Experimental study on regeneration performance of the heat localization method for absorption air-conditioning system

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Abstract. Due to serious energy shortage, it is urgent to reduce energy consumption from burning of fossil fuels. Driven by low-grade heat, absorption system is a promising energy conservative air-conditioning system for buildings. However, the main obstacle is the poor performance as a result of the energy waste in conventional thermal regeneration process. With the aim of performance improvement, a heat localization method is proposed for the regeneration process of absorption system. It can improve energy utilization efficiency through thermal energy localization on the evaporation surface. Preliminary experiments have been conducted to test the regeneration performance with this new method. Some parameters have been investigated with the experimental data. Moreover, by comparison between the heat localization method and traditional heating method, it indicates the energy utilization efficiency with the heat localization method are 1.8 to 2.8 times higher than that with the traditional heating method. The performance of the system has been greatly improved. The energy utilization efficiency of the regeneration process can reach 36.9% under certain working conditions. With the performance improvement, the popularization of absorption system will be promoted.

1. Introduction
Energy is essential for humans and the energy shortage has limited the development of economy and society. With the demand increase on energy, efficient utilization of energy is not an unattractive option to solve the increasingly serious energy problem. Buildings account for about 40% of the world’s total energy consumption while the air-conditioning system contributes to the largest share of building energy consumption [1], [2]. As a result, an efficient air-conditioning system is critical for energy problem-solving. Nowadays the vapor compression air-conditioning system has been widely used because of its high performance. However, it is driven by electric power and brings a great burden to the grid. Therefore, a promising alternative is absorption air-conditioning system, which can be driven by low-grade heat. The low-grade heat can be obtained from renewable energy (e.g. solar energy) and industrial waste heat (e.g. flue gas from coke ovens) [3], [4]. Nevertheless, the main drawback is that the performance of absorption system is relatively low compared with vapor compression system. It is mainly because too much energy has been wasted in conventional thermal regeneration process. After regeneration process, absorbent solution is relatively hot because it contains much unutilized thermal energy. A large portion of the input energy is used for heating absorbent solution rather than regeneration. Moreover, the high temperature of absorbent solution is harm to the following absorption process. So regenerated absorbent solution needs to be cooled down to a low temperature. The thermal energy contained in regenerated absorbent solution not only reduces the energy utilization efficiency in regeneration process but also needs to be removed by consuming excess energy, which leads to a poor performance of the whole system. To solve this problem, the membrane regeneration method and the
capacitive deionization regeneration method have been used to improve the regeneration performance of absorption system [5], [6]. The regeneration process can be essentially considered as a desalination process, so these two methods can be applied to the regeneration process. Besides, the heat localization method is an appropriate method as well.

Chen et al. [7] proposed a solar steam generation approach and corresponding material structure using heat localization. Through heat localization method, thermal energy is localized on the evaporation surface and thus the heat loss to bulk liquid can be minimized [8]. In other words, the heating of bulk liquid is significantly reduced, and the temperature of bulk liquid can maintain at a low level. The decrease of energy waste will lead to a high energy utilization efficiency [9]. In recent years, many researches on heat localization method have been made: Kaur et al. [10] have developed an all-ceramic microfibrous solar steam generator to obtain clean water efficiently. Xia et al. [11] have proposed a new type of porous photothermal material based on halloysite nanotubes and graphene oxide mixture composite materials for efficient solar steam generation.

The heat localization method localizes thermal energy on the evaporation surface and thus minimizes the heat loss to bulk liquid. On account of the energy waste in conventional thermal regeneration process, the performance of absorption system is poor. With the use of heat localization method, absorbent solution can keep a low temperature after regeneration. It not only reduces the thermal energy contained in regenerated absorbent solution but also avoids cooling of regenerated absorbent solution, resulting in a higher performance of the whole system. Up till now, previous researches on heat localization method mainly concentrate on materials with high solar absorption ability and corresponding experiments are almost based on pure water [12], [13]. There is no research on absorbent solution based on heat localization method, which is critical for absorption system. The absorbent solution is different from pure water and previous research conclusions are not applicable for absorbent solution. The evaporation of water from solution is harder than from pure water and solution has stronger absorption capability with the increasing concentration. In addition, no one apply the heat localization method to other energy sources except solar energy. The change of energy source can make a difference to corresponding experimental device, which must be changed to fit the alternative energy source. They have the same principle, but the actual performance is unknown. So it is meaningful to reveal the actual performance of absorption system with heat localization method.

