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Performance of a Diesel Locomotive Waste-Heat-Powered Adsorption Air Conditioning System

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Abstract. An innovative exhausted-heat-powered solid adsorption air conditioning system with zeolite-water as working pair is designed for providing air-conditioning for the driver's cab of a diesel locomotive. Only one adsorber is used in the system and a cold storage water tank is attached to provide cooling during generation process to ensure the continuous cooling output. Experiments on the laboratory prototype have been carried out and a mean cooling power output of about 3.3 kW is obtained when the condensing temperature and the evaporating temperature are 40°C and 7°C respectively. The influences of some operating conditions on the system performance are analyzed by simulation and experiments. The results of the performance testing of the prototype installed in a diesel locomotive are also discussed as well. An average cooling power of 4.1 kW is got under typical summer condition. It is proved that such a system is quite competitive even if a little bit heavier.

Keywords: adsorption, zeolite, air conditioning, exhausted heat, diesel locomotive

1. Introduction

Solid adsorption air conditioning system, which utilizes natural substance as refrigerant and exhausted heat as driving force, has drawn more and more attention since the 1990s. Two-bed adsorption chillers with silica gel-water working pair powered by hot water have been successfully commercialized in Japan (Boelman et al., 1995). Both experimental and theoretical studies have been undertaken by many others, especially the adsorption cooling systems for automobile/engine waste heat recovery with zeolite-water working pair. Because the exhausted gases from internal combustion engines of automobiles or locomotives have a temperature of 400 to 600°C usually, it can be easily utilized as the regeneration source of an adsorption system with the working pair of zeolite-water.

Zhu et al. (1992) measured the cooling capacity of a waste heat driven adsorption chiller in a diesel engine powered fishing boat and the temperature variation of the zeolite adsorbent bed. Suzuki (1995) studied the effects of heat transfer coefficient on the cooling power of a passenger car theoretically for a waste heat driven adsorption air conditioning system. An experimental intermittent adsorption cooling unit driven by the exhausted heat from a diesel engine is also presented by Zhang (2000). In order to improve the heat transfer of adsorption systems utilizing waste heat, a working pair of composite adsorbent (zeolite and expanded natural graphite) -water used in heat recovery cycle system was designed by Poyelle et al. (1996). It was driven by combustion gas and the anticipated COP is 0.8 with the specific cooling power of 300 W/kg.

However, there are still no reports about the practical applications of zeolite-water adsorption air conditioners powered by engine exhausted heat. Results of a comparison (Aceves, 1996) indicate that the adsorption air conditioner is inferior to vapor compression system for electric vehicle application. Nevertheless such an adsorption system, normally being large

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and heavy, is particularly advantageous to provide air-conditioning for diesel locomotives in developing countries. In China, there are more than 7000 diesel locomotives in use now, and few of them are equipped with air conditioning systems.

One adsorber adsorption refrigeration system cannot provide cooling continuously. Two methods can be adopted to solve the problem. The first one is to install two adsorbers. Each of them shifts their working phases (adsorption or desorption) to get continuous adsorption cooling. The second one is to attach a cold storage tank to the system so as to provide cooling even if during desorption process due to the enough cold storage. In the latter case, the exhausted heat is used intermittently, and the total cooling production during the adsorption process is greater than the cooling output because a part of it must be stored to cool the water or other coolant in the cold storage tank. Compared with the widely investigated multi-adsorber system, study on adsorption refrigeration system with cold storage is rarely touched upon, which is, nevertheless, simpler and easier to manipulate.

In this paper, a one-adsorber adsorption air conditioner system with cold storage is studied. Experiments on the performance of the system installed in a locomotive is analyzed.

2. System Setup and Description

The laboratory experimental setup of the adsorption air conditioning system is indicated in Fig. 1 and Fig. 2 shows the photograph of the system. In the laboratory system, an oil burner is used to provide high-temperature fume gas. The main parts of the closed-cycle adsorption refrigeration system consist of one adsorber, one condenser, one reservoir, one evaporator and one cold storage tank. Zeolite-water combination is selected to be the working pair.

The operation of the adsorption refrigeration system is a periodic succession of adsorption and desorption processes. While the adsorbent is heated up, the refrigerant vapour is desorbed and condensed in the condenser, and then the condensed liquid is transferred into the evaporator. The refrigerant vapour is readsorbed by the adsorbent when the latter is cooled down. Obviously a basic adsorption refrigeration cycle can not provide cooling during generation process. So there is a cold storage tank in the presented system, in which the partial refrigeration load can be stored during adsorption process and then released during generation process.

To intensify the heat and mass transfer of the adsorbent bed, the heat exchanger, composed of a number of copper-finned stainless steel tubes, was specially designed. A schematic diagram of the cross section of the adsorber is shown in Fig. 3. The adsorber has a length of 1000 mm, a width of 1500 mm and a height of 450 mm. Heating or cooling fluid flows through the internal channels of the tubes. A total of 140 kg of 13X zeolite grains (average diameter: 3 mm) is packed between the fins of the tubes, while the total metal mass of the adsorber is about 260 kg.

