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Evaporative air cooler coupled with variable frequency drive for dehumidification of indoor air

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ABSTRACT

This study deals about the investigation of a solar-powered desiccant dehumidification system coupled with variable frequency drive (VFD). The proposed design of the system consists of two evaporative air coolers. One cooler performs as an absorber and the other one as desiccant regenerator coupled with a solar water heater. The VFD is connected with the first evaporative air cooler. In this work, using solar energy, a zeolite is regenerated as part of the investigation. Regeneration cycle for hot water absorption is explained and analysed. A simple expression for the cycle is proposed. System efficiency is derived with consideration of flow of work and heat to and from the system. The operating concentration of desiccant used greatly affected regeneration temperature limits and mass of strong solution for unit mass of vapour produced.

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KEYWORDS
Dehumidification; desiccant; adsorption; variable frequency drive; zeolite

1. Introduction

The fascination towards the use of solar-powered air conditioning and refrigeration systems for cooling increases greatly in the hot and high humidity content areas having heavy moisture (Kakabaev and Khandurdyev 1969; Krause, Saman, and Vajen 2005; Daou, Wang, and Xia 2006). As a single path on the way to many sustainable energy systems, the solar-operated variable frequency drive (VFD) for cooling purpose offers numerous advantages. This technology can effectively accommodate large latent loads, and by allowing more ventilation with tight control of humidity to a great extent, it can improve the indoor air quality. On the other hand, the ever-increasing awareness towards environmental issues such as green house gas effect (Yang and Wang 1994; Grossman 2002; Alosaimy 2013) has made the solar-operated air conditioning to acclaim emerging interest in the recent past years. These systems are mainly absorption systems (liquid–vapour and solid–vapour absorption or adsorption), vapour compression systems and hybrid vapour compression desiccant systems (Yang and Yan 1992; Dieckmann and Brodrick 2008). A regenerator is an important component in the liquid desiccant air conditioning systems. In such regenerators, the desiccant is concentrated and also reused in the system. The heat needed to regenerate the weak desiccant solution is supplied from either hot air or hot desiccant solution into the regenerator (Yang and Wang 2001; Aly, Zeidan, and Hamed 2011). The heat required for this purpose can be sourced from any type of low-grade thermal energy like the solar thermal conversion applications. VFD plays a crucial role in the proposed system.

VFD is a motor-controlled device which drives an electric motor and varies the frequency and voltage supplied to the electric motor. Numbers of designs of regenerator are studied and also for analysing the regeneration process, a variety of theoretical models are employed. A parametric analysis of the system has been performed to calculate the rate of evaporation of water from the solution as a function of the system variables and the climatic conditions.

The effect of regeneration temperature on the rate of water evaporation from the liquid desiccant shows that an increase in the solution temperature increases the vapour pressure on the surface of the solution and consequently, the potential of mass transfer. In situations, when the solar heaters are used for regeneration processes, solar water heaters are employed for regeneration of the desiccant solution (Alosaimy 2013). Hot water can be used to heat the regeneration air in an air heater and then blown to the packing of the humidifier, where the solution is re-calculated by the solution pump. The main function of the desiccant dehumidification system is to pump humidity from the conditioned space, which has moisture sources, to the outside space. Different design configurations for such systems are available in literature.

2. Proposed system

The proposed system is presented. The system comprises two air evaporative coolers. One of the two coolers functions as an absorber (the indoor unit) and the second (the outdoor unit), which is coupled with water heater, functions as a desiccant regenerator (Alosaimy 2013). The VFD is fitted on the first air cooler, in order to control the motion/speed of the blower. By varying the blower speed, the air absorption rate can be increased for an efficient output in the system. The Zeolite solution is regenerated in the evaporative cooler (desiccant regenerator) which is supplied with hot air from a finned tube air/water heat exchanger. Water from the water heater is

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circulated through the heat exchanger to heat the flowing air. A strong solution from the outdoor unit is directed to the indoor unit and a weak solution from the indoor unit is pumped to the regenerator via a solution pump (Alizadeh and Saman 2002; Lazzarin and Castellotti 2007). Room humid air is blown and dehumidified in the indoor unit. This system actually functions as a humidity pump. A direct contact between air and desiccant is carried out in the packing used in the evaporative cooler to increase the contact area. For the purpose of heat recovery, a solution heat exchanger is applied to cool the strong solution coming out from the regenerator (outdoor unit) (Hurdogana et al. 2010; Alosaimy 2013).

3. Advantages aiming from the proposed system

By using zeolite over calcium chloride, the heat absorbed by this desiccant will be two times greater when compared to calcium chloride.

- The efficiency will be greater to the previous set-up.
- By using the VFD technique, the speed can be monitored and controlled automatically using this technique.
- Using this technique energy can be saved.
- The VFD can also control the performance of acceleration, flow and pressure.
- In the previous experimental set-up, the blower speed cannot be varied or controlled.
- In the proposed method, the blower speed can be controlled using the VFD technology.
- In proposed set-up, the desiccant used is zeolite.

4. Result and discussions

In the experimental side, five group tests were conducted and analysed. Figure 1 indicates the variation in the output values given by various desiccant solutions for a given time period, at inlet and outlet of the heat exchanger for the first group of tests.

