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Performance analysis of a no-frost hybrid air conditioning system with integrated liquid desiccant dehumidification

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ABSTRACT

This paper reports a performance analysis for a hybrid air conditioning system. In this system, the sensible heat load is primarily treated by a vapor compression heat hump; the latent heat load is treated by a liquid dehumidification system that uses a lithium chloride solution as a desiccant. In addition, by decreasing the humidity ratio of air flowing through the outdoor heat exchanger of the vapor compression heat pump, frosting can be retarded. The overall system performance was evaluated by a cycle simulation conducted both in summer and winter modes. Compared to a traditional air conditioning system, the hybrid air conditioning system improves the coefficient of performance (COP) by approximately 20% and 100% in summer and winter, respectively.

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Analyse de la performance d’ un système de conditionnement d’ air hybride sans formation de givre à déshumidification à déshydratant liquide

Mots clés : Conditionnement d’air ; Système à compression ; Système à déshydratant ; Modélisation ; Simulation : Performance ; Givrage

1. Introduction

In the air-conditioning field, more attention needs to be paid to saving energy while increasing indoor air quality at the same time. Reducing the temperature and humidity of a stream of air is the major requirement for air conditioning systems, especially in tropical areas. In a conventional air conditioning system, air is conditioned by passing it over a cooling coil to achieve both cooling and dehumidification; dehumidification is realized by cooling the air to below its dew

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Nomenclature

A_1-A_7	air state points
C	concentration of solution (%)
COP	coefficient of performance
h	enthalpy (kJ kg^{-1})
HP	heat pump
LHRU	latent heat removal unit
m	mass flow rate (kg s^{-1})
Q_{sen}	sensible heat load (kW)
Q_{lat}	latent heat load (kW)
RH	relative humidity of air (%)
SHRU	sensible heat removal unit
T	temperature (°C)
T_{dew}	dew point of air (°C)
$T_{s,heating}$	heating temperature of solution (°C)
$T_{s,cooling}$	cooling temperature of solution (°C)
W_{com}	electric power consumption of compressor (kW)
X	humidity ratio of air (g (kg dry air)$^{-1}$)

Greek symbols

ϵ_d	humidity effectiveness
ϵ_h	enthalpy effectiveness
ϵ_{ex}	effectiveness of heat exchanger
η_{com}	isentropic efficiency of compressor

Subscripts

a	air
con	condenser
deh	dehumidifier
eva	evaporator
fre	fresh air
in	inlet
nf	no frost air
out	outlet
reg	regenerator
ret	return air
s	solution
v	vapor

point. As a result, the dehumidified air is cooler than the required indoor comfort level, which in turn causes reheating and further energy loss. Meanwhile, since chilled water with a relatively lower temperature is needed, the performance of chillers is decreased. Furthermore, health problems can occur because the condensed water makes the coil surface a breeding ground for bacteria.

Separating the control of humidity and temperature using a desiccant could result in energy savings and improved humidity control. Desiccants are usually chemicals with a high affinity to moisture. Desiccants may be either solid or liquid. Solid desiccants used in air conditioning include silica gel and molecular sieves, while liquid desiccants include lithium chloride, lithium bromide, calcium chloride, and triethylene glycol. Liquid desiccants have some advantages over solid desiccants. The pressure drop through liquid desiccants is lower than that through a solid desiccant system; liquid desiccant systems can be driven by low-grade heat sources, such as solar energy; and liquid desiccants have the ability to remove dirt and floating contaminants from air. But the regenerating temperature to solid desiccants is about 100 °C (Ge et al., 2009; Elasyed et al., 2006). Common problems involving liquid desiccants include corrosion, the carryover of solution into the air stream, and crystallization. The earliest liquid desiccant system (LDS) was suggested and experimentally tested by Lof (1955) using triethylene glycol as the desiccant. Li et al. (2005), Mahmoudm and Ball (1992), Elsayed (1994) and Kessling et al. (1998) have all described different air handling systems using liquid desiccants.

The merits of conventional vapor compression systems (VCS) include their handling of sensible heat, high effectiveness for heat transfer, compact size, mature technology, and convenience of operation. However, they are not effective in handing latent heat because they depend on deep-freezing to remove the latent heat of air. Desiccant dehumidification is advantageous for handing latent heat. Therefore, it can be used effectively as a supplement to conventional vapor compression systems to remove the latent heat part of the cooling load. A new hybrid system can combine the advantages of desiccant dehumidification and VCS together.

Many studies have been carried out using liquid desiccants in hybrid air conditioning systems aiming at improving the performance of traditional air conditioning systems. Mohan et al. (2008) conducted a performance study of a liquid desiccant–vapor compression hybrid system, in which the evaporating and condensing heats for the vapor compression system were used to pre-cool process air and preheat regenerating air. Liu et al. (2004) provided a hybrid air conditioning system, consisting of cogenerators, liquid desiccant system, vapor compression and absorption chillers. Power is used to meet the electrical loads and waste heat is used to regenerate desiccant, driving absorption chiller in summer and heating the building in winter. The system is found to be energy efficient and environmental friendly. Kinsara et al. (1998) carried out a parametric study to investigate the effects of different key variables on the COP of hybrid air conditioning using $CaCl_2$ as a desiccant. The effect of key variables on the performance of the system—such as the ambient temperature, inlet temperature of the liquid desiccant, and effectiveness of the heat exchanger—is presented in their paper. Dai et al. (2001) established a hybrid air conditioning system which consists of desiccant dehumidification, evaporative cooling, and vapor compression air conditioning. The overall COP of the hybrid air conditioning system was reported to be enhanced by 44–55% compared to a traditional vapor compression system. Wu et al. (2006) investigated an internally cooled liquid desiccant dehumidifier; the evaporator of the vapor compression system was set in the dehumidifier to remove the condensing heats of vapor and cool process air, and the condenser equipped in the regenerator was used to heat the regenerating solution. They reported that the moisture removing effectiveness was improved by using the internally cooled dehumidifier. Howell and Peterson (1986) studied a hybrid system combining LDS with VCS. They found that the hybrid system reduced the area of evaporation and

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