In this paper, we propose and test a heat localization method based absorption system. The regeneration process can be driven by low-grade heat source. For convenience, electric power is used to simulate the heat source. The experiments based on heat localization method and traditional heating method have been conducted respectively. In terms of experimental data, preliminary analysis has been made. Compared with traditional heating method, regeneration process with heat localization method has a higher energy utilization efficiency. The high regeneration performance of absorption system makes it a promising air-conditioning system.

2. Material and method

2.1. Principle of the absorption air-conditioning system

The absorption air-conditioning system is one of the oldest air-conditioning systems, which can be driven by low-grade heat. Figure 1 presents the schematic diagram of traditional absorption air-conditioning system. The main process of this system is: when adequate heat is added to the generator, the strong solution and the refrigerant vapor are obtained in regeneration process. Then the refrigerant vapor is condensed in the condenser, and the liquid refrigerant expands to a low-pressure level through the expansion valve. Next, the liquid refrigerant is evaporated in the evaporator and takes heat away to achieve refrigeration. Meanwhile, the acquired strong solution from generator is cooled in solution heat exchanger, and then expands to a low-pressure level through the expansion valve. After that, the strong solution is sent to the absorber. It is diluted to the weak solution as a result of the absorption of refrigerant vapor. Before return to generator, it is heated preliminarily in solution heat exchanger. The above cycle can repeat to achieve refrigeration continuously.
The regeneration of absorbent solution costs the most energy in absorption system, which can be driven by low-grade heat source. However, too much energy has been wasted in conventional thermal regeneration process, which causes a poor performance of the whole system. The reason for that is because absorbent solution is relatively hot after regeneration, which means the input energy is not used to the full. In addition, the hot absorbent solution needs to be cooled down to a low temperature because the absorbent solution with lower temperature has a better absorption ability. The thermal energy contained in regenerated absorbent solution not only reduces the energy utilization efficiency in regeneration process but also needs to be removed by consuming excess energy. Therefore, it is necessary to improve the regeneration process of absorption system.

2.2. Principle of the heat localization method
Chen and his colleagues first proposed efficient solar steam generation approach with the use of heat localization [7]. The heat localization method brings a high energy utilization efficiency of solar steam generation because it localizes the thermal energy on the evaporation surface, which minimizes the heat loss to bulk liquid [8]. The temperature of bulk liquid can maintain at a low level during evaporation and thus the energy waste in bulk liquid is reduced. The representative heat localization structure is composed of a solar absorber layer and a thermal insulation layer (figure 2). The solar absorber layer absorbs incident solar light and converts it into thermal energy for evaporation. The thermal insulation layer should have a low thermal conductivity, which reduces the heat loss to bulk liquid. There are many channels in both the solar absorber layer and the thermal insulation layer, which wick adequate liquid from the bulk liquid to the evaporation surface under capillary action for continuous steam generation. In such a structure, the solar energy utilization efficiency can reach 84.6% at a light density of 1 kW/m² [15]. The heat localization method will have a great influence in many practical applications including absorption system.

Figure 1. Schematic diagram of traditional absorption air-conditioning system [14].

Figure 2. Schematic diagram of the representative heat localization structure [8].
The heat localization method can achieve efficient utilization of energy by localizing the thermal energy on the evaporation surface. This method reduces energy waste in heating bulk liquid and maintains bulk liquid at a low temperature during evaporation. It can be applied to the regeneration process of absorption system. Through heat localization method, the temperature of regenerated absorbent solution can maintain at a low level. The heat localization method not only reduces energy waste in heating absorbent solution but also avoids excess energy input to cool regenerated absorbent solution, which will significantly improve the performance of absorption system.

2.3. Experimental system
The regeneration process of absorbent solution costs the most energy of absorption system, which plays a vital role in the whole system. Natural wood possesses many advantages for application in heat localization structure, including excellent hydrophilicity, self-floating ability, natural microchannels and low thermal conductivity [16], [17]. We used cunninghamia as the basis of heat localization structure. The process of making heat localization structure involves two steps: wood was cut into cylindrical piece with 4 cm diameter. Then the electric heating wire as the heat source was uniformly distributed onto a cunninghamia cylindrical piece which acts as the thermal insulation layer and the liquid transport channel. The heat localization structure was showed in figure 3. In the heat localization regeneration device, heat localization structure was placed in the beaker with the volume of 20ml absorbent solution (figure 4). We chose LiCl solution as absorbent solution and tested the regeneration performance with different concentrations. The mass of absorbent solid and deionized water were measured with a high-accuracy balance (FA1004, Liangping Co., Ltd), whose accuracy was ±0.5%. It was also used to detect the solution mass change in regeneration process, which was recorded every ten seconds in fifty minutes. The energy input was 1.5W, which was supplied by a DC regulated energy source (MP1350D, Maihao Co., Ltd) with the accuracy of ±0.5%. The experiment with traditional heating method has been conducted to compare with that with heat localization method. Compared with heat localization method, the major change is that the heat localization structure is replaced by electric heating wire. It directly heated the whole absorbent solution in regeneration process. With these experimental devices, the actual evaporation rate in regeneration process has been acquired and thus energy utilization efficiency of these two methods can be obtained.

