Theoretical and Experimental Research on a novel adsorption refrigerator based on low temperature geothermal water

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Abstract. In view of the problems existing in adsorption refrigeration based on low temperature geothermal water, the adsorbent with high mass transfer performance was prepared by carbonization activation method. The specific methods are as follows: firstly, Chinese fir sawdust is immersed in calcium chloride solution, then taken out and dried, and the mixture is carbonized and activated at high temperature to form a porous activated carbon/calcium chloride composite adsorbent, and then expanded graphite is added to enhance the thermal conductivity of the composite adsorbent. The results show that: The proportion of calcium chloride in the composite adsorbent can be significantly increased by carbonization activation method, which makes the composite adsorbent have abundant microporous structure and uniform element distribution. The thermal conductivity of the composite adsorbent can be improved by adding expanded graphite.

1. INTRODUCTION

There are still a lot of low temperature geothermal water available in the world. The energy efficiency of thermal power generation is usually only 40%. Most of the heat energy in the energy system is discharged in the form of waste heat at 70-500°C. In our country, the waste heat emission at 100-200°C is equivalent to the standard coal, which reaches tens of millions of tons every year. In addition, there are still a lot of solar and geothermal energy to be studied and developed.

Solid adsorption refrigeration, as a green and energy-saving refrigeration technology, can effectively utilize a large number of low and medium temperature waste heat, renewable energy (such as solar energy, geothermal tail water, etc.) to drive, reduce the consumption of high-grade energy such as electricity. In addition, adsorption refrigeration uses natural refrigerants, such as ammonia, water, methanol and so on. It does not destroy CFCs and HCFC, nor does it have the problem of greenhouse effect. Therefore, solid adsorption refrigeration conforms to the general trend of coordinated development of energy and environment, and has broad application prospects.

Compared with vapor compression refrigeration system, adsorption refrigeration has a series of advantages, such as simple structure, less one-time investment, low operating cost, no moving parts, long service life, no noise, no environmental pollution, and can effectively utilize low-grade heat sources. Its application site is almost unlimited. Compared with the absorption refrigeration system, the adsorption refrigeration system does not have crystallization and fractionation problems, and can be used in vibration, tilt or rotation occasions. However, the size of adsorption refrigeration system is often too large, which limits its development and application.
2. Materials and Methods

The working pair of the adsorbent refrigeratory developed in this paper is activated carbon/calcium chloride/expanded graphite-ammonia. The system operates under positive pressure, which is conducive to mass transfer of the system and is not easy to leak. Therefore, the reliability of the system operation should be considered in design. In view of the fact that the reliability of the adsorption refrigeration system is related to the number of valves in operation, and drawing on the design experience of silica Gel-Water chiller of Xidian Air Conditioning Co., Ltd., Japan, an activated carbon/calcium chloride/expanded graphite-ammonia adsorption refrigeration machine was developed.

The refrigerator adopts single adsorption bed, single evaporator and single condenser structure, forming a working chamber of intermittent refrigeration and carrying out a basic refrigeration cycle. There is no valve connection between adsorbent bed and condenser, adsorbent bed and evaporator. The cross-section area from adsorbent bed to condenser and adsorbent bed to evaporator is large, which is conducive to mass transfer. The adsorption bed, evaporator and condenser are installed in a cylindrical cavity filled with 11.78 kg ammonia. In order to facilitate maintenance, flange connection is adopted between the cavity cover and the cavity body. In order to arrange the components in the refrigerator compactly and reasonably, the arrangement of evaporator, adsorption bed and condenser in the vacuum chamber is arranged vertically in the lower, middle and upper parts. The arrangement not only meets the requirement of compact arrangement, but also makes the condensate have a certain liquid level in the distributor, which makes the distribution uniform. Because the mass transfer channel between the adsorbent bed and each heat exchanger is a cavity with large flow cross section, the flow rate of ammonia vapor and the pressure drop of the vapor are reduced, thus the loss of refrigeration capacity of the refrigeration unit is reduced. The whole refrigeration system of the refrigerator consists of hot water system, cooling water system and chilled water system. Two processes are needed to complete a cycle of the developed adsorption refrigerator: (1) adsorption refrigeration process. In this process, valves 1, 3 and 5 are opened and valves 2 and 4 are closed. Cold water passes through the adsorption bed to take away the adsorption heat of the adsorption bed; the adsorbent in the adsorption bed absorbs ammonia vapor from the evaporator to maintain the low pressure in the evaporator, so that ammonia liquid evaporates continuously in the evaporator to produce refrigeration effect, and the resulting cooling capacity is taken away by the frozen water for users to use. (2) Desorption and condensation process. In this process, valves 3 and 5 are closed and valves 1, 2 and 4 are opened. The adsorption bed is heated by hot water, from which the ammonia previously adsorbed is desorbed. The desorbed ammonia gas is condensed by a condenser with condensed water, and the condensed ammonia liquid flows to the evaporator through a strip hole on the liquid collecting tray installed under the condensation tube.

3. Results and Discussion

Desorption/adsorption time is an important parameter affecting the refrigeration performance of adsorption refrigerators. In this experiment, the adsorbent used in the refrigerator has the best
performance when the adsorption time is 15 minutes, so the adsorption time is set at 15 minutes when
the influence of desorption/adsorption time on the refrigerator is investigated. The effects of
desorption time on the desorption/adsorption time are emphatically investigated, i.e., 30/15, 25/15,
20/15, 15, 10/15 and 5/15 minutes. The heat source of the adsorption refrigeration system comes from
the electric heater, and the temperature of the hot water output will fluctuate slightly. The temperature
of the heat source referred to later is approximate temperature. When the influence of cycle time on
adsorption refrigeration unit is investigated, the change of heat source temperature does not affect the
experimental results.

