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TECHNICAL NOTE

Efficiency of a Liquid Desiccant Dehumidification System Regenerated by Using Solar Collectors/ Regenerators with Photovoltaic Fans

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ABSTRACT

A hybrid solar dehumidification air-conditioning system was used to study the absorption of water vapor from moist air by contacting the air with aqueous solutions that contained from 90 to 94% triethylene glycol (TEG). For the packings of 2-inch polypropylene Jaeger Tri-Packs, which have a surface-to-volume ratio of 157 m^2/m^3 (48 ft^2/ft^3), the efficiency of dehumidification can reach 93.3%. The environmental air was introduced into the dehumidifier cocurrently flowing with the liquid desiccant, and the liquid desiccant was sprayed on the top of the packing material. The air-to-liquid mass flow ratio was controlled in a range of 0.46 to 1.36. As the moisture was absorbed from air by the TEG solution, the solution was diluted. The regeneration of the solution was carried out in 20-piece (38.8 m^2) basin-type solar collectors/regenerators whose regeneration coefficients of performance are above 0.2. Air generated by photovoltaic fans was blown into the solar collectors/regenerators and carried away the water vapor from the evaporation of the aqueous desiccant solution. On the basis of the experimental results, the system performance is acceptable for most applications.

INTRODUCTION

Since a liquid desiccant is regenerated after absorbing water vapor from environmental air, a desiccant dehumidification system can be operated

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continuously. Increases in the quality of life and of the consciousness to environmental protection have led to applications of renewable energy. Solar energy was used to regenerate the liquid desiccant in this desiccant dehumidification system. A number of studies (1–3) have focused on the regeneration of a solution by using solar energy. In these studies, solar energy was used to generate hot water or to heat air before it was introduced to the regeneration column. Solar energy used directly to evaporate water vapor from a dilute desiccant solution was employed in the study of Swami et al. (5).

By combining the design concepts of Swami et al. (5) with the ideas of a typical absorption-regeneration system, a solar desiccant dehumidification system is developed in this study. The dehumidifier operates with a large regeneration unit which contains the solar collectors/regenerators used for desiccant solution regeneration as designed in this study. The desiccant solution used in this study was an aqueous solution of triethylene glycol, and the operating temperature in the dehumidifier was kept at an acceptable environmental temperature. Therefore, the processed air can be used directly in residential applications.

In this study, around 900 L desiccant solution containing from 90 to 94% triethylene glycol (TEG) passed through 10 sets (20 pieces) of basin-type solar collectors/regenerators for regeneration. An auxiliary electrical heater was used for solution regeneration when solar energy was not available. The regenerated desiccant solution is sent back to the dehumidifier for environmental air drying. The dehumidifier is basically a packed tower which contains 2-inch polypropylene Jaeger Tri-Packs random packings. The efficiency of water vapor removal in the dehumidifier was studied under different operating conditions. The parameters changed during our studies were temperature, flow rate, and desiccant concentration.

EXPERIMENTAL SECTION

A schematic flow diagram of the system is shown in Fig. 1. In the dehumidifier, the liquid desiccant is sprayed on the top of the packing materials, and the diluted liquid desiccant is sent to the solar collectors/regenerators to evaporate the water vapor. Since the temperature of the desiccant solution from the solar collectors/regenerators is still high enough for additional stripping regeneration, a modified cooling tower for secondary regeneration is used. A further cooling of the solution is needed when the solution is sent back to the dehumidifier. Therefore, a refrigeration system is used to lower the temperature of the desiccant solution.

