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Research on ration selection of mixed absorbent solution for membrane air-conditioning system

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ABSTRACT

Absorption air-conditioning system is a good alternative to vapor compression system for developing low carbon society. To improve the performance of the traditional absorption system, the membrane air-conditioning system is configured and its COP can reach as high as 6. Mixed absorbents are potential for cost reduction of the membrane system while maintaining a high COP. On the purpose of finding ideal mixed absorbent groups, this paper makes analysis on COP, cost-effectiveness and economy of the membrane system with mixed LiBr–$CaCl_2$ absorbent solution. The models of the system have been developed for the analysis. The results show the COP is higher for the absorbent groups with lower concentration of the total solute and higher concentration ratio of LiBr. It also reveals when the total solutes concentration is about 50%, it achieves the best cost-effectiveness and the economy. The process of the analysis provides a useful method for mixed absorbents selection.

1. Introduction

To prevent global warming, it is important to reduce CO_2 emission. One way is to reduce the energy consumption from the combustion of fossil fuels, which is the major source of CO_2 emission. The energy consumption in buildings takes up more than 40% of the total energy supply while the air-conditioning system is a leading energy consumer in buildings [1–3]. It is the tendency to make air-conditioning system more energy efficient and less dependent on electric power converted from fossil fuels. The most widely used air-conditioning system is vapor compression system, which heavily depends on the electric power and the refrigerant causes some environmental problems. Absorption air-conditioning system is one promising replacement for vapor compression system. It can be driven by low-grade heat got from renewable energy and the refrigerant is more environment-friendly [4,5].

In general, the performance of absorption system is lower than vapor compression system. On the purpose of performance improvement, many progresses have been made. Some works were about multi-stage absorption and double effect absorption system [6–9]. Combination system is also an effective measure [10]. Gadhamshetty et al suggested a combination system consists of a desalination system and an absorption system [11]. Zheng, Jain, Seyfouri et al made research on absorption–compression system [12–14]. Garousi Farshi, Hong et al made progresses on ejector–absorption combined system [15,16]. Gogoi designed a combined power/cooling cycle to improve the whole performance [17]. Membrane technology is another choice, Wang et al proposed a vacuum membrane distillation method for lithium bromide absorption refrigeration system [18].

The low efficiency of the traditional absorption system is caused by heat waste. We proposed an electric energy driven membrane absorption system to replace the thermal energy driven system [19]. The new system adopts electrodialysis (ED) regenerator instead of generator and condenser for concentrating absorbent solution. Small solar and wind power generators can drive it. The coefficient of performance (COP) could reach 6 under certain working conditions, makes it as competitive as the vapor compression system. COP is influenced by the absorbent variety and the concentration of strong solution [19]. Fig. 1 shows the COP of three common used absorbent solutions within their typical working concentration ranges. Among them, LiBr solution has the highest COP within the same concentration range. However, LiBr is also the most expensive one. To decrease investment without sacrificing COP, mixed absorbent solution (like mixed LiBr–$CaCl_2$ solution) could be a good plan. To test this idea and find an ideal mixed absorbent group, we make analysis on the performance of the system adopting mixed LiBr–$CaCl_2$ solution. The models are developed

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Nomenclature

a_w	activity of water (dimensionless)
Con	mass concentration (%)
COP	coefficient of performance (dimensionless)
F	Faraday constant (s A/mol)
f_w	activity coefficient (dimensionless)
l_w	latent heat of water vaporization (kJ/(kg K))
M_s	molecular weight of the solute in the absorbent solution (kg/mol)
m	mass flow rate (kg/s)
N	cell number (dimensionless)
p	vapor pressure (Pa)
P_{ED}	electric power consumption (kW)
Q_0	cooling capacity (kW)
U	voltage (V)
z	electrochemical valence (dimensionless)

Greek letters

ζ	current utilization (dimensionless)

Subscripts

ED	electrodialysis
LiBr	solute LiBr
$CaCl_2$	solute $CaCl_2$
Li^+	ion Li^+
Ca^{2+}	ion Ca^{2+}
s	solute
w	water

based on the mass and energy balance equations. By applying these models, COP, cost-effectiveness and economic features are calculated for different mixed absorbent groups. Comparisons have been made between these groups, which reveals the better mixed absorbent groups with both good COP and economy. The whole analysis provides a method to conduct any mixed absorbents selection by prediction.