A plate heat exchanger cooled by water is used as the condenser. The evaporator and the cold storage tank are combined in one device and separated by a baffle

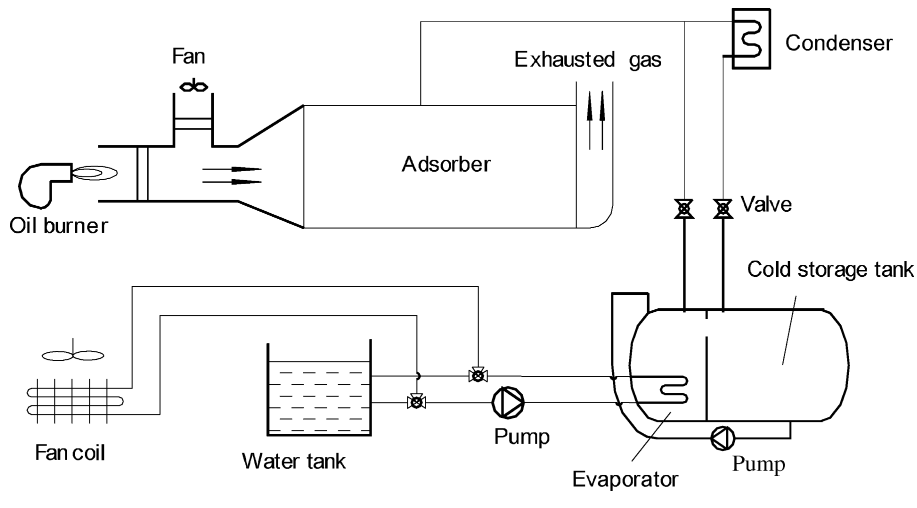

Figure 1. Schematic of the experimental setup.

Figure 2. Photograph of the experimental setup.

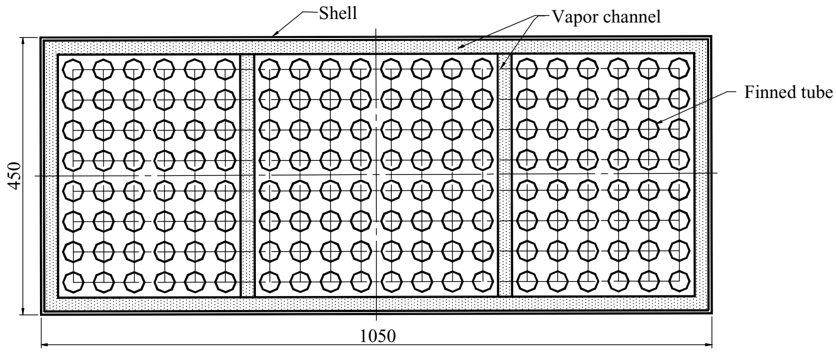

Figure 3. Cross section of the adsorber.

between them. The adsorber, the evaporator and the cold storage tank are filled with 185 kg of water which functions not only as refrigerant but also as the coolant medium for cold storage. A small pump is attached to ensure water circulation between the evaporator and the cold storage tank during the cold charging and discharging periods.

The chilled water may go either into an ordinary air-conditioning installation or into a water buffer tank after leaving the evaporator, where it is heated by a water-water heat exchanger. Experimental results indicate that the water buffer tank is preferably selected to be a dummy load instead of a fan coil, for the heating power of the former can be easily controlled by an electric heater. Thus the temperature of the chilled water is fine-tuned to the level required at the chiller's inlet.

The temperature of the heat exchanging fluid is measured at the entrance and the exit of the heat exchanger, while the temperature within the adsorber is measured at 7 locations. Also the temperatures of the vapor surrounding the adsorber and in the evaporator and condenser are observed from several thermal couples. Beside the temperature, pressures are also measured in the adsorber, the condenser and the evaporator respectively.

3. Main Equations Used to Analyze the Experiments

3.1. *Dubinin-Astakhov (D-A) Equation*

D-A equation is widely adopted to describe the adsorption of water on zeolite at equilibrium status, which is expressed as (Wang, Wu, Dai et al., 2002)

$$x = x_0 \exp\left(-k\left(\frac{T}{T_s} - 1\right)^n\right) \tag{1}$$

where the adsorption capacity x represents the concentration of refrigerant adsorbed in bed at temperature T and pressure p, x_0 is the saturated adsorption capacity, T_s is the saturated temperature at bed pressure p, and both k and n are the adsorption parameters depending on the material of the adsorbent-refrigerant pair.

3.2. Energy Balance Equations

The heat power input is expressed as the following:

$$\begin{aligned} q_{\text{in}} &= \dot{m}_{\text{gas}} \cdot c_{p,\text{gas}} \cdot (T_{\text{gas,in}} - T_{\text{gas,out}}) \\ &= m_z \cdot (c_{p,z} + x \cdot c_{p,w}) \cdot \frac{dT}{dt} + m_{\text{st}} \cdot c_{p,\text{st}} \cdot \frac{dT_{\text{st}}}{dt} \\ &\quad + m_z \cdot Q_{\text{ads}} \cdot \frac{dx}{dt} + q_{\text{loss}} \end{aligned} \tag{2}$$

The four parts on the right of the above equation indicate respectively the sensible heat variation of the adsorbent and the refrigerant adsorbed, the sensible heat variation of the steel tubes, the generation heat and the heat losses dissipated to the environment. The heat loss of the adsorber is a function of the bed temperature and the ambient temperature, which can be determined through experiments.