2.4. Performance estimation of the experimental system
The performance of absorption system largely depends on regeneration process, which can be measured in terms of energy utilization efficiency. The energy utilization efficiency $\eta$ can be calculated as:

$$\eta = \frac{Q}{P} = \frac{lm}{U}$$

(1)

$Q$ is the utilization of energy of the experimental system, $l$ is the latent heat of water vaporization, and $m$ is the evaporation rate of water. $P$ is the input power of the experimental system, $U$ is the voltage,
and $I$ is the current intensity. The energy utilization efficiency of the experimental system can be calculated by using equation (1).

## 3. Results and discussion

### 3.1. Experimental results

The regeneration process has great impact on the performance of absorption system. A series of experiments have been carried out to test the actual performance of regeneration process. Figure 5(a) presents the evaporation rate of LiCl solution with the mass concentration of 25%. The evaporation rate with the heat localization method did not have obvious change, which kept stable after a slight increase at the beginning. Correspondingly, the evaporation rate with traditional heating method increased significantly in the first 25 minutes, then it became stable. Overall, the evaporation rate with heat localization method was higher from beginning to end. The evaporation rate of LiCl solution (the mass concentrations are 25%, 30%, 35%) are shown in figure 5. The evaporation rate of these two methods appeared significantly drop with the increasing concentration. The reason for that is because the solution has stronger absorption capability with the increasing concentration, so it is harder to evaporate water from solution. Even in this case, it was obvious that the evaporation rate with heat localization method was higher than that with corresponding traditional heating method.

![Graphs showing evaporation rate with different concentrations](image)

(a) mass concentration of 25%  
(b) mass concentration of 30%  
(c) mass concentration of 35%

**Figure 5.** The evaporation rate of LiCl solution with different concentrations.

### 3.2. Energy utilization efficiency of the experimental system

The energy utilization efficiency can reflect the performance of regeneration process, which has a great impact on the performance of absorption system. The energy utilization efficiency of LiCl solution is
calculated and the results is shown in figure 6. The change rules and reasons of energy utilization efficiency were the same as that of evaporation rate. The energy utilization efficiency with heat localization method was higher than that with traditional heating method. The energy utilization efficiency with both methods decreased with the increasing concentration of solution. When the regeneration process was stable, the energy utilization efficiency with heat localization method reached 36.9% with the mass concentration of 25%. The average energy utilization efficiency with heat localization and traditional heating method were 35.9% and 20.4% respectively. Compared with traditional heating method, the average energy utilization efficiency improvement achieved 76.3%. When the mass concentration was 35%, the average energy utilization efficiency with heat localization method was only 21.2%. However, the improvement also achieved 180.1%.

Figure 6. Energy utilization efficiency of the experimental system.

3.3. Discussion
The performance of traditional absorption system is poor because of energy waste in conventional thermal regeneration process. This problem can be solved by applying the heat localization method in regeneration process. The heat localization method in regeneration process has a high energy utilization efficiency. The reason for that is mainly because the thermal energy is localized on the evaporation surface and thus reduces the heat loss to bulk liquid. The temperature of regenerated absorbent solution can maintain at a low level, which not only reduces energy waste in heating absorbent solution but also avoids the cooling of regenerated absorbent solution.

4. Conclusions
Experimental researches of the regeneration process have been made with heat localization and traditional heating method. The results indicate heat localization method greatly improves the energy utilization efficiency, which means the performance of the whole system is further improved. When the regeneration process was stable, the energy utilization efficiency with heat localization method can reach 36.9% with the mass concentration of 25%. The energy utilization efficiency with heat localization method are 1.8 to 2.8 times higher than that with traditional heating method. The regeneration performance of absorption system is significantly improved with heat localization method. The heat localization method has been proved to be an effective method for absorption system. Further works will focus on finding the most suitable absorbent for heat localization method.

5. References
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