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Investigation on drying performance and alternative analysis of different liquid desiccants in compressed air drying system

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ABSTRACT

Drying performance of a novel compressed air drying method using different liquid desiccants, including LiCl solution, LiBr solution and mixed solutions ($LiCl/CaCl_2$), is compared by experiments. It is found that drying performance of LiCl solution is better than that of LiBr solution. Besides, drying performance of three mixed solutions (44%, 46% and 49%) selected is similar to that of 40% LiCl solution, verifying the feasibility of substituting single solution with much cheaper mixed solution. The water vapor pressure of mixed solutions and LiCl solution is same in experiments, therefore it can be selected as an indicative factor to evaluate substitute of LiCl solution. Moreover, the cost of the three mixed solutions is 18% cheaper than that of 40% LiCl solution at least, which shows significant economization in application. Finally, system performance of the compressed air drying system is analyzed. The dew point of outlet compressed air could reach −7.7 °C at operating pressure of 0.8 MPa, indicating the dryness can satisfy requirement of various industrial applications which used typical electricity-driven cooling-drying method. The solution temperature of regeneration could reach 70 °C, validating that it is feasible to use waste heat recycled from the air compressor to drive solution regeneration.

1. Introduction

Compressed air is widely used in various industries, which accounts for 10% of industrial electricity consumption in the European Union [1–3]. When the humidity ratio exceeds a certain amount in the compressed air, it would adversely affect the production process. For example, it would cause reduced electrical insulation, corrosion of valves and so on. Therefore, drying compressed air has become more and more necessary to satisfy increasing demands of industrial applications in recent years.

At present, solid adsorption dehumidification and cooling dehumidification are two traditional dehumidification technologies, but have following deficiencies. For solid adsorption dehumidification, dehumidifiers would be large which need lots of space to place. Moreover, regenerating solid desiccant requires high-grade heat consumption [4]. For cooling dehumidification, dehumidification only works well when the surface temperature of evaporator is higher than 2 °C. Besides, it would consume huge electricity power [5,6]. Considering the standpoint of energy saving, liquid desiccant used in air dehumidification is widely investigated by many scholars [7–11]. Thus, a novel compressed air drying method using liquid desiccant was proposed in our previous work [12].

Liquid desiccant used in air dehumidification is divided into two categories: organic liquid desiccant and inorganic salt liquid desiccant. Triethylene glycol was used as liquid desiccant at early time, while it was replaced by inorganic salt solution liquid desiccant for its high viscosity and easily volatile property. Though Chen [13] mixed some organic salt with inorganic salt to creature some new liquid desiccants which have nearby surface vapor pressure of pure LiCl solution, some of these mixed solutions still have high viscosity and easily volatile property. The commonly used inorganic liquid desiccants are LiCl, LiBr and $CaCl_2$ [6,14–16]. LiCl and LiBr have low saturated vapor pressure with excellent dehumidification performance [14], while their price is high. The price of $CaCl_2$ is very low, while its dehumidification ability is worse than LiCl and LiBr because of its high saturated vapor pressure. Hence, considering dehumidification ability and price of liquid desiccants, mixed

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Nomenclature

B	atmospheric pressure [Pa]
c_p	specific heat capacity [kJ/(kg K)]
$COST_s$	the cost of solution [$]
$COST_{LiCl}$	the cost of LiCl salt per kilogram [$]
M	mass flow rate [kg/s]
M'_w	moisture removal rate [g/s]
$NRTL$	nonrandom two-liquid
P	pressure [Pa]
P_{st}	saturated water vapor pressure [Pa]
p_v	water vapor pressure [Pa]
Q	energy consumption [kW]
T	temperature [;°C]
V	volume [m^3]
v	velocity [m/s]
w	humidity ratio [g/kg]
X	mass concentration of solution [%]
Greek symbol	
φ	relative humidity of air [RH%]
ρ	density [kg/m^3]
Subscripts	
a	air
com	compressed air
de	dew point
deh	dehumidifier
in	inlet
out	outlet
rec	recovery
reg	regenerator
s	solution

