Research on the working medium of the absorption air-conditioning system with a new regeneration method

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Abstract. To be environmentally friendly and save energy, absorption air-conditioning system is a good attempt. However, plenty of heat waste in the regeneration limits its performance. For further application, the capacitive deionization (CDI) regeneration method has been proposed which works between the electrode pairs of the capacitor to achieve the interconversion between water and solution. Previous work shows the theoretical COP of the new system could reach up to 6 under certain conditions. Different absorbents have been calculated and experimented in this paper to find a most suitable absorbent to approach the highest possible COP. Different concentrations also has been considered. It is found that the COP of the CDI based system can attain 2 to 3. Experimental results agree well with theoretical results of the tendency of the system performance among different absorbents and different concentrations. There is some difference of the COP because the energy recovery rate in our experiment can not approach 50% which is calculated at 50% theoretically. In practical applications, the COP could be higher with energy recovery of CDI.

1. Introduction
The concepts and technologies of sustainable development of energy, water and environment have been discussed in many researches [1]. In the last decades, the energy consumption of buildings takes up more than 40% of the global energy consumption [2]. The energy supply of air-conditioning system account for 1/3 in buildings [3]. The conventional vapor compression system leads to some environmental problems, such as ozonosphere hole [4]. Absorption air-conditioning system is a good tempt, which can be supported by renewable energy and use water as refrigerant [5].
To improve COP, a capacitive deionization (CDI) method for absorption system has been proposed in our research: strong absorbent solution and pure water are acquired with the joint work of two CDI units so that the deionization and regeneration processes are completed between the electrode pairs of the capacitor [6]. The energy recovery ability of the capacitor has a great benefit to improve the system performance [7]. However, there is only theoretical result while the actual performance of the CDI based absorption system has not been tested [6]. So the paper researches on the theoretical analysis and practical experiment to test the actual performance of the system with different absorbents.

2. Materials and methods

2.1. Principle of the capacitive deionization regeneration system
Figure 1 is the principle of the capacitive deionization and regeneration process. In the deionization process, charging the electrodes, the ions in the salt water will move to the electrodes driven by the electric field force. We can acquire deionized water in the exit. As for regeneration step, along with
canceling the electric supply, the original electric field will disappear so that the ions will release to the deionized water to get salt water again. In this way, using two CDI units, the deionization and regeneration processes can happen at the same time. With this method, the generator and absorber in the traditional absorption system can be instead. The other part of the system is the same with traditional system.

Figure 1. Principle of the capacitive deionization process.

2.2. Mass and energy models of the CDI regeneration process
In the absorption process, assume the mass of the absorbent solution flowing into the absorber per second is \( m_{ia} \). The concentration of the solution is \( Con_{ia} \). And the mass of the deionized water at the outlet of the absorber is \( m_{oa} \). The concentration of it is \( Con_{oa} \). \( \Delta m_{w} \) is the mass flow rate of the absorbed water vapor. In the regeneration process, \( m_{ir} \) is the mass flow rate of the absorbent solution flowing into the regenerator. \( Con_{ir} \) is the concentration of it. \( m_{or} \) is the mass flow rate of the regenerated solution at the outlet of the regenerator. The concentration is \( Con_{or} \). \( \Delta m_{s} \) is the amount of the ions released from electrodes. \( Con_{ia} \) and \( Con_{or} \) are equal; \( Con_{oa} \) and \( Con_{ir} \) are equal. The mass balance equations are:

\[
\begin{align*}
    m_{ia} + \Delta m_{w} &= m_{oa} & (1) \\
    m_{ia} Con_{ia} &= m_{oa} Con_{oa} & (2) \\
    m_{ir} + \Delta m_{s} &= m_{or} & (3) \\
    m_{ir} Con_{ir} + \Delta m_{s} &= m_{or} Con_{or} & (4)
\end{align*}
\]

As for the energy supply to the deionizer, there’s the equation between \( \Delta m_{s} \) and current:

\[
\frac{\Delta m_{s}}{M_{s}} = \frac{\lambda I}{zF}
\]

(5)

\( \lambda \) is the charging efficiency. \( P_{de} \) is the energy demand. \( U \) is the supplied voltage. The total energy need for the CDI based system (\( P_{CDI} \)) is:

\[
P_{CDI} = P_{de} - P_{rec}
\]