The total thermal energy input is calculated as

$$Q_{\text{in}} = \int q_{\text{in}} \cdot dt \tag{3}$$

3.3. Refrigeration Capacity and Cooling Output

The experimental cooling power output is calculated from the measured temperature difference of the inlet and outlet of the chilled water multiplied by its flow rate and specific heat.

$$P_{\text{exp}} = \dot{m}_{\text{chil}} c_{p,w} (T_{\text{chil,in}} - T_{\text{chil,out}}) \tag{4}$$

And the total cooling capacity is

$$Q_{c,\text{exp}} = \int P_{\text{exp}}\, dt \tag{5}$$

The mean cycle cooling power output is then expressed as

$$P_{\text{mean}} = \frac{Q_c}{t_{\text{cycle}}} \tag{6}$$

where the cycle time t_{cycle} includes the heating and the cooling time.

The theoretical cooling power can be simulated with D-A equation

$$P_{\text{theo}} = m_z \cdot \frac{dx}{dt} \cdot (q_{fg} - c_p(T_{\text{cond}} - T_{\text{ev}})) \tag{7}$$

And the total cooling capacity can also be simulated simultaneously.

$$Q_{c,\text{theo}} = m_z(x_1 - x_2)(q_{fg} - c_p(T_{\text{cond}} - T_{\text{ev}})) \tag{8}$$

where q_{fg} is the evaporation heat of water, and x_1 and x_2 are the adsorption capacities at the process the adsorption and desorption states respectively.

3.4. Coefficient of Performance (COP)

The COP of the system is calculated as

$$COP = \frac{Q_c}{Q_{\text{in}}} \tag{9}$$

4. Experimental Results and Analysis

In the following experiments, the mass flow of the oil burned during heating process is about 14 kg/h, and the volume flow of the heat transfer fluid is about 700 m^3/h for fume gases and 1200 m^3/h for cooling air respectively.

4.1. Adsorption Isobars

The adsorption isobars of the zeolite-water have been shown in Fig. 4, in which the saturated pressures corresponds to the saturated temperatures 10°C, 34°C and 45°C respectively. According to the experimental data, the simulated equilibrium adsorption capacity can be expressed as

$$x_{\text{eq}} = 0.261 \cdot \exp(-5.36(T/T_s - 1)^{1.73}) \tag{10}$$

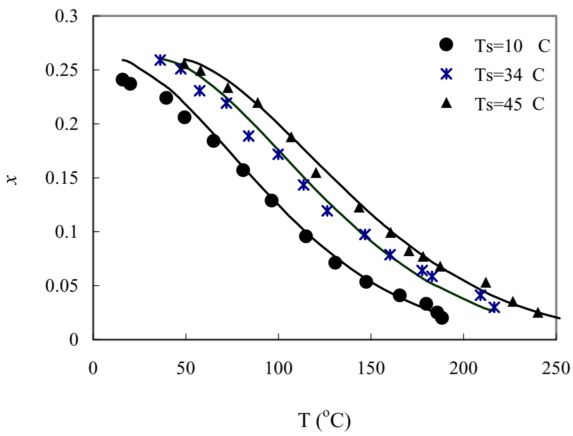

Figure 4. Adsorption capacity isobar of zeolite-water.

Because the operating cycle time of the experimental system is considerably long, its adsorption characteristics are close to those at equilibrium status. Therefore, it is reasonable to adopt the D-A equation in the study of the performance of the system.

4.2. Temperature of the Heat Source and the Adsorbent Bed

Figure 5 shows the temperature of the inlet and outlet of the heat transfer fluid (fume gases or air) and the mean temperature of the adsorbent bed varied with running time, when the generation temperature T_g and the adsorption temperature T_a are at 200°C and 80°C respectively.

Before heating, the temperature of the oil burner is closed to the ambient temperature, so the inlet temperature of the fume gases is very low at the beginning of heating, which results in the considerably long cycle time and is viewed as a disadvantage of the experimental setup. In real application unit, this disadvantage will be avoided due to the continuous fume gases supply.

4.3. Analysis of the Processes of Experimental Cycle

4.3.1. p-T-x Diagram. An ideal adsorption refrigeration cycle consists of four processes: heating, desorption, cooling and adsorption, shown as the course A-B, B-C, C-D and D-A in the *p-T-x* diagram in Fig. 6. The desorption and adsorption processes follow isobars, and the heating and cooling processes follow isosteres (constant adsorption capacity). The experimental results, also shown in the figure, coincide with the theoretical data well, except that the pressure of the adsorbent bed is difficult to maintain constant in experiments.

