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Renewable Energy 30 (2005) 2247–2256
RENEWABLE ENERGY
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The effect of absorber packing height on the performance of a hybrid liquid desiccant system

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Received 4 June 2004; accepted 16 January 2005
Available online 23 February 2005

Abstract

A hybrid system consisting of vapour compression unit, a liquid desiccant system, and a flat solar hot water collector were designed, fabricated and tested. This combination allowed for a separate control of humidity and temperature without energy penalty. Various packing heights of the absorber component were tested to determine the optimal performance of the combined unit. A 1000 mm packing height with cross-sectional area of 600×600 mm, proved to be the best height that gives promising improvements in the coefficient of performance of the vapour compression unit.

Keywords: Liquid desiccant; Packing material height; Absorber

1. Introduction

The 1990s and 1980s were challenging decades for the Heating, Ventilation, and Air-Conditioning (HVAC) industry. The need for ever more efficient heating, cooling, ventilation and dehumidification technologies became more urgent than during the energy crisis of the 1970s. Energy resources are more depleted and the energy demands of a growing global population continued to increase with the increase in the demand for comfort cooling, even in the developing countries.

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0960-1481/$ - see front matter
doi:10.1016/j.renene.2005.01.011

Traditionally, air conditioning has been achieved by conventional vapour compression systems (CVCs). These systems have merits of high effectiveness as heat transfer machines, which make them very efficient in handling air conditioning loads characterised by high sensible heat ratio [1]. They are also proven technology with a great market penetration. However, conventional vapour compression systems have their drawbacks of large electricity consumption, dependence on deep freezing to remove latent heat, and mostly, they used the fully halogenated chloroflourocarbons (CFCs). Which have provided much needed refrigerants for refrigeration and air-conditioning for about 60 years, these CFCs are among the gases responsible for the depletion of the ozone layer, and for creating global warming. They must be phased out by now, but in fact they are still being produced and about 65% produced annually are being used only to replace the leaked out CFCs and the remaining 35% are used in manufacturing new refrigerators, air-conditioners and other cooling appliances. All this means a need to reduce the use of these refrigerants and if possible a shift to another source to provide the refrigeration and air-conditioning is much needed [2].

1.1. Hybrid desiccant system

Conventional vapour compression systems have been inefficient in handling air-conditioning loads associated with high latent heat fraction from the energy point of view. In order to perform the dehumidification task, they should operate at very low evaporator temperature with the consequence of consuming more energy to meet the load. This situation worsens when the system experiences a high latent load with relatively small or no sensible load at part load condition. In order to find an alternative that can solve the above problems, a hybrid system, which is defined as a combination of a desiccant system integrated with either a vapour compression system as investigated by Dai et al. [1], Oliveira et al. [3], Yadav and Kaushik [4], Aly et al. [5], Worek and Chung [6], and Adnan et al. [7], Sheridan and Mitchell [8] or an absorption refrigeration system as studied by Khalid Ahmed et al. [2], and Gari et al. [9], or as stand alone desiccant systems integrated with an evaporative cooler for sensible cooling as given by Davanagere et al. [10,11], has to be used. Hybrid systems have been the topic of research by many researcher for the last 20 years, and apart from the system investigated by Dai et al. [1], which was carried out experimentally most other systems are mathematically modelled systems with programs code written to investigate them. Desiccant systems handle either fully or partially the latent load fraction at a very efficient way, while the other system ‘vapour compression, absorption machine, or evaporative coolers’ will handle the sensible load fraction. This arrangement would make it possible to independently control the temperature and humidity of the process air without excessive energy consumption.