2. Material and method

2.1. System configuration

In the conventional absorption refrigeration air-conditioning system, take LiBr–H_2O system for example, strong solution absorbs water vapor for evaporating cooling. The solution concentration decreases and it needs regeneration to continue the cycle. That is done with generator and condenser, through which both strong solution and refrigerant water are got. In the membrane air-conditioning system, a membrane regenerator replaces the generator and the condenser. The flow chart is described in Fig. 2. The weak solution is sent from the absorber to the regenerator. The regenerator uses ED method to concentrate absorbent solution. In ED method, ions concentrate in specified compartments by selectively passing through the cation exchange membrane (CM) or the anion exchange membrane (AM) [20–22]. Fig. 3 shows the process of ED method: cations are only allowed to pass through CM while anions are only allowed to pass through AM; solution

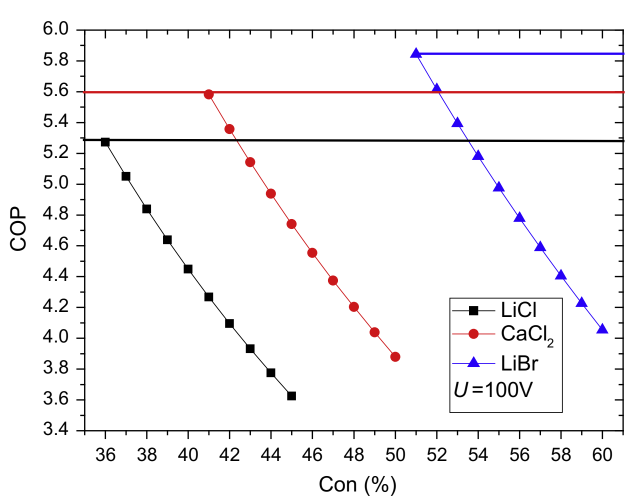

Fig. 1. *COP* variation with different absorbent solutions [19].

is concentrated and diluted in alternating compartments under electrical field. In this way, strong solution is obtained from the concentrated cells of the regenerator and sent back to the absorber. Solution from the diluted cells is sent to Solution Storage Tank 1 or 2 for repeated use and keeps the balance of the mass flow volume. Water storage pool is used to store pure water acquired in the regeneration process [19].

Experiments have been conducted on a small ED regenerator adopting titanium alloy electrodes (Fig. 4). The size of the regenerator is 350 mm × 200 mm × 123.5 mm. The thickness is 123.5 mm, including the membrane pairs, the division plates and the compartments. The membrane type is CMV for cation exchange membrane and AMV for anion exchange membrane (Asahi Glass Co.). The membrane pair number is 25 and the size of a single membrane is 280 mm×160 mm. The effect area of every membrane is 0.021 m^2 under the electric field. The solution concentration was 35% before regeneration. The mass flow rate of the solution was 0.016 kg/s for both the concentrated cells and the diluted cells. The concentration change ΔCon under different voltages is shown in Fig. 5. The results show a steady regeneration of the solution and the concentration change increases with the increasing voltage. With higher voltage, larger size membrane and more membrane pairs, the ED regeneration method can meet the need of the absorption air-conditioning system.

2.2. Mass and energy equations of mixed-absorbents system

In the membrane system adopting mixed LiBr–$CaCl_2$ solution, the absorption process is same as the traditional absorption system. For the absorption process, assume the mass flow rate of the mixed absorbent solution at the absorber entrance is m_1. The concentration of LiBr is $Con_{\mathrm{LiBr},1}$, the concentration of $CaCl_2$ is $Con_{\mathrm{CaCl_2},1}$. Assume the mass flow rate at the absorber exit is m_2. The concentration of LiBr is $Con_{\mathrm{LiBr},2}$, the concentration of $CaCl_2$ is $Con_{\mathrm{CaCl_2},2}$. The amount of the absorbed water vapor is Δm_w per second, the mass balance equations are:

$$m_1 + \Delta m_w = m_2 \tag{1}$$

$$m_1 Con_{\mathrm{LiBr},1} = m_2 Con_{\mathrm{LiBr},2} \tag{2}$$

$$m_1 Con_{\mathrm{CaCl_2},1} = m_2 Con_{\mathrm{CaCl_2},2} \tag{3}$$

For the regeneration process, the mass flow rate of the mixed absorbent solution at the regenerator entrance is m_2, equal to that at the exit of the absorber. The concentration of LiBr and $CaCl_2$ at the regenerator entrance are equal to $Con_{\mathrm{LiBr},2}$ and $Con_{\mathrm{CaCl_2},2}$. The concentrations of LiBr and $CaCl_2$ at the regenerator exit are equal to $Con_{\mathrm{LiBr},1}$ and $Con_{\mathrm{CaCl_2},1}$, which are the concentration at the