solutions are concerned. Ertas et al. [17] conducted an experimental measurement of some thermal properties of mixed $LiCleCaCl_2$, such as viscosity, vapor pressure and density. Considering the cost effectiveness, they concluded that the $LiCl/CaCl_2$ ratio of 1:1 should be a better choice. Nevertheless, there is still no experimental verification and the solutions with the same vapor pressure were not compared to find a cheaper mixed solution. Zhao et al. [18] compared the dehumidification performance of $LiCl/LiBr + CaCl_2/MgCl_2$ and found mixed solution had better dehumidification performance than single salt solution. However, the mass content of LiCl in mixed solutions was fixed so that an economical mixed solution with less LiCl could not find in their study.

Above study was investigated under atmospheric pressure as the purpose of air conditioning application. Literature survey shows that little study has been conducted on drying performance of compressed air dehumidification using different liquid desiccants. The mass transfer driving force under high pressure is stronger than that under atmospheric pressure. The water vapor pressure of compressed air is higher than that of atmospheric air, thus a bigger water vapor difference between solution and air can be obtained, which strengthens mass transfer driving force. Besides, the increase in pressure enhances the disturbance of the interface between solution and air, which is beneficial for dehumidification. Thus, the characteristic of dehumidification using different desiccants and theirs behavior should be discovered.

This paper presents experimental tests to compare the dehumidification performance of LiCl, LiBr and mixed solutions ($LiCl/CaCl_2$). The possibility of mixed solutions ($LiCl/CaCl_2$) substituting LiCl solution is discussed in the paper. Besides, a test bench of the whole compressed air drying system including dehumidifier and regenerator is established to investigate system performance including drying performance and energy consumption. Moreover, the feasibility of the experimental system, which uses the waste heat from the air compressor to drive liquid desiccant cycle, is verified.

2. Methodology

2.1. Working procedure of the compressed air drying system

Fig. 1 shows working procedure of a drying system of compressed air using liquid desiccant. The system is made up of compressed air treatment process and solution cycle. In the compressed air treatment process, the air compressor compresses the air. The compressed air comes into the air tank and then enters into the pressurized dehumidifier. Finally, the moisture in the compressed air is absorbed by concentrated solution in the pressurized dehumidifier.

In the solution cycle, the diluted solution at the bottom of the pressurized dehumidifier is throttled to atmospheric pressure by the throttle valve, and then comes into the regenerator to be regenerated. The diluted solution is heated by lubricating oil in the air compressor, and the heat recovery device is installed in the air compressor system. The concentrated solution from regenerator is pressurized by pressurized pump, and then comes into the pressurized dehumidifier to dry the compressed air. The inlet solution temperature of pressurized dehumidifier is adjusted by the solution cooler.

2.2. Test bench of the whole compressed air drying system

A test bench of the whole compressed air drying system was established to investigate drying performance and verify the feasibility of using waste heat recycled from the air compressor to regenerate liquid desiccant, using LiCl as desiccant, as shown in Fig. 2. The pressurized dehumidifier and regenerator are core equipment and structure of them is same while the tower body is made up of different materials. The materials of the dehumidifier and regenerator are T316 stainless steel and acrylic respectively. The height and the diameter of the tower body are respectively of 1200 mm and 80 mm. Structured packing is placed in tower body with specific surface area of 500 m^2/m^3, the porosity of 93%, the net height of 800 mm.

In order to control the liquid amount in two solution tanks to make sure the balance, the two liquid tanks are connected by a connecting pipe. The concentration of the solutions in the two solution tanks is substantially equal after the system operates in the steady state, which means dehumidification rate is equal to regeneration rate. Valve V-4 is used to regulate the flow rate of solution into the heat exchanger to control the inlet temperature of solution entering the regenerator.

Measuring points and measuring devices are shown in Fig. 2(b), and all the data is collected into a computer. The compressed air is throttled by the throttle valve to atmospheric pressure, and humidity ratio is kept constant during this process which is measured by dew point meter. Mass fraction of LiCl solution is obtained based on the values of temperature and density of liquid desiccant [19]. Detailed information of different measuring devices can be seen in Table 1.