2. Description of the system

The hybrid system used consists of a vapour compression unit combined with liquid desiccant system using lithium chloride solution as a desiccant and a flat plate solar hot water collector. The desiccant system consists of a packed absorber (the main component in this paper), a packed regenerator, where the desiccant is re-activated or regenerated, and two water to solution heat exchangers, one with the absorber for cooling the desiccant before entering the absorber and the other is with the regenerator for heating the desiccant for regeneration purposes. A chiller is used to provide the cooling water for cooling the desiccant, and the solar system provided the heated water for regenerating the desiccant. This solar system consists of a flat plate collector, a tank supplemented with an electric heater as back up for the solar radiation in case of insufficient solar insolation due to cloud or rain. The main components of the whole hybrid system are shown schematically in Fig. 1a and b, as Fig. 1a explore the absorber unit and the vapour compression unit, while Fig. 1b shows the regenerator part of the liquid desiccant system with the solar collector unit.

3. Test rig

The whole system shown in Fig. 1 consists of the three major sub-systems, the desiccant system, vapour compression system, and solar collector with its auxiliary items.

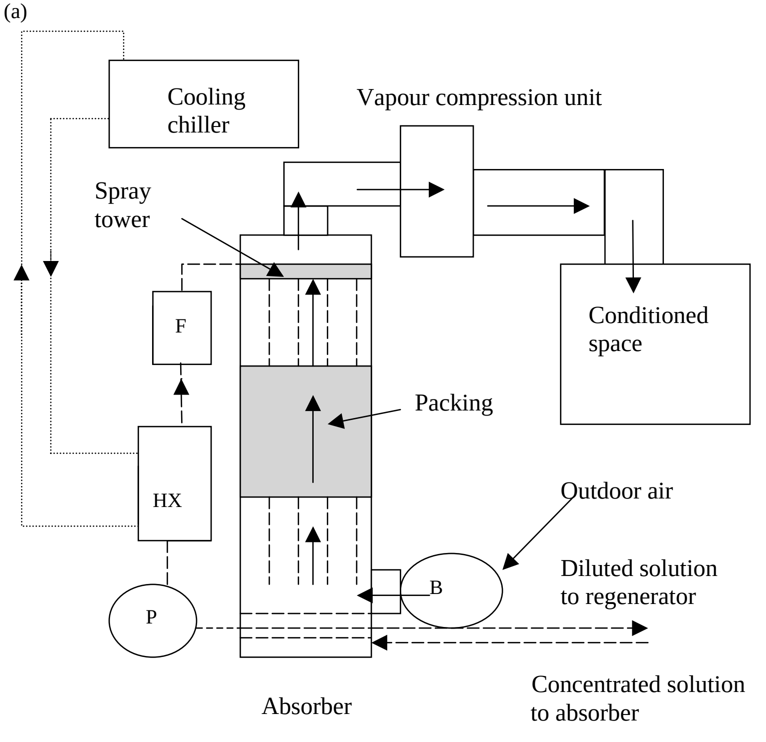

Fig. 1. (a) Absorber and vapour compression unit. P, pump; B, blower; F, flowmeter; HX, heat exchanger. (b) Regenerator and solar hot water collector. P, pump; H, auxiliary heater; B, blower; F, flowmeter; HX, heat exchanger.

