Applied Energy 88 (2011) 143–149

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Control performance of a dedicated outdoor air system adopting liquid desiccant dehumidification

Fu Xiao, Gaoming Ge*, Xiaofeng Niu

Department of Building Services Engineering, The Hong Kong Polytechnic University, Kowloon, Hong Kong

ARTICLE INFO

Article history:
Received 29 March 2010
Received in revised form 18 June 2010
Accepted 22 June 2010
Available online 14 July 2010

Keywords:
Dedicated outdoor air system
Total heat exchanger
Liquid desiccant
Dehumidification
Control strategy
System performance

ABSTRACT

Liquid desiccant is energy efficient for dehumidification in air-conditioning systems. In this study, a novel dedicated outdoor air system (DOAS) adopting lithium chloride solution as liquid desiccant is proposed to process supply air. The DOAS mainly consists of a membrane-based total heat exchanger, a liquid dehumidifier, a regenerator and a dry cooling coil. It can realize independent temperature and humidity controls for supply air. Control strategies for the supply air dehumidification and cooling process as well as the desiccant solution regeneration process in the DOAS are developed and verified. The control performances of the proposed dedicated outdoor air system are investigated at different operation conditions by simulation tests. The results show that the DOAS is more suitable for hot and humid climates. The effects of the total heat exchanger on the performance of the DOAS are also evaluated. It can improve the system energy performance by 19.9–34.8%.

1. Introduction

Combining with parallel chilled ceiling systems or other sensible cooling terminals, dedicated outdoor air systems (DOAS) can realize independent temperature, humidity and ventilation controls in buildings. The DOAS-integrated system can provide a more healthy and comfortable indoor environment as well as save energy consumption compared with traditional air-conditioning schemes [1–3]. In the DOAS-integrated system, the DOAS subsystem is responsible for treating the total latent load and a part of sensible load of the conditioned space, and simultaneously meeting the ventilation requirement of occupants in space, while the parallel sensible cooling terminals bear the remainder sensible cooling load of space.

In the DOAS, the dehumidification and cooling process of supply air is energy-intensive, especially in hot and humid regions. Different dehumidification methods can be adopted, including mechanical dehumidification and desiccant dehumidification methods. In the conventional mechanical dehumidification and cooling process, in order to remove the moisture from the supply air, the process air should be cooled below its dew-point temperature, and reheating is needed to ensure comfortable supply air temperature. In this situation, the cooling and reheating process wastes intensive energy and it lowers the system energy efficiency. Meanwhile, the cooling coil works under the wet condition, which may cause health problems since the condensed water makes the coil surface a breeding ground for bacterial. In recent research, desiccants are widely utilized to dehumidify air in the air-conditioning field. The desiccant dehumidification schemes are more energy efficient and healthy than the mechanical dehumidification manners [1,4,5]. Desiccants may be either solid or liquid. Solid desiccants widely used in air-conditioning systems include silica gel and molecular sieves, while liquid desiccants include lithium chloride (LiCl), lithium bromide (LiBr), calcium chloride ($CaCl_2$), and triethylene glycol. Liquid desiccant dehumidification has some advantages over solid desiccant dehumidification [6]. The liquid desiccant system can be driven by low-grade heat sources, such as solar energy or waste heat, and it has the capacity of energy storage.

Much research on fundamental analysis of the liquid desiccant devices has been carried out. Fumo and Goswami [7] provided theoretical and experimental analysis on heat and mass transfer in air–liquid (LiCl) desiccant packed towers of counter-flow configuration. The finite difference model was used to predict dehumidification and regeneration processes. It was found that desiccant concentration, desiccant temperature, air flow rate and air humidity ratio had the greatest impact on the performance of the dehumidifier, while desiccant temperature, desiccant concentration and air flow rate had the greatest impact on the performance of the regenerator. It was also noticed that the dehumidification or regeneration process was almost not affected by the air temperature and the desiccant solution flow rate. Chen et al. [8] and Babakhani and Soleymani [9] presented simplified analytical solutions of heat and mass transfer processes occurring in counter-flow packed-type liquid desiccant equipments. Using simple correlations, the influences of different design variables such as air and desiccant flow

* Corresponding author. Tel.: +852 27664698.
E-mail address: 07902065r@polyu.edu.hk (G. Ge).

0306-2619/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.apenergy.2010.06.019

rates, air temperature and humidity, and desiccant temperature and concentration, on the water condensation from the air and evaporation rate from the desiccant solution were evaluated.

Recently, many research works on the performance study of the liquid desiccant air-conditioning systems have been conducted. Kinsara et al. [10,11] carried out a parametric study to investigate the effects of different key variables on the coefficient of performance (*COP*) of a hybrid air-conditioning system using $CaCl_2$ as 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, was presented in the paper. Tu et al. [12] proposed a novel energy efficient air-conditioning system utilizing LiCl solution as liquid desiccant, and analyzed the effect of some key variables on the performance of the system by simulation tests. Xiong et al. [13] reported a novel two-stage liquid desiccant dehumidification system assisted by $CaCl_2$ solution. The thermal coefficient performance of the system can be increased from 0.24 to 0.73 under the given conditions.

