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Analysis on the ideal energy efficiency of dehumidification process from buildings

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ABSTRACT

As dehumidification is one of the most important tasks of environment control of the building, it is necessary to know the energy efficiency of dehumidification processes. The energy efficiency can give the energy cost of drawing moisture from indoor air to the outside environment. This paper presents analysis of the ideal cost of dehumidification process by a liquid desiccant cycle. Formulas to calculate ideal efficiency of dehumidification process are obtained, which is determined by indoor temperature, outdoor temperature, and the temperature of the intersection point of the iso-relative humidity line of indoor air and the iso-humidity ratio line of outdoor air. The ideal efficiency of the condensing dehumidification method is lower than the ideal dehumidification process, due to the fact that condensing dehumidification method must dehumidify the air at the temperature of dew point. Results from this paper can be used as theoretical foundation for the further analysis of various dehumidification methods and the development of new dehumidification processes.

1. Introduction

Latent load covers 20–40% of the total air conditioning load. Up till now, there are various kinds of dehumidification methods, such as condensing method, compressing method [1], and adsorption or absorption method [2–4]. Condensing method dehumidifies the air by cooling the air below its dew point, in which moisture being condensed out from the conditioned air. Compressing method dehumidifies the air by compressing it to increase the pressure of the vapor to the saturate pressure and to condense the moisture out. Adsorption or absorption method dehumidifies the air by sorption and regeneration cycle of hygroscopic material including solid desiccant and liquid desiccant [2]. Lazzarin and Castellotti [5] and Li et al. [6] studied the performance of liquid desiccant dehumidification process, in which heat pump was included in the liquid desiccant system. The cooling capacity from evaporator was used to cool liquid desiccant in order to enhance the desiccant's absorption ability, and the heat from condenser of heat pump was used to regenerate liquid desiccant. Similar liquid desiccant system will be adopted in this paper to analyze the dehumidification performance from buildings.

All the dehumidification methods can be regarded as a machine (dehumidification equipment) operating between two humidity sources. Take the dehumidification process from buildings to the outdoor environment as an example, one humidity source is the indoor environment and another source is the outdoor climate. The dehumidification equipment works as a pump to carry humidity between the two sources, which is similar to a heat pump working between two heat sources.

As the Carnot's theorem being used to analyze refrigeration cycle (or heat pump cycle), a similar theorem is required to analyze various dehumidification processes. The condensing method is the most popular dehumidification method, so the cooling capacity of the dehumidification process is usually considered as the thermodynamic input of the process. However, those considerations do not have sufficient theoretical support. As moisture control is one of the most important tasks of environment control of the building, it is necessary to know what the ideal process is and what the ideal efficiency a dehumidification process can achieve. Hence a thermodynamic analysis which tells the ideal efficiency of all the dehumidification methods is needed. The results of the analysis can indicate whether the method can be realized and what efficiency can it achieve.

Based on the basic dehumidification process of removing moisture from buildings to the outdoor environment, this paper focuses on setting up a theorem to analyze the dehumidification process. A simple ideal dehumidification process is then proposed, and the minimum energy input of this process is obtained. Based on the process analysis, formula for the thermodynamic cost of dehumidification process is introduced. The ideal dehumidification process is based on liquid desiccant dehumidification and the analysis extended to the other dehumidification methods. The analysis results are used as guidance for the comparison of various dehumidification processes.

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Nomenclature

C	constant
ΔH_w	vaporization latent heat of water, kJ/kg
P	pressure, kPa
Q	latent heat of dehumidification, kJ
R	gas constant, kJ/(kg K)
T	temperature, K
Δw	humidity source, kg
w	humidity ratio, kg/kg
W	work, kJ
φ	relative humidity, %
η	ideal energy efficiency
η_c	ideal energy efficiency of condensing dehumidification method
$\eta_{compress}$	ideal energy efficiency of compressing dehumidification method
Subscript	
A	indoor air state
L	dew point
v	water vapor
O	outdoor air state

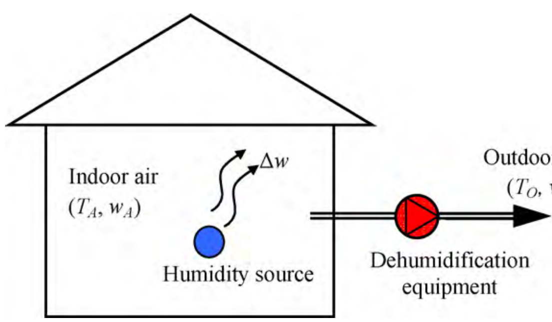

Fig. 1. Model of dehumidification process removing moisture from building to the outdoor environment.