4.3.2. Desorption Process. At the beginning of the process, the valve between the adsorber and the condenser is kept closed until the pressure of the two parts

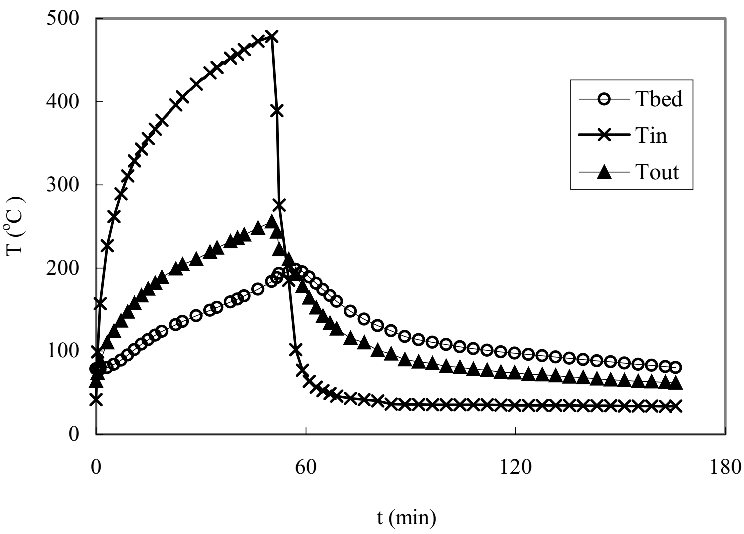

Figure 5. Temperature of the inlet and outlet of the working fluid and the average temperature of the adsorbent bed varied with running time.

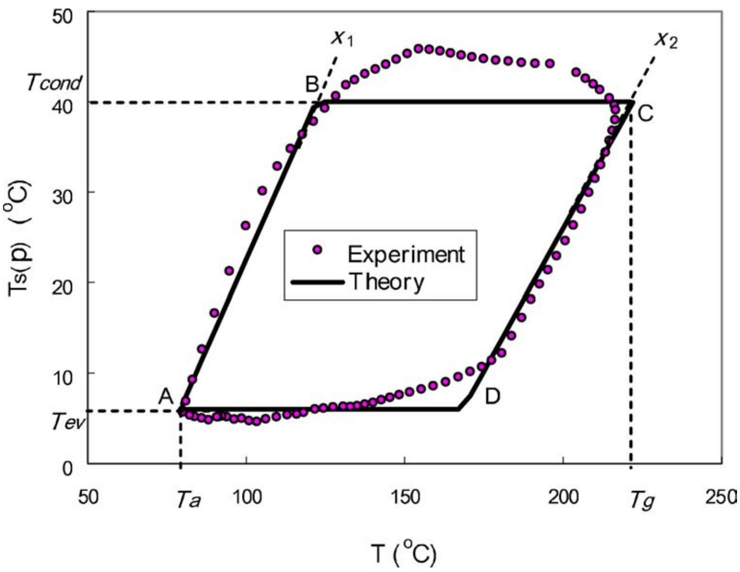

Figure 6. p-T-x diagram of an operating cycle.

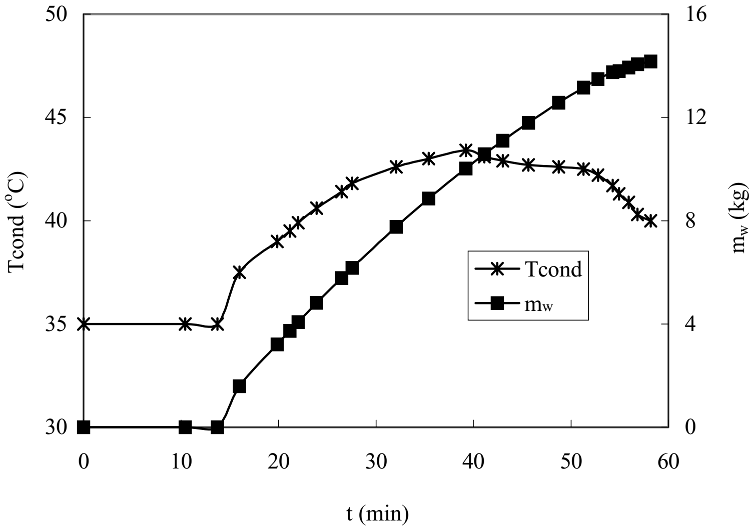

Figure 7. Condenser temperature and mass of condensed water varied with heating time.

is equal. Figure 7 shows the condensing temperature T_{cond}, defined as the saturated temperature corresponding to the condenser pressure, and the mass of condensed water m_w obtained in the reservoir during the desorpation process. At the late stage of the desorption process, the water increase in the reservoir becomes slower.

4.3.3. Adsorption Process and Cooling Output. In comparison with the desorption process, the adsorption process lasts much longer. The reason is that the temperature difference between the adsorbent bed and the heat transfer fluid is less than that of the desorption process, and, the adsorption rate is slower than the desorption one for a zeolite-water adsorption system since the adsorption process occurs at a relatively low pressure.

Figure 8 shows the relationship among the cooling power output, the water temperature of the evaporator and the cycle time. During the heating and desorption process, the cooling output is achieved due to

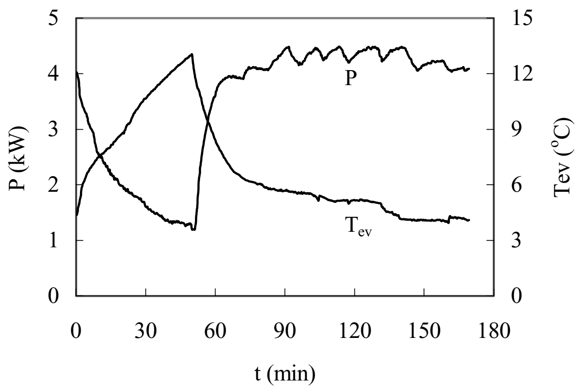

Figure 8. Cooling power and evaporator temperature varied with running time.