Figure 2 shows the design of the solar collector/regenerator. In this design the water in the solution is evaporated by solar energy, and the water vapor is carried away by photovoltaic fans. At high solar intensity,

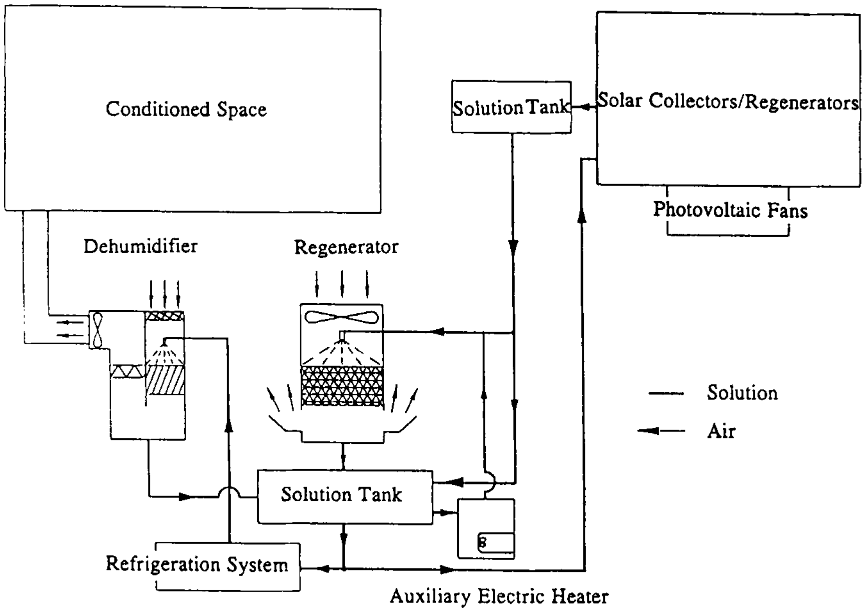

FIG. 1 The hybrid solar dehumidification system used for this study.

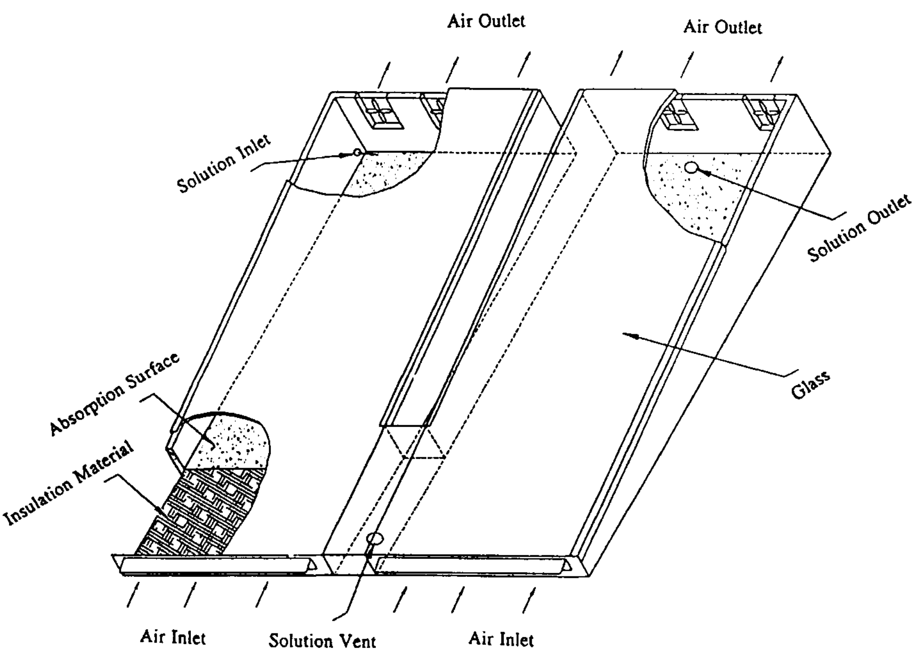

FIG. 2 Assembly of the solar collector/regenerator.

the evaporation rate of the water is high and the speed of the fans is fast. More water vapor can be carried away from the solar collector/regenerator during times of high solar intensity. Therefore, water-vapor condensation on the glass surface of the solar collectors/regenerators can be avoided.