Figure 2 presents the variation in the output values given by various desiccant solutions for a given time period, at inlet and outlet of the heat exchanger for the final group of test. From the results, it is revealed that at constant ambient parameters (temperature and humidity), the minimum regeneration temperature increases inversely with the relative humidity. This phenomenon is due to the fact of the requirement of a higher concentration solution to absorb moisture from air with minimal values of relative humidity at the same ambient temperature. As a conclusion, the temperature that would be required to pump the humidity content from the space in the ambient condition directly varies with the humidity value between the space and the atmospheric air (Alosaimy 2013). Alternatively, the outdoor temperature increases the regeneration temperature at constant ambient conditions and outdoor humidity (Alosaimy 2013).

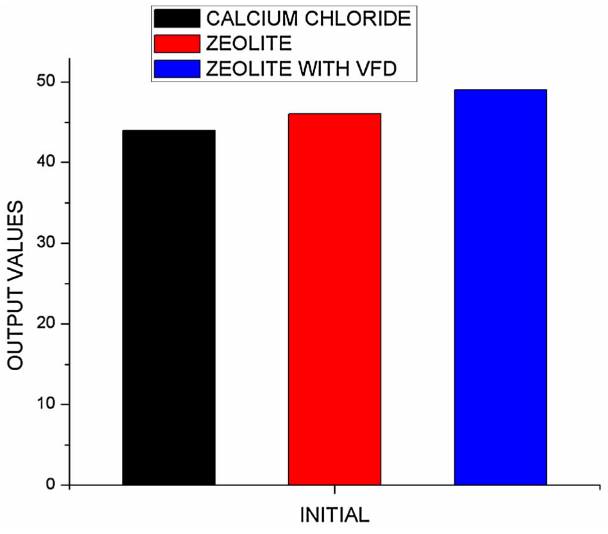

Figure 1. Output values desiccant solutions at given time period (initial).

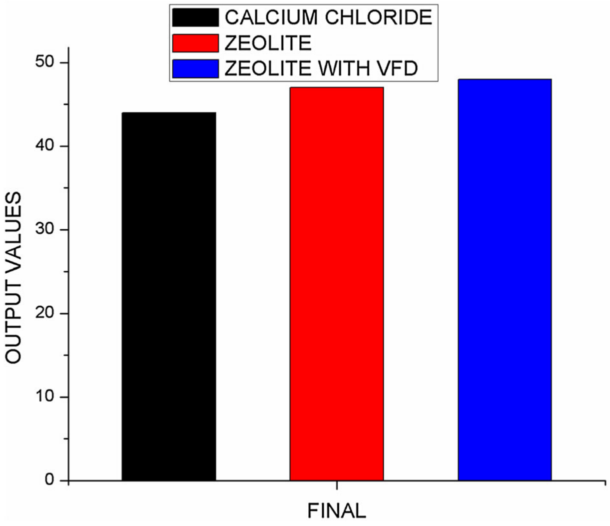

Figure 2. Output values desiccant solutions at given time period (final).

For an initial mass of solution of 80 g and initial concentration of 30%, an experimental test is carried out for a period of 3 h (from 11 am to 2 pm). From the plot, it can be noted that a maximum water temperature at heat exchanger inlet of about 52°C is recorded at 11 am, whereas, the output temperature was found to be 46°C for the first period of test with zeolite. Certain fluctuation in the system was noted in the temperature during the observation of the 3 h period, which is plotted in the graph.

For an initial mass of solution of 80 g and initial concentration of 30%, an experimental test is carried out for a period of 3 h (from 11 am to 2 pm). From the plot, it can be noted that a maximum water temperature at heat exchanger inlet of about 52°C is recorded at 11 am, whereas the output temperature was found to be 44°C for the first period of test with calcium chloride. Certain fluctuation in the system was noted in the temperature during the observation of the 3 h period, which is plotted in the graph.

For an initial mass of solution of 80 g and initial concentration of 30%, an experimental test is carried out for a period of 3 h (from 11 am to 2 pm). From the plot, it can be noted that a maximum water temperature at heat exchanger inlet of about 52°C is recorded at 11 am, whereas the output temperature was found to be 49°C for the first period of test with zeolite with VFD. Certain fluctuation in the system was noted in the temperature during the observation of the 3-h period, which is plotted in the graph. It is found that the desiccant of zeolite with VFD gave more efficiency compared to the other desiccant. Several analyses were done and similar values were taken. Calculations were done and the result was found to be positive.

5. Conclusions

A novel design of desiccant with VFD-operated humidity pump has been presented and analysed. In the proposed design, air humidifiers are applied for dehumidification of processed air and regeneration of liquid desiccant. The VFD is fitted for varying the blower speed in order to alter the amount of air pulled into the system. The effects of meteorological conditions and system design parameters are well defined. Also, the system efficiency is defined by the input and output parameters. The appropriate selection of desiccant concentration at the end of sorption has been discussed. Based on the obtained experimental results, the following conclusions can be drawn:

- Desiccant minimum regeneration temperature is proportional to the humidity potential between the indoor and outdoor conditions (temperature and humidity).
- Experimental results show that zeolite with VFD solution with 30% concentration can be regenerated up to 50% using VFD.
- The stability of heating temperature is important. The water can either be heated using the solar heater or by the previous heating method.
- Good agreement between the outputs from the inputs and the corresponding results from the experimental analysis is found. It is also concluded that the proposed model can be successfully used for predicting the overall efficiency of the system on the basis of the system input and output data.

Disclosure statement

No potential conflict of interest was reported by the authors.

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