The effect of desorption/adsorption time on the performance of refrigerators is shown in Fig. 2.
Under the conditions of evaporation temperature, cooling water temperature, heat source
temperature and adsorption time of 5, 30, 90 oC and 15 min respectively, when the desorption time is 5, 10, 15, 20,
25 and 30 min, the refrigeration power is 517, 627.6, 639.1, 664.2, 617.4 and 547.8 W, respectively.
As shown in Fig. 5.1, the refrigeration power increases first and then decreases with the increase of
desorption time, reaching its maximum value when the desorption time is 20 minutes.

![Fig.2 Effects of the desorption time on the cooling power](image)

Desorption temperature is another important operating parameter. Generally, the higher the heat
source temperature of the system is, the faster the heating rate of the adsorbent bed is and the higher
the desorption rate is. Therefore, the higher the refrigeration power is under the same cycle. However,
the COP of the system has an optimal heat source temperature. As the increase of heat source
temperature makes the adsorption bed work better in the same cycle, it will inevitably improve the
SCP of the system. However, the increase of heat source temperature also increases the heating
capacity of the system, which does not necessarily increase the COP of the system.

Fig. 3 shows the variation of the refrigeration power of the composite adsorbent with the
temperature of the heat source under the conditions of 40 min cycle time, 5 evaporation temperature
and 30 condensation temperature, respectively. Under these conditions, the refrigeration power of the
refrigerator reaches 173.9, 284.1, 451.29 and 542.54W when the heat source temperature reaches 65,
75, 85 and 95%. It can be seen from the diagram that the refrigeration power of the adsorption
refrigerator increases with the increase of the temperature of the heat source. This is mainly because
the driving force for ammonia desorption from calcium chloride comes from the difference between
the temperature of the heat source and the desorption temperature. The larger the difference, the faster
and more sufficient the ammonia desorption from the adsorption bed, and the stronger the adsorption
capacity of the adsorbent.
4. CONCLUSION
A new type of adsorption refrigeration unit was developed with activated carbon/calcium chloride/expanded graphite obtained by carbonization activation method as adsorbent and ammonia as refrigerant. The factors affecting the performance of refrigerators during the operation of refrigerators are investigated and the following conclusions are drawn:

1. In this adsorbent refrigerator, the design of silica Gel-Water adsorbent refrigerator which has been commercialized is used for reference. The adsorbent bed, evaporator and condenser are integrated in a closed cavity. There is no valve connection between the adsorbent bed and evaporator, and between the adsorbent bed and the condenser, which improves the airtightness and effectiveness.
of the device. In fact, after the system is built, the cumulative running time is up to two months, during which there is no leakage phenomenon, and the refrigeration performance of the system has not been attenuated.

2. The desorption/adsorption time has a great influence on the performance of refrigerators. Improving the temperature of heat source is an important method to improve the performance of adsorption refrigerators. The higher the temperature of heat source, the higher the refrigeration power of the refrigerators.

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References
[1] Carquefou N. Experimental results of a zeolite - water heat pump cycle process[C]. Solid Sorption Refrigeration Sym , France :Paris ,1992. 112～117.
[2] Tchernev D I. The use of zeolite for solar cooling[C]. Proceedings of the Fifth International Conference on Zeolites ,London : England ,1980.788～794.
[3] Motoyuki S. Application of adsorption cooling system to auto mobiles[C]. Proc of the Symposium: solid sorption refrigeration ,France :Paris ,1992. 1541～1559.
[4] Wang L W, Wang R Z, Wu J Y, Wang K, et al. Adsorption ice makers for fishing boats driven by the exhaust heat from diesel engine: choice of adsorption pair [J]. Energy Convers Manage, 2004; 45: 2043–2057.
[5] Wang L W, Wang R Z, Wu J Y, et al. Compound adsorbent for adsorption ice maker on fishing boats[J]. Int J Refrig , 2004; 27: 401–408.
[6] Iloeje O C, Ndili A N, Enibe S O. Computer simulation of a CaCl2 solid adsorption solar refrigerator[J]. Energy. 1995; 20(11):1141–1151.
[7] Noeje O C. Parametric effects on the performance of a solar - powered solid adsorption refrigerator. Solar Energy ,1988 ;40 (3) :191～195
[8] Wang K, Wu J Y, Wang R Z, et al. Composite adsorbent of CaCl2 and expanded graphite for adsorption ice maker on fishing boats [J]. Int J Refrig 2006;29:199–210.
[9] Mauran S, Lebrun M, Prades P, Moreau M, Spinner B, Drapier C. Active composite and its use as reaction medium [P]. US Patent 5,283,219. 1994.
[10] Wang L W, Wang R Z, Wu J Y, et al. Research on the chemical adsorption precursor state of CaCl2–NH3 for adsorption refrigeration [J]. Sci China Ser E 2005;48(1):70–82.
[11] Vasiliev L L, Mishkinis D A, Antukh AA, et al. Resorption heat pump[J]. Appl Therm Eng 2004;24:1893–1903.