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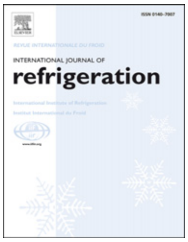

Investigation of an improved solar-powered open absorption system for cooling, dehumidification and air conditioning

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ABSTRACT

This study is concerned with an open absorption (liquid desiccant) system, capable of producing both cooling and dehumidification for air conditioning, utilizing low-grade heat. The system includes a novel solution heat and mass exchanger (HME) designed to serve as a desiccant solution reservoir for both the absorber and desorber, enabling mass transfer between them with minimum heat transfer losses and eliminating the need for an external recuperative heat exchanger. The use of this new HME together with an improved solution flow arrangement in the new system facilitates the use of adiabatic absorption/desorption with minimum circulation heat losses and wetting problems. The characteristic performance of the system was studied under varying operating conditions. The use of the new HME has fulfilled the objective of reducing the time constant of the system, helped correct idling and level control problems and ensures maximum solution concentration on the absorber side during desorber operation.

Etude sur un système ouvert amélioré à absorption fonctionnant à l'énergie solaire utilisé pour le refroidissement, la déshumidification et le conditionnement d'air

Mots clés : Déshydratant liquide ; Conditionnement d'air ; Déshumidification ; Système ouvert ; Absorption

1. Introduction

Growing demand for air conditioning in recent years has caused a significant increase in demand for energy resources, not only in hot and humid climates such as in Mediterranean countries, but also in European countries with no air conditioning tradition. Electric utilities have their peak loads in hot summer days, and are struggling with brown-out situations, often barely capable of meeting the demand. With suitable technology, solar cooling can

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Nomenclature

A/C	air conditioning
CFC	chlorofluorocarbon
COP	coefficient of performance
HME	heat and mass exchanger
LDS	liquid desiccant system
SSHX	solution-to-solution heat exchanger

help alleviate, if not eliminate the problem. It is a good application for solar energy due to the fact that the greatest demand for air conditioning occurs during times of highest solar radiation.

Liquid desiccant systems for cooling and dehumidification stand as a good alternative to conventional electric-powered cooling systems. They operate essentially as open-cycle absorption devices. Such systems are capable of using industrial waste heat or low-grade solar heat from low-cost flat plate collectors as their source of power, and have the potential to provide both cooling and dehumidification, as required by the load.

Earlier work has been conducted on liquid desiccant systems for cooling and dehumidification, using solar energy for regeneration – removal of moisture absorbed into the desiccant during the earlier absorption stage, to enable its re-use for air dehumidification (Oberg and Goswami, 1998; Grossman, 2002). In several cases, direct regeneration of the desiccant in the sun was considered, using a special type of collector. Some 30 years ago, Kakabaev et al. (1981) reported on the operation of a large scale air conditioning system employing LiCl–water, where both direct regeneration in open collectors and cold storage in the form of regenerated solution have been attempted. Kessling (1997) studied a LiCl–water system operating at a large concentration difference between the strong and weak desiccant, to facilitate cold storage by means of a regenerated solution. Saman and Alizadeh (2002) modeled and experimented with a liquid desiccant system based on a cross-flow plate heat exchanger. Our group has built earlier version of the system described in this article (Gommed et al., 2004; Gommed and Grossman, 2007).

Liquid desiccant systems (LDSs) are exceptionally good at dehumidification, thereby taking care of the latent heat load. In conventional air conditioning (A/C) systems this task is achieved by over-cooling the air below its dew point, which leads to both thermodynamic and practical inefficiencies. The power source for LDS is heat, whereas conventional A/C requires electricity. An optimal A/C system would be hybrid, consisting of electric vapor compression or closed absorption heat pump to handle the sensible heat and a solar-driven liquid desiccant system with storage capability to handle the latent heat. The hybrid system has the added advantage of allowing independent control of temperature and humidity.

LDS powered by solar, waste or other forms of low-grade heat can play an increasing role in A/C systems as the cost of electric power and fossil fuels increases. One study (Khalid Ahmed et al., 1997) estimated this as a 35% reduction in electrical demand. The possibility of using low-grade energy goes a long way toward the elimination of pollution and utilizing renewable and environmentally-safe energy sources. The use of hygroscopic salts in direct contact with moist air provides an attractive alternative to conventional cooling systems employing ozone-depleting CFCs.

2. Liquid desiccant system description

A schematic description of a largely familiar LDS is given in Fig. 1. The system consists of six major components: an air dehumidifier or absorber, a solution regenerator or desorber, two water-to-solution heat exchangers, a solution-to-solution heat exchanger, and an air-to-air heat exchanger. Arabic numerals indicate working fluids state points at specific locations. Air flow is represented by thick solid lines, solution flow by thin solid lines and water flow by thin dashed lines.

The dehumidifier (absorber) consists of a packed tower and operates in an adiabatic mode. Ambient air at state 13 entering the bottom of the absorber packed section is brought into contact with a concentrated absorbent solution entering the top of the unit at state 8. Water vapor is removed from the air stream by being absorbed into the solution stream. The dehumidified warm air leaving the absorber passes through the blower and leaves the system toward the air-conditioned space at state 14. Solution is pumped from the absorber pool at the bottom of the tower into the plate heat exchanger (state 7), where it is cooled by water from a cooling tower. The solution leaving the heat exchanger (state 8) then proceeds to the distributor at the top of the packing, from where it trickles down in counter-flow to the air stream and collects in the pool.

The regenerator (desorber) device is very similar to the dehumidifier, and so are the flow system and associated components. The solution is heated in the liquid-to-liquid heat exchanger from state 3 to state 4 by hot water (states 1–2) heated by solar or by another form of low-grade heat. Ambient air is pre-heated in the air-to-air heat exchanger by heat recovered from the exhaust air leaving the desorber. After pre-heating, the air stream (state 15) enters the desorber where it serves to re-concentrate the hot solution.

In order to remove weak solution from the absorber and replace it by regenerated solution from the desorber, a controlled amount of solution is continuously transferred from the absorber pool to the desorber, as shown in Fig. 1 (state 11). The return (pumped) stream from the desorber (10) goes directly into the absorber pool. To obtain a high degree of dehumidification for the supply air, the solution concentration at the absorber pool should be maintained as high as possible (ideally close to that in the desorber). At the same time, the temperature of the solution in the absorber should be maintained as low as possible. To resolve these contradictory requirements, a solution-to-solution heat exchanger (SSHX), as described in Fig. 1, facilitates pre-heating of the weak solution leaving the absorber (states 11–12) and recovers heat from the hot strong solution leaving the desorber (states 9–10). However, since the SSHX is not ideal, only part of the solution circulated in each of the reactors (absorber and desorber) is exchanged between them, with an optimum splitting ratio (controlled by the splitter) which ensures a low concentration