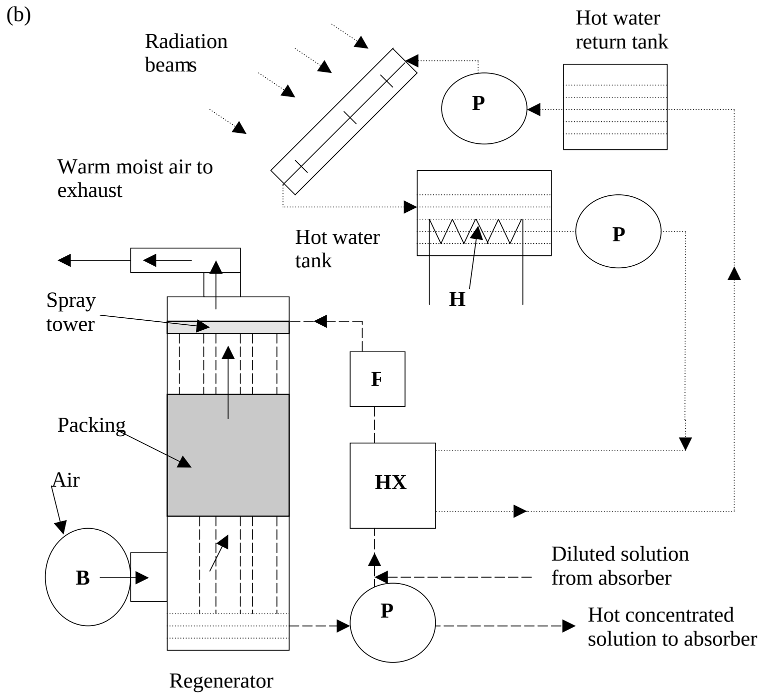

Fig. 1 (*continued*)

In this paper the effect of the packing height on the performance of the vapour compression unit is discussed. To do so, the absorber was built from fiberglass in pieces that can be assembled for each run to give the correct height for that particular run.

3.1. Test procedures and instrumentation

As mentioned before, the absorber was built in such a way that different packing heights can be tested in each run. A $600\times600\times200$ mm piece will be added in each run to make the 200, 400, up to 1000 mm (in five steps of 200 mm each) making up five different absorber heights to be tested. A flexible duct and dampers were used to maintain the supply of the process air to the vapour compression. Air is ducted to the vapour compression unit either fully from ambient to test the unit with air by passing the desiccant absorber ‘stand alone’, or fully from the absorber, and finally as partly from the absorber (50%) and the other (50%) from ambient air (both mixed well before entering the evaporator of the vapour compression unit). Lithium chloride solution was used as the desiccant in the absorber, and a counter-current flow arrangement was maintained between the liquid desiccant (flowing downwards) and the process air upwards. Five tests were done for testing the vapour compression unit. And for both of the air supply of 50% and full supply, the air volumes have been varied by three values which are 4.9, 5.7, and 6.4 m^3/min. These values were maintained using a voltage regulator for the blowers,

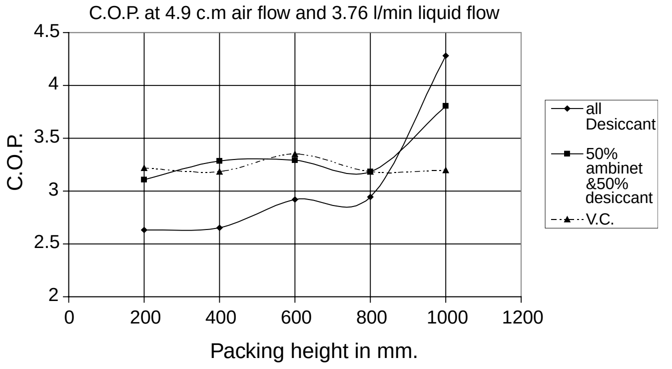

Fig. 2. Coefficient of performance at air volume of 4.9 m^3/min and 3.76 l/min liquid desiccant flowrate. VC, vapour compression alone.

and dampers. Corresponding to these values, the desiccant solution flow rates were also varied (3.76, 4.39, and 5.01 l/min), these flow rates were obtained with the aid of by-pass valves returning some liquid back to the absorber sump. This makes a total of 90 runs of the absorber and the vapour compression unit to cover the variables considered. Flowmeters were used to measure the liquid desiccant flow rate, refrigerant flow rate and these measurements were taken manually. Temperature measurements were recorded using type k thermocouples with the aid of a data acquisition system. This data acquisition system includes a computer card ‘C I O-DAS 08’ with extended card ‘C I O-EXP 32’, which enables thermocouple terminals to be directly attached to it. The testing record was arranged to be every minute for the thermocouples with the system scanning every 6 s and averaging the value every minute and recording it into the computer. System stability was reached at every test run before recording the measurements, and each run was allowed to run for 15 min. Counter-current flow pattern between the desiccant, kept at 35–40% concentration by weight, and the air, were used. The desiccant temperature was kept between 25 and 27 °C by using cooling water from the cooling chiller through the heat