In the dehumidifier, air flow rates changed from 47 to 92 kg/min·m^2 as the liquid flow rates vary in the 66 to 104 kg/min·m^2 range. Two solution concentrations were used, and the solution temperatures were kept at the environmental temperature. With this arrangement, the processed air was controlled to match the environmental temperature. Therefore, the processed air can be used directly in residential air-conditioning applications.

RESULTS AND DISCUSSIONS

The performance of the absorption system was evaluated by carrying out a series of runs with aqueous solutions that contained from 90 to 94% triethylene glycol. Other parameters that were also varied during experimentation include air and liquid flow ratio, temperature and humidity of the air, and temperature of the desiccant solution. Various operation conditions are presented in Table 1. The efficiency of the absorber was determined as the ratio of the actual change in moisture content of the air leaving the absorber to the maximum possible change in moisture content under a given set of operating conditions. Therefore, the column efficiency, ϵ, can be expressed as

$$\epsilon = \frac{W_{in} - W_{out}}{W_{in} - W_{equ}}$$

where W_{in} and W_{out} are the water contents of the inlet and outlet air streams, respectively. W_{equ} is the water content of the air, which is in equilibrium with the triethylene glycol solution at a particular concentration and temperature. The column efficiencies calculated from the experimental data are also provided in Table 1 and are plotted versus the inlet air flow rate in Fig. 3. As expected, the efficiency decreased with an increase of the inlet air flow rate; the change was linear. As the inlet air flow rate is increased, the amount of moisture removed to achieve the same efficiency also increased. Since the packing height and the liquid flow rate remained constant, the column efficiency decreased. In Table 1, at a liquid flow rate of about 50 kg/min·m^2, the column efficiencies decreased significantly because this liquid flow rate is not high enough to completely wet the packing surface. Therefore, determination of the proper liquid flow rate should be based on the wetting rate. Figure 4 shows that the column efficiencies increased as the liquid flow rates were increased. Since the processed air was not changed and more desiccant solution was used, the column efficiency of moisture removal increased.

TABLE 1
Experimental Data of This Study

Air flow rate $\left(\frac{kg}{min \cdot m^2}\right)$	Liquid flow rate $\left(\frac{kg}{min \cdot m^2}\right)$	Air inlet temperature (°C)	Air outlet temperature (°C)	Liquid inlet temperature (°C)	Liquid outlet temperature (°C)	Air inlet humidity $\left(\frac{g\ water}{kg\ dry\ air}\right)$	Air outlet humidity $\left(\frac{g\ water}{kg\ dry\ air}\right)$	Equilibrium humidity $\left(\frac{g\ water}{kg\ dry\ air}\right)$	Liquid concentration (wt%)	Efficiency (%)
47.1	67.1	30.3	32.7	29.4	31.8	16.8	12.5	11.6	90	82.7
62.7	69.2	25.1	31.1	27.4	29.7	14.9	11.1	10.2	90	80.9
75.9	68.8	25.2	31.6	28.3	30.4	15.8	12.0	11.0	90	79.2
91.5	67.4	29.0	31.8	29.0	31.4	16.2	12.5	11.4	90	77.1
47.1	103.5	27.6	32.1	28.8	31.7	17.2	12.0	11.4	90	89.7
47.1	84.8	27.6	33.6	29.4	32.3	17.2	12.3	11.6	90	87.5
47.1	50.5	27.7	30.3	27.0	29.2	17.8	12.8	10.0	90	64.1
47.1	67.3	29.0	32.0	29.7	31.4	15.1	10.5	10.0	94	90.2
62.7	66.3	30.9	33.6	31.9	32.6	15.0	12.2	11.8	94	87.5
75.9	68.0	28.4	33.1	32.0	32.8	16.4	12.5	11.8	94	84.8
91.5	67.9	28.0	33.8	33.0	34.4	16.5	13.2	12.5	94	82.5
47.1	103.2	26.1	32.8	33.6	34.3	17.3	13.1	12.8	94	93.3
47.1	82.9	26.0	33.6	32.0	32.8	16.2	12.2	11.8	94	90.9
47.1	50.7	25.6	32.0	32.1	32.7	17.6	13.8	11.8	94	65.5