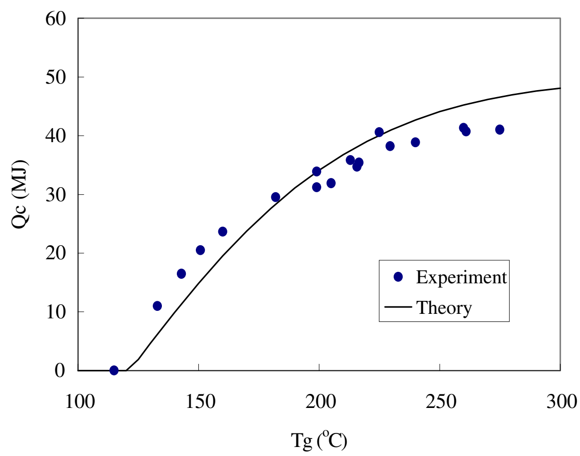

Figure 9. Influence of generation temperature on cooling capacity.

the temperature rise of the chilled water in the storage tank and the evaporator. During this period, the cooling power is only about 1.8 kW. Therefore, it is necessary to increase the cooling power during heating –desorption processes of the experimental system, either by enlarging the cold storage tank or by enhancing the heat and mass transfer of the adsorber.

At the beginning of the adsorption process, the cooling power output increases slowly for a part of cooling capacity have to be used to reduce the water temperature in the evaporator. Then the cooling power increases rapidly to more than 4 kW lasting for about one and a half hour. During the cooling and adsorption process, the mean cooling power is about 4 kW, while in the whole cycle the mean cooling power is 3.3 kW with a cycle COP of 0.25.

4.4. *Influence of the Generation Temperature and Adsorption Temperature*

The generation temperature of the cycle T_g is assumed as the mean bed temperature when the heat transfer fluid at the inlet and outlet of the adsorbent bed reaches the temperature at the end of generation process, for there are no heat exchange between the fluid and the adsorbent bed during that period. Similarly, at the end of cooling process, the adsorption temperature T_a is considered as the mean bed temperature when the fluid at the inlet and outlet of the bed reaches the temperature.

The cooling capacities of the system at different generation temperatures are shown in Fig. 9, when T_a, T_{cond} and T_{ev} are 80°C, 40°C and 7°C respectively. The cooling power and the cycle COP of the system are shown in Fig. 10. The solid line in Fig. 9 denotes the theoretical value calculated according to Eq. (8). There is no cooling output until the generation temperature exceeds a minimal required generation temperature, $T_{g\min}$, which is 120°C in the figure. The cooling capacity increases with the increase of generation temperature when the latter is greater than $T_{g\min}$. According to the figure it can be seen that in a wide range of generation temperature when it is higher than 150°C, the cooling power and COP vary little and maintain almost at 3 to 3.5 kW and 0.21 to 0.25 respectively. However, when the generation temperature is too high, the cooling power and COP both decrease resulting from the increase of the cycle time and the heat dissipation.

The discrepancy between the theoretical and experimental cooling capacity is shown in Fig. 9. When the generation temperatures are comparatively low, the experimental values will be higher and cooling may be produced below $T_{g\min}$. The main reason lies in the nonuniform bed temperature. That is to say, the temperatures in some parts of the bed are high enough to desorb the water within them, although the mean bed temperature is low. On the other hand, the experimental values are lower than the theoretical ones at comparatively high generation temperatures. This is because the generation of water from the adsorbent is non-equilibrium for the experimental cycle, which results in the less water desorbed from the bed.

Figure 11 shows the cooling capacity and cooling power of the system varied with adsorption

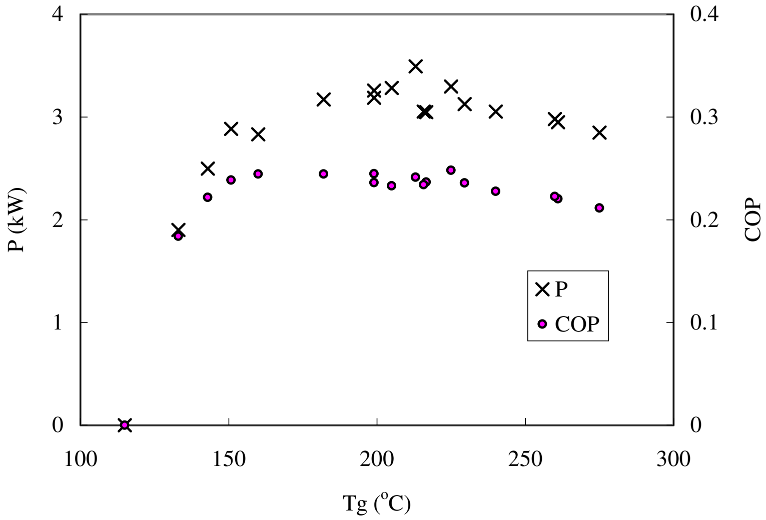

Figure 10. Cooling power and COP varied with generation temperature.