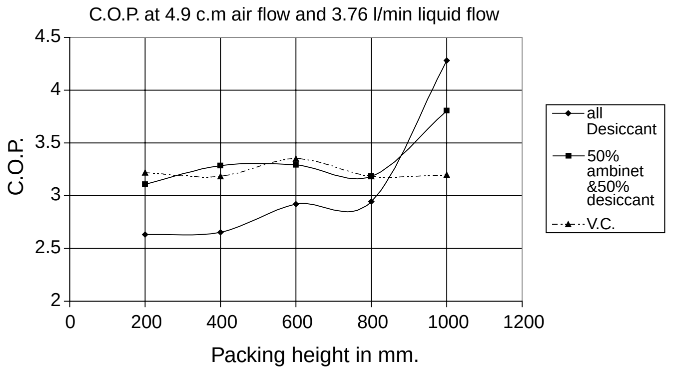

Fig. 3. Coefficient of performance at air volume of 4.9 m^3/min and 4.39 l/min liquid desiccant flowrate. VC, vapour compression alone.

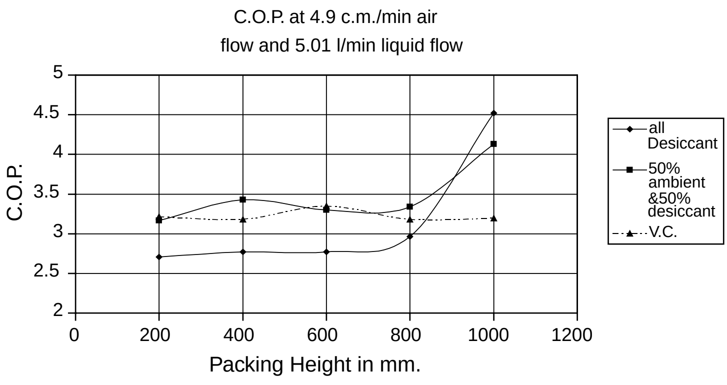

Fig. 4. Coefficient of performance at air volume of 4.9 m^3/min and 5.01 l/min liquid desiccant flowrate. VC, vapour compression alone.

exchanger prior to entering the absorber. The refrigerant pressure was recorded manually using pressure gauges.

3.2. Regeneration of the liquid desiccant

Regeneration of the desiccant solution has been attained through using a flat plate solar hot water collector with a supplementary electrical heater. The solar hot water collector heats water in sunny days up to 65 °C which is used to heat the desiccant solution using heat exchanger. When the collector hot water does not reach 65 °C, the supplementary heater is used to raise the temperature of the hot water to the desired temperature. To make the system more economical a small liquid desiccant tank was used to store the concentrated desiccant to be used during low solar radiation or during rainy days. This arrangement allows for minimum usage of the electrical heater installed in the hot water tank. Details of the regeneration packing height, liquid desiccant flow rate and inlet

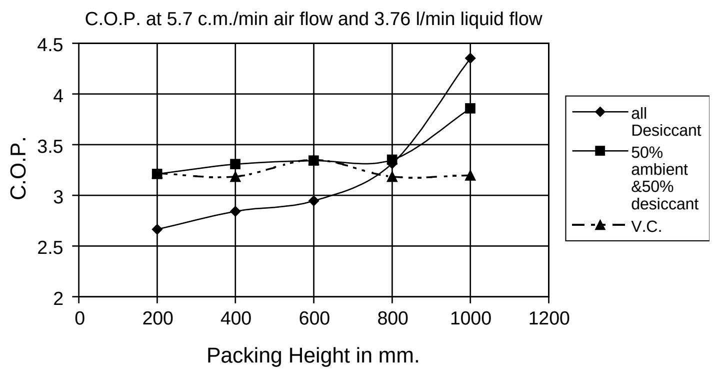

Fig. 5. Coefficient of performance at air volume of 5.7 m^3/min and 3.76 l/min liquid desiccant flowrate. VC, vapour compression alone.