(6)

The COP of the CDI based system is:
\[ \text{COP} = \frac{Q_e}{P_{CDI}} = \frac{I_w \Delta m_w}{P_{de} - P_{rec}} = \frac{I_w \Delta m_w}{(1 - \eta) P_{de}} = \frac{I_w \Delta m_w}{z F \Delta m U (1 - \eta)} = \frac{I_w (1 - \text{Con}_{\text{des}}) \lambda M_{S}}{z F U (1 - \eta) \text{Con}_{\text{des}}} \]  (7)

2.3. Experimental system

We have designed a system to test the deionization and regeneration process. Figure 2 shows the simplified circuit of it. First, open valves 1 and 3. The initial solution with certain concentration flows through the CDI unit driven by the pump with energy supply. The absorbed solution flows out is stored in the Deionized Solution Storage Tank. When the number displayed by the conductive meter is stable, it means the absorption ability of the CDI unit approach its highest limitation. Previous work finds the process lasts for 20 minutes. Then close valves 1 and 3 and open 2 and 4. Power off the CDI unit. The deionized solution flows through the unit. We can get regenerated solution at the outlet and store it in the Regenerated Solution Storage Tank.

3. Results and discussion

3.1. Theoretical performance of the CDI based system

![Figure 3. Theoretical COP of different absorbent systems.](image-url)
With Eq. (7), COP can be calculated and the performance can be analyzed with different absorbents. Figure 3 presents the COP with different absorbents. COP changes along with the concentration of the regenerated solution. And the COP is higher with lower concentration. Because, the solution with low concentration doesn’t need so much solutes added to it and reduce the energy demand in the absorption process. Within their respective working concentration ranges, the system COP with LiBr is the highest, which can reach 2.5. The COP with CaCl$_2$ is second, which is between 1.6 and 2.4. COP with LiCl is the last one, but it still can approach 2.18. The COP of the CDI based system with four absorbents is all better than traditional absorption air-conditioning system.

3.2. Experimental results

![Figure 4. Experimental performance of different absorbent systems.](image)

We can get the COP of the three systems, which are shown in Figure 4. The energy consumption of LiBr system is the highest, but its performance is still the best because its salt regeneration capacity is significantly higher than others. The COP of CaCl$_2$ system is also good because its salt regeneration capacity and energy consumption both are at a good level. According the usual working concentration of absorbents in traditional air-conditioning, LiBr system has the best performance in our experiment, which can approach above 2. It is a little lower than the theoretical result, but still higher than traditional system.

3.3. Discussion

CDI based system is a good alternative to improve the performance of absorption air-conditioning. Compared with traditional absorption system, it avoids the heat waste during the regeneration process and reduces the electric demand.Activated carbon is the widely used material of electrodes, which only costs about 0.89 dollars/m$^2$. It is very cheap. The most importantly, CDI based system has better performance. In our experimental system, the COP can reach up to 2. The energy recovery ability is a large advantage. By changing the electrode material and completing the energy recovery model, the energy recovery ability can be improved to get high COP of the system.

4. Conclusion

CDI based absorption system has been proposed to improve the performance. It has big advantages compared to the traditional absorption system. Some theoretical analyses have been carried out before. However, there is few experiment on the specific performance with different absorbents. So theoretical and experimental researches of different absorbents (LiBr, LiCl and CaCl$_2$) have been done in this paper. According to the mass and energy model, the theoretical performance of different absorbents has been
acquired. It is found that all the systems with the four absorbents have good performance. COP of LiBr system is the highest, which can attain 2.5 with 50% energy recovery ratio. It is worth mentioning that it can be much higher due to the energy recovery ability. Although the other three absorbent systems are not as good as LiBr system, their COP can also reach 2 in certain working conditions.

Experiments have been made to test the actual performance among different absorbent systems. The results show that previous theoretical results have certain reliability. With our experimental facility, LiBr system still has the highest salt regeneration capacity and COP, which can approach 1.94 under its usually worked concentration. While ensuring the ability to absorb water vapor in the absorber, properly reducing the concentration of the salt solution can increase the COP.

5. References
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