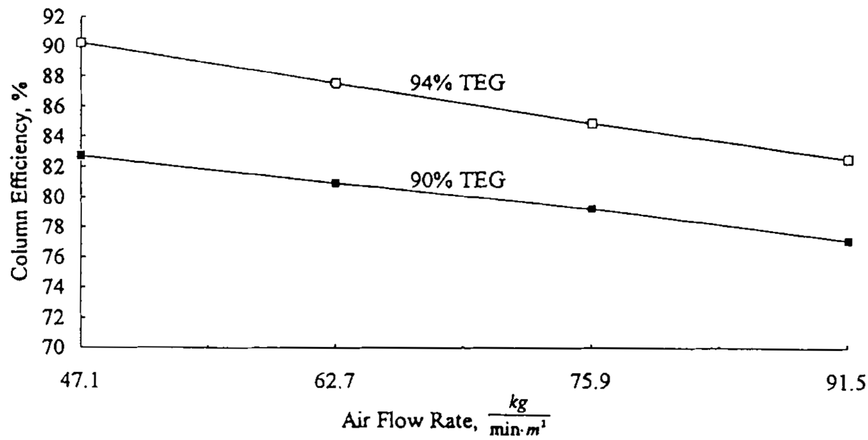

FIG. 3 Effect of inlet air flow rate on column efficiency.

There are 10 sets (20 pieces) of solar collectors/regenerators in this system, which provided a solar collecting area of 38.8 m^2. The solar collectors/regenerators used in this study were of the basin type, with performance regeneration coefficients above 0.2. Solar energy was the major heat source used to evaporate water from the diluted desiccant solution. Solar regeneration of the desiccant solution and dilution of the desiccant

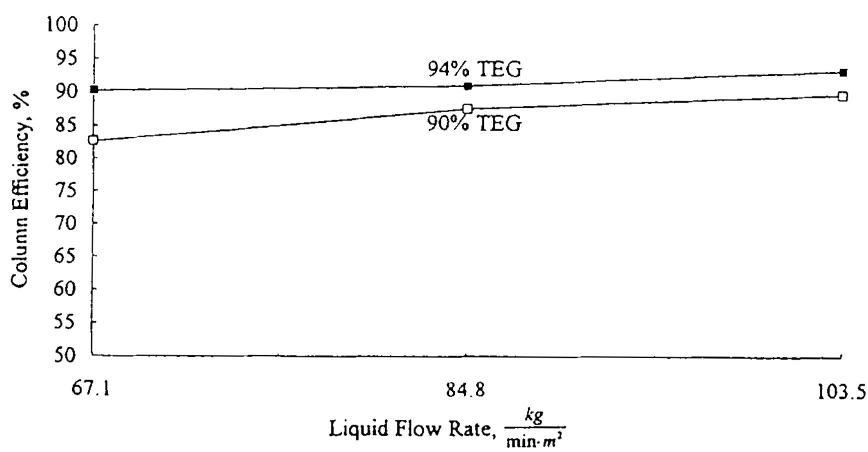

FIG. 4 Effect of liquid circulation rate on column efficiency.

solution due to the absorption of water vapor were balanced. Therefore, the solution concentration was kept constant in each experimental run.

CONCLUSION

A hybrid solar dehumidification air-conditioning system has been designed and tested for the dehumidification of environmental air. For a given height of packings, the column efficiencies were decreased as the air flow rate increased, and increased as the liquid flow rate increased. A higher absorption performance occurred when a higher concentration of desiccant solution was used. These columns have the properties of most absorption columns, so the system design is reasonable. Solar energy was successful for concentrating the diluted desiccant solution. The rates of dilution and regeneration of the solution in this study can be balanced. Therefore, variation of the solution concentration during experimental runs was neglected. The system performance can therefore be controlled.

This system provides a means to operate a dehumidifier continuously, and thus is a key factor in commercializing this kind of dehumidification system.

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