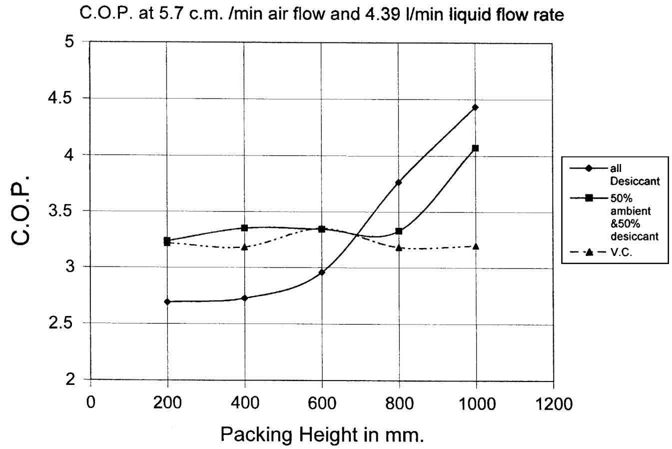

Fig. 6. Coefficient of performance at air volume of 5.7 m^3/min and 4.39 l/min liquid desiccant flowrate. VC, vapour compression alone.

water temperature and the efficiency of the collector for regeneration are given in another paper to be published soon.

4. Results and discussion

The corresponding enthalpies were calculated from the measured data and hence the coefficient of performance for each run was obtained for 50 and 100% air flow through the desiccant and compared with the use of the vapour compression system alone. These obtained values of the coefficient of performance are shown graphically in Figs. 2–10. It was noticed that throughout the schematic diagrams of coefficients of performance versus the packing heights, all runs with 50% process air through the desiccant absorber, for all

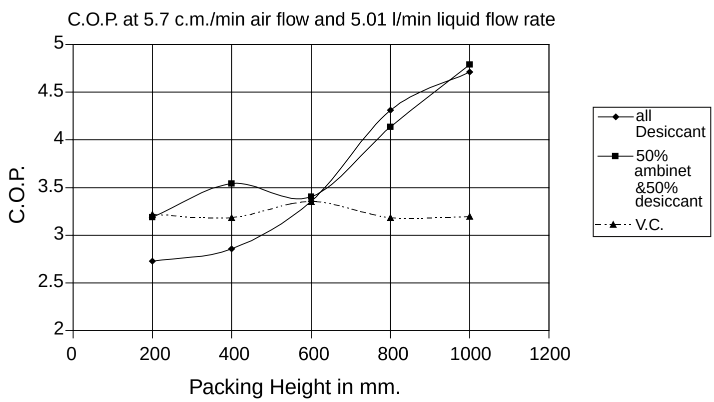

Fig. 7. Coefficient of performance at air volume of 5.7 m^3/min and 5.01 l/min liquid desiccant flowrate. VC, vapour compression alone.

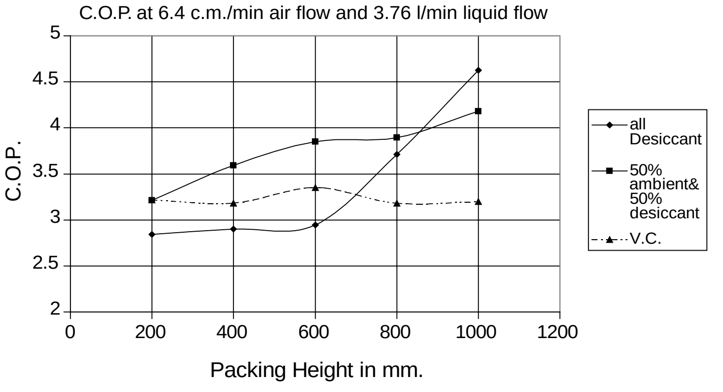

Fig. 8. Coefficient of performance at air volume of 6.4 m^3/min and 3.76 l/min liquid desiccant flowrate. VC, vapour compression alone.