temperature, when T_g, T_{cond} and T_{ev} are 200°C, 40°C and 7°C respectively. It is obvious that the cooling capacity is greater at lower adsorption temperature. However, the average cooling power is not always higher at a lower adsorption temperature, because the heat transfer of the adsorber is poor when the adsorbent temperature is close to that of the ambient. Both the experiments and simulated results shown in Fig. 11 indicate that the optimal adsorption temperature is about 77°C to ensure a best cooling power under the aforementioned condition. This optimized value may be varied with the variation of generation temperature. And the maximal cooling power can be obtained when the adsorption and generation temperatures are about 80°C and 230°C respectively, while the mean cooling power output is about 3.5 kW with the cycle COP being 0.25.

4.5. *Influence of Evaporating Temperature and Condensing Temperature*

Figures 12 and 13 show respectively the experimental cooling capacity at different evaporating temperatures and condensing temperatures, when T_g and T_a are 200°C and 80°C respectively. T_{cond} in Fig. 12 and the T_{ev} in Fig. 13 are 40°C and 7°C respectively.

According to the figures, the cooling capacity is greater at higher T_{ev} and lower T_{cond}. Cooling capacity increases by 1.5% while T_{ev} increases by 1°C or T_{cond}

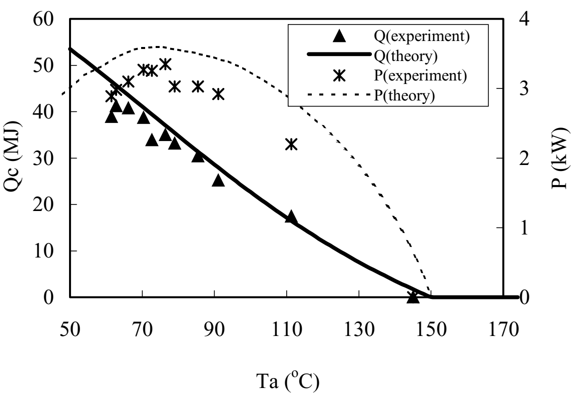

Figure 11. Influence of adsorption temperature on cooling capacity and cooling power.

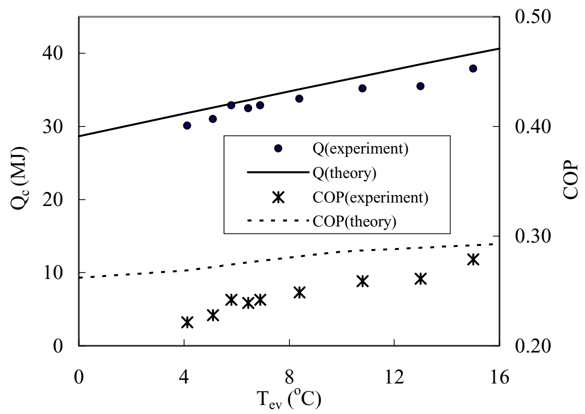

Figure 12. Influence of evaporating temperature on cooling capacity and COP.

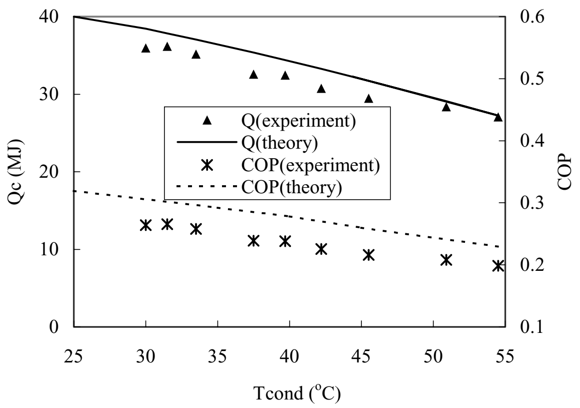

Figure 13. Influence of condensing temperature on cooling capacity.

decreases by 1°C. The experimental results show that the influence of T_{ev} and T_{cond} on the performance of zeolite-water refrigeration system is not so significant as on those with other working pairs. Comparatively good performance of the system can be achieved even when the condensing temperature is as high as 55°C. This is because of the nonlinear adsorption of water on zeolite, that is, the pressure has little impact on the adsorption capacity, which can hardly be realized with other working pairs, such as activated carbon-methanol and silica gel-water (Cho and Kin, 1992). Therefore the zeolite-water system presents particular advantages in the case that the condensing temperature is relatively high, for example air conditioning for locomotive or automobile, where an air-cooled condenser is normally used.

4.6. *Analysis of the Heat and Mass Transfer of the Adsorber*

Heat transfer intensification is one of the keys to the adsorption refrigeration development. The research activities in this field mainly aim at the improvement of the heat and mass transfer inside the adsorber bed (Guilieminot et al., 1993). However, the heat transfer between the working fluid and the walls of the adsorbers is also significant and cannot be neglected, especially when the adsorber is heated or cooled with fume gas or air respectively.

