October and 11.4 to 8.8 g/kg in May. The peak values of equilibrium humidity ratio on solution surface were 63.1 g/ kg in May and 46.1 g/kg in October. The total amount of evaporation of water from the solar regenerator in May and October were 14 and 12.7 kg, respectively for almost similar irradiance and same initial solution concentration. The evaporation of water from the desiccant solution in the solar regenerator in May which has dryer ambient air was better than in October which has relatively moist or humid air.

The effects of different glazing gaps on regeneration of $CaCl_2$ solution in humid ambient air condition (or in the month of October) for almost same initial concentration, on five separate days, at five different glazing gaps (8.5, 11, 13.5, 16 and 18.5 cm) and it was found out that glazing gap does not affect regeneration performance. The maximum solution temperature observed on regeneration of lithium chloride solution using SR-A was 68^oC in May when the ambient temperature or solution temperature was 45^oC. In this open type solar regenerator, the maximum difference in temperature value between the solution and ambient is 23 ^oC which has an advantage in reducing the cooling energy requirement of the desiccant solution to the operating temperature of an air dehumidifier when the two work in a cycle. However, it was found that the evaporation flux of water increases exponentially with increase in solution temperature. The brine temperature going to solar regenerator can be enhanced by using a solar still as solution tank instead of the polyethylene tank and/ or by preheating the solution in a heat exchanger using hot water generated by evacuated tube or flat plate solar collector. There is also a possibility of making the entire solar regeneration process hundred percent solar by installing solar PV system that can power the solution pump.

In conclusion, open type solar liquid desiccant regenerator is a viable technology that has a good scope to be integrated as an integral or preferably as a standalone alternative liquid desiccant regenerator for Sorption air conditioning technologies. However, standalone desiccant regenerator can alleviate the adverse impacts of fluctuating environmental and operating condition on the regeneration of liquid desiccant. Furthermore the strict inlet condition requirements of desiccant solution at inlet to the air dehumidifier can be avoided by decoupling the solar regenerator from the air dehumidifier unit and operating it as standalone unit. In an open type flat plate solar thermal liquid desiccant regenerator sunlight collection, conversion into heat and concentrating of the weak solution through water evaporation are all concurrently achieved at fluctuating ambient conditions. These features make a standalone open type solar regenerators sustainable over other alternative regeneration technologies. It has also a good potential for operating hundred percent by solar energy with possible performance enhancing using a solar still as the solution tank and solar PV technology to drive the solution pump.