2. Ideal dehumidification process and its efficiency

The process to dehumidify moisture from buildings to outdoor environment is described in Fig. 1, where Δw is the water vapor released by the humidity source of the building. The moisture comes from indoor occupants, plants, wet surfaces, infiltration, cooking, laundry, etc. The states of indoor air and outdoor air are (T_A, w_A) and (T_o, w_o), respectively. The aim of dehumidification process is to remove Δw from indoor air to outdoor environment.

The ideal process requires the minimum energy cost. According to the thermodynamic law, if a process is reversible, it requires the minimum energy input. So the ideal dehumidification process is expected to have neither temperature difference for heat transfer nor vapor pressure difference for moisture transfer.

Liquid desiccant can act as a media for cooling, heating, humidifying and dehumidifying the processed air. The commonly used liquid desiccants include lithium bromide (LiBr) aqueous solution, lithium chloride (LiCl) aqueous solution. The state of liquid desiccant can be shown in the air psychrometric chart by the equilibrium condition [4], that is, the same temperature and the same water vapor pressure. As indicated in Fig. 2, the desiccant iso-concentration line is almost coincident with the air iso-relative humidity line, and the detailed analysis is illustrated in Appendix A. For an arbitrary air state, it is possible to find a liquid desiccant state that has the same temperature and water vapor pressure with those in the air state. So if the area of heat and mass transfer is big enough, it is possible to realize reversible handling process, in which the temperature difference and pressure difference of water vapor are both zero. Other air handling methods such as cooling coil or air washer cannot realize the reversible processes because they can only dehumidify the air along the saturated line.

Some assumptions are made in the following analysis: (1) the enthalpy of condensed or absorbed liquid water is neglected, since the enthalpy of liquid water is much smaller than that of water vapor. The influence of the neglect on the accuracy will be analyzed in the next section; (2) the iso-concentration line of liquid desiccant coincides with the iso-relative humidity line of the air. Further explanation is shown in Appendix A; and (3) the heat and mass transfer processes discussed here are all reversible processes.

Energy consumption of the ideal dehumidification process is influenced by the indoor and outdoor air states. The following discussion is divided into three cases according to the indoor and outdoor air states: (1) indoor air and outdoor air have the same relative humidity, $\varphi_O = \varphi_A$; (2) relative humidity of outdoor air is smaller than that of the indoor air, $\varphi_O < \varphi_A$; and (3) relative humidity of outdoor air is larger than that of the indoor air, $\varphi_O > \varphi_A$.

2.1. Case 1: $\varphi_O = \varphi_A$

When the indoor air state A is on the same relative humidity line as that of the outdoor air state O, the two air states are on the same iso-concentration line of liquid desiccant according to the result of Appendix A. The ideal dehumidification process is shown in Fig. 3, in which a heat pump is introduced between the indoor and outdoor air environment. When indoor air A contacts the liquid desiccant, it is dehumidified. Heat is released during the dehumidification process, and the released heat is then absorbed by the evaporator of the heat pump. The outdoor air can reversibly regenerate the liq-

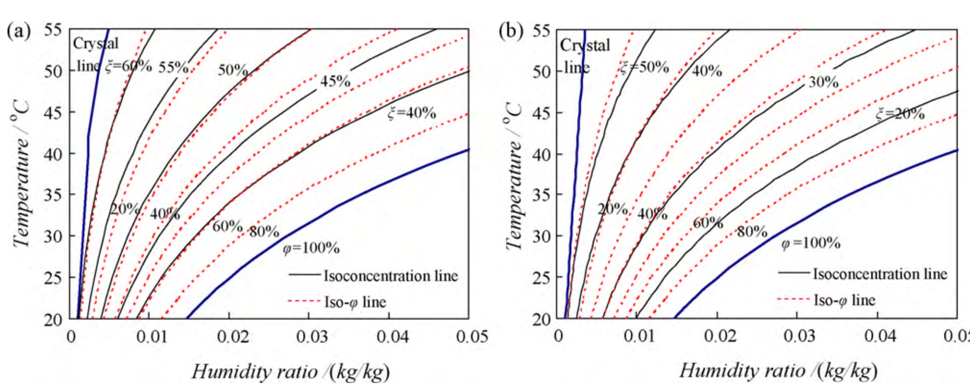

Fig. 2. State of commonly used liquid desiccants shown in the air psychrometric chart: (a) LiBr aqueous solution; and (b) LiCl aqueous solution.