The heat the adsorber obtained from the working fluid can be expressed as following:

$$\begin{aligned} q &= \dot{m}_{\text{fluid}} \cdot c_{p,\text{fluid}}(T_{\text{fluid,in}} - T_{\text{fluid,out}}) \\ &= \alpha \cdot A \cdot (T_{\text{fluid,mean}} - T_{\text{bed,mean}}) \end{aligned} \tag{11}$$

From the above equation, the heat transfer coefficient α between the fluid and the adsorbent can be calculated. α may also be separated into two parts: the heat transfer coefficient of the fluid, α_{fluid}, and that of the adsorbent bed, α_{bed}.

$$\frac{1}{\alpha} = \frac{1}{\alpha_{\text{fluid}}} + \frac{1}{\alpha_{\text{bed}}} \tag{12}$$

In the typical working condition of the present system, the mean heat transfer coefficient α calculated according to Eq. (12) is 12 W/mK during desorption process and 15 W/mK during adsorption process. The α_{fluid}, calculated from the equation under condition of inner-tube convection, is 16 W/mK for fume gas and 20 W/mK for air. The heat transfer coefficient is lower during desorption mainly because of the lower flow rate of the fume gas. Obviously the thermal resistance of the heat transfer mainly exists in the gas side. Thus the influence of the thermal conductivity of the adsorbent is not so significant as that of the systems powered by liquid heat transfer fluid. To enhance the performance of the present system, more consideration must be given to the heat transfer coefficient of the working gas other than that of the adsorbent bed.

Qualitative analyses of the mass transfer of the adsorbent bed have been studied experimentally during an adiabatic adsorption process shown as Fig. 14. Such a process is helpful for producing cooling when there is no cooling air passing through the adsorber. Before the experiment, the adsorbent bed was cooled down while the adsorption capacity remains at a small value after a generation process. The adiabatic adsorption starts with the opening of the valve between the

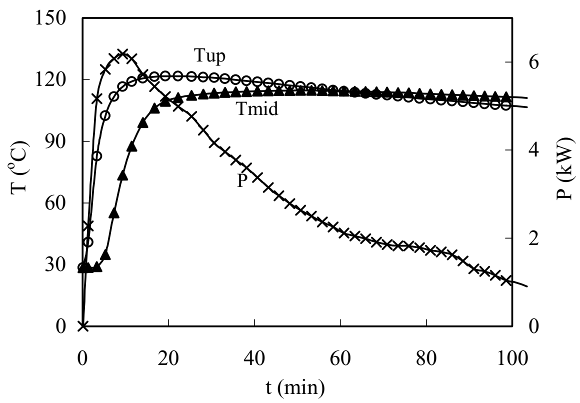

Figure 14. Variation of adsorbent temperature and cooling power during an adiabatic adsorption process.

adsorber and the evaporator, simultaneously there is no heat transfer fluid passing through the adsorber. Then the latent heat of adsorption transfers into the sensible heat of the adsorbent bed, which results in the increase of the adsorbent temperature. As is shown in Fig. 14, T_{up}, the temperature of the adsorbent which is at the upside of the adsorber and adjacent to the vapor channel, increases quickly. However, T_{mid}, the temperature of the adsorbent which is at the middle of the adsorber and at a distance from the vapor channel, increases not as quick as T_{up} (about 10 minutes time lag). The experiment indicates that the flow of refrigerant vapor inside the zeolite-packed bed is blocked to some extent. Therefore the mass transfer of the adsorber is needed to be improved.

5. Application of the System for Locomotive Air Conditioning

An adsorption air conditioning system similar to the experimental prototype mentioned above has been installed in a diesel locomotive to provide cooling for the driver's cab. During the generation process, the adsorber is heated by the fume gas exhausted from the internal combustion engine instead of an oil burner. In addition the condenser installed on the upside of the locomotive is cooled by ambient air. The locomotive runs between Shanghai and Hangzhou, both of which locate in the east of China. The running time is about 2 hours and there is an intermission of several hours between two runs.

The operating test begins with adsorption process, that is, the valve between the adsorber and the evaporator is open at the startup of the locomotive when the temperature of the adsorbent bed is comparatively low. Simultaneously the adsorbent bed is cooled by the ambient air. Due to the water vapor adsorption on the adsorbent, the bed temperature increases while the evaporator temperature decreases rapidly. Consequently, the pump, which circulates the chilled water running between the evaporator and the fan coil, is switched on when the evaporator temperature is low enough. Thus the temperature of the cab drops down by the chilled water circulation through a fan coil.

The variations of the adsorbent temperature, the evaporator temperature, the chilled water temperature and the output refrigeration power with the running time are show in Figs. 15 and 16 respectively. During the test, the temperature of the air-conditioned cab was kept at 25°C in most of the time, while the ambient temperature was at about 33°C. The refrigeration power was more than 4 kW during most of the adsorption process, which lasted for one and a half hours. After that, the adsorbent bed was heated by the high-temperature exhausted gas and the refrigerant was regenerated from the bed. The generation temperature was near 350°C and the condensing temperature was 65°C after the generation process lasted for 30 minutes.