In the above reviewed studies, heat and mass transfer characteristics and the performance analysis of liquid desiccant systems were investigated. However, little control issue about the liquid desiccant system was presented. In open literature, the supply air state is not controlled and it always varies when the system operation condition changes. But in practical applications, the supply air state is expected to be automatically regulated to meet the pre-setting outlet state, which is determined by the instant cooling load, i.e. sensible load and latent load of space. Hence, control strategies for the liquid desiccant system are requisite to develop, which are crucial to ensure the desiccant dehumidification system continuously operate and achieve the expected supply air state.

In addition, because the DOAS is a 100-percent outdoor air system, energy recovery is required in most cases according to ANSI/ASHRAE/IESNA Standard 90.1-2007, and the energy-recovery system should be with at least 50-percent recovery effectiveness [14]. Both sensible heat exchanger and total heat exchanger can be used for energy recovery. But for hot and humid climates, the total heat exchanger is superior to sensible heat exchanger. Many studies have been conducted in recent years on theoretical and experimental analysis of energy recovery [15,16], and results revealed that heat recovery could save 29–42% of primary energy depending on the system involved [17]. Energy wheel and membrane-based total heat exchanger are widely used and investigated to recover energy from exhaust air. The membrane total heat exchanger has some merits over the energy wheel, such as no cross contamination, no moving part and lower pressure drops.

In the present study, a dedicated outdoor air system adopting liquid desiccant dehumidification is proposed. A membrane-based total heat exchanger is applied to recover the heat and moisture from exhaust air. Control strategies for supply air dehumidification and cooling process as well as the desiccant solution regeneration process in the DOAS are developed and illustrated. A simulator of the DOAS, which takes into account all components, including the membrane-based total heat exchanger, dehumidifier, regenerator, cooling coil and more, is built up on the simulation platform of TRNSYS [18]. Control performances of the DOAS at different operating conditions are investigated by simulation tests. Moreover, the effects of membrane-based total heat exchanger on the system performances are also evaluated.

2. Proposed dedicated outdoor air system and control strategies

The schematic of the proposed liquid desiccant-based dedicated outdoor air system and its control system is shown in Fig. 1. The DOAS contains three loops: the process air loop, the liquid desiccant solution loop and the regeneration air loop.

The process air loop includes a membrane-based total heat exchanger, a liquid dehumidifier, and a dry cooling coil. In this loop, fresh air from outside is firstly delivered through the membrane-based total heat exchanger, where it transfers heat and humidity with the return air from the conditioned space. Then the pre-conditioned supply air is dehumidified by a liquid dehumidifier, and lastly is sensibly cooled down by the dry cooling coil to the pre-setting state to meet the comfort requirement in the conditioned space. Return air from the conditioned space passes through the membrane exchanger and exchanges heat and moisture with fresh air before exhausted to outside.

The desiccant solution loop is critically important for continuous air processing in the DOAS. It is composed of a water cooler, a dehumidifier, a solution-to-solution heat exchanger (*Sensible HE1*), a heater and a regenerator. Lithium chloride solution is used as the liquid desiccant in the dehumidification system. The re-concentrated solution from the regenerator is firstly pre-cooled by sensible HE1 and then cooled by a water cooler before it is sprayed into the dehumidifier for supply air dehumidifying. From the dehumidifier, the diluted solution is pre-heated by the sensible HE1 and further heated by a heater, and finally re-concentrated in the regenerator.

The regeneration air loop is comparatively simple. It consisted of an air-to-air sensible heat exchanger (*Sensible HE2*) and a regenerator. The inlet air in the solution regeneration process is firstly pre-heated in sensible HE2, and then fed into the regenerator to absorb water vapor from weak solution. The temperature of the air leaving from the regenerator is higher than that of the inlet air. Hence, the outlet air can sensibly pre-heat the inlet air in sensible HE2 before be discharged to outside.

In this study, control strategies for the supply air dehumidification and cooling process as well as the desiccant solution regeneration process in the DOAS are developed. As shown in Fig. 1, the supply air humidity ratio ($W_{a,sup}$) of the DOAS system is controlled by regulating the strong solution inlet temperature into the liquid dehumidifier, which is realized by adjusting the cooled water flow rate entering the cooler. The supply air temperature ($T_{a,sup}$) is maintained by modulating the supply cooled water flow rate into the dry cooling coil. In the solution regeneration process, the outlet solution concentration ($C_{s,out}$) from the regenerator is controlled by regulating the inlet solution temperature into the regenerator, which can be achieved by adjusting the heat input. In the solution regeneration process, the concentration of the desiccant solution can be measured by a conductivity meter [19].

3. Mathematical modeling

The proposed liquid desiccant-based DOAS is consisted of several components, as shown in Fig. 1. In this study, these components are modeled and the whole system simulator is built up on the platform of TRNSYS. The control performance of the DOAS will be studied based on simulation tests.

3.1. Membrane-based total heat exchanger

In the modeling process, both finite difference model and effectiveness-number transfer unit (ε-*NTU*) model can be adopted to simulate the membrane-based total heat exchanger [20,21]. The finite difference model is detailed and accurate, but it is time-consuming. To simulate the cross-flow heat exchanger, if the finite difference model is utilized, there is a large amount of control volumes to calculate. It will influence the computing speed of the simulator. The ε-*NTU* model is simple and fast, and it is reliable to