combination of air volumes and liquid desiccant flowrates experience an improved coefficient of performance compared with the vapour compression unit alone, as shown in Figs. 2–10. The 800 mm packing height represents the point with both air patterns (mixed or fully from the desiccant) where the coefficient of performance improved over the vapour compression system alone. At this height, sufficient contact time was allowed for the process air to interact with the liquid desiccant solution, even with the small values of air volume and liquid desiccant flowrate. Better results were obtained at 1000 mm packing height as more contact is allowed while still maintaining reasonable pressure drop. So with the 800 and 1000 mm packing heights the mass transfer operation is enhanced by complete wetting of the packing material and sufficient mass transfer area. When the system worked under the supply of fully treated air (with the low values of air volumes) through the desiccant unit, it experienced a situation were the load imposed on it was very small. This small load made the vapour compression unit perform very poorly. And so as up to

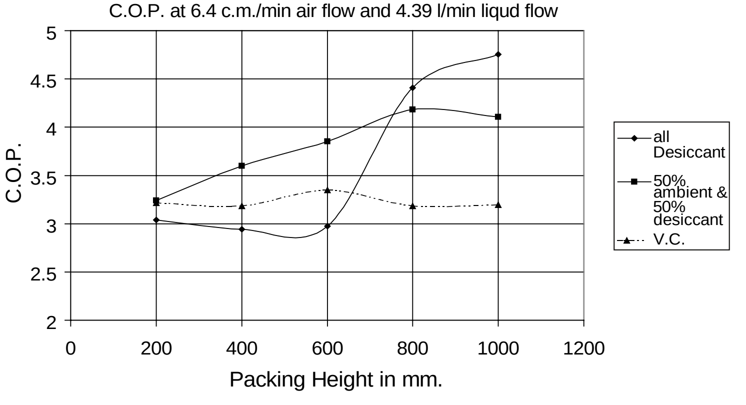

Fig. 9. Coefficient of performance at air volume of 6.4 m^3/min and 4.39 l/min liquid flowrate. VC, vapour compression alone.

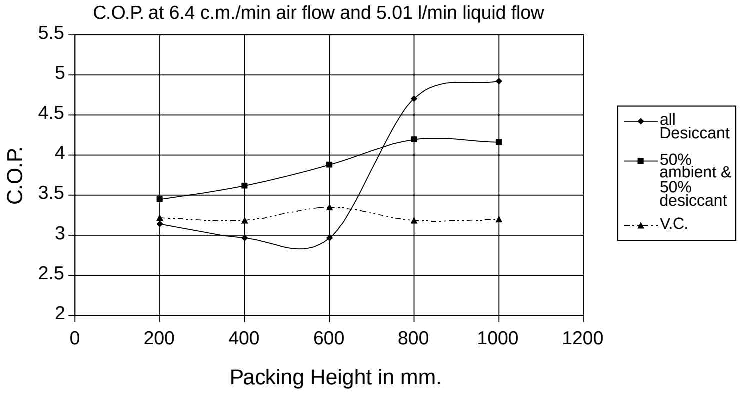

Fig. 10. Coefficient of performance at air volume of 6.4 m^3/min and 5.01 l/min liquid flowrate. VC, vapour compression alone.

600 mm packing height the load is far from the full capacity of the unit, and it performance poorly below 800 mm packing height for the case of air through desiccant only scenario.

5. Conclusion

The hybrid system of desiccant sub-system and vapour compression unit has shown promising results in terms of separate control of temperature and humidity. This has been achieved without energy penalty and in fact energy savings were anticipated as demonstrated by the improvements in the coefficient of performance of the vapour compression system. A 800 mm packing height is found to be the breaking limit with both air supply either fully from the desiccant or partly that would result in improvement in the performance of the vapour compression unit. 1000 mm packing height is found to be the most suitable among the tested range and the one which result in 17.9–48.5% improvement of the coefficient of performance.

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