During the generation process, the air-conditioning of the cab was realized by the cold discharge of the sensible heat of the water in the evaporator and the cold storage tank. As a result the evaporator temperature increased rapidly. However, the cooling power

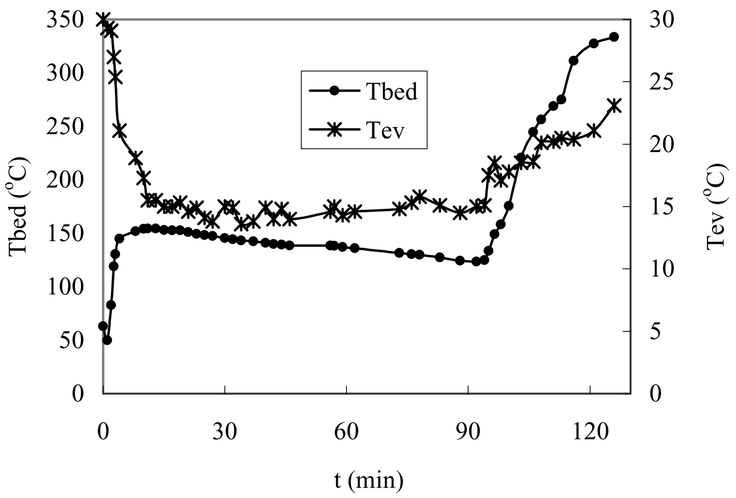

Figure 15. Variation of adsorbent temperature and evaporator temperature for locomotive air-conditioning.

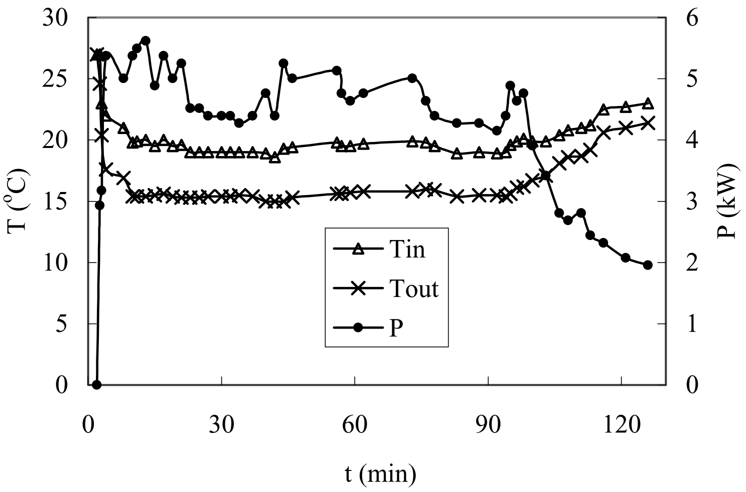

Figure 16. Variation of the temperature of inlet and outlet of the chilled water and the output refrigeration power for locomotive air-conditioning.

output during the cold discharging process was less than that during the adsorption process. The average cooling power for the whole running time was 4.1 kW. It was also found that the temperature fluctuation of the driver cab was about 1°C, which is usually satisfied in such air conditioning system.

There were some drawbacks of the system. Firstly the air flux through the adsorbent bed in very small, which resulted in the poor heat transfer between the air and the adsorbent bed. Therefore the adsorption temperature at the end of adsorption process was up to 120°C, which results in considerably low cooling power output. Secondly the mass transfer in the adsorbent bed was also very poor as aforementioned. The enhancement of the heat and mass transfer will be regarded for the further improvement on the system, so as to get a higher cooling power or reduce the volume and mass of the adsorber.

6. Conclusions

Experimental studies have shown that the one-bed adsorption refrigeration cycle with cold storage presented in this paper is considerably simple and efficient to provide cooling output when it was applied for the diesel locomotive air conditioning. The optimized ratio between the heating time and the cooling time can be available for such a system, which enhances the cycle performance compared with multi-bed adsorption refrigeration system. An average refrigeration power of about 4.1 kW is obtained for the prototype, which is good enough to make the driver's cab comfortable. However the heat and mass transfer of the adsorber is needed to be improved to get a better performance.

Nomenclature

A	Area of heat transfer surface (m^2)
COP	Coefficient of performance
c_p	Specific heat (Jkg^{-1} K^{-1})
k	Constant
m	Mass (kg)
$\dot{m}$	Flow rate (kg/s)
n	Constant
p	Pressure (Pa)
p	Cooling power (W)
q_{ads}	Adsorption heat (J kg^{-1})
q_{fg}	Latent heat of evaporation (J kg^{-1})
q_{in}	Heat power input (W)
Q_c	Cooling capacity (J)
Q_{in}	Heat input (J)
T	Time (s)
T	Temperature (K)
x	Adsorption capacity
x_0	Saturated adsorption capacity
x_1	Adsorption capacity at the end of adsorption process
x_2	Adsorption capacity at the end of generation process
α	Heat transfer coefficient (Wm^{-2} K^{-1})

Subscripts

a	Adsorption
cond	Condenser
chil	Chilled water
ev	Evaporator
exp	Experimental value
fluid	Heat transfer fluid
g	Generation
in	Inlet
mid	Middle
out	Outlet
st	Stainless steel
theo	Theoretical value
up	Upside
w	Water
z	Zeolite

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