EXPERIMENTAL RESEARCH ON INFLUENCE OF OPERATING PARAMETERS ON SYSTEM PERFORMANCES FOR A CONTINUOUS HEAT REGENERATIVE ADSORPTION HEAT PUMP

Wu Jingyi, Wang Ruzhu, Xu Yuxiong
Institute of Refrigeration and Cryogenics, Shanghai Jiao Tong University, Shanghai, P.R.China

Abstract

Operating parameters include heat source temperature, cooling water temperature, cycle time and stroke of flow control valve, etc. Though analyzing the experimental data, influences of the operating parameters on Clapeyron diagram, SCP and COP have been asserted. And causes of the influence are also analyzed. A series of conclusions are obtained. The work laid a foundation for optimum operation of the system.

KEYWORDS

adsorption heat pump, operating parameters, system performances, experimental research

INTRODUCTION

In a continuous heat regenerative adsorption heat pump, parameters effecting system performances mainly include desorption temperature, adsorption temperature, condensing temperature, evaporating temperature and cycle time, etc. Desorption temperature is influenced by heat source temperature, and adsorption temperature and condensing temperature influenced by cooling water temperature, but evaporating temperature will be set according to requirements. Therefore, factors effecting the system operation include heat source temperature, cooling water temperature and cycle time. In addition, in the continuous heat regenerative system, the flow control valve also plays an important role. In research on this respect, many experts[1-6] have discussed influence of system operating parameters on system performances.

In this paper, Influences of the system operating parameters, such as heat source temperature, cooling water temperature, cycle time and stroke of flow control valve, on Clapeyron diagram and specific cooling power (SCP) and coefficient of performance (COP) are discussed through analyzing experimental data. And causes of the influence are also analyzed. A series of conclusions are obtained. The work laid a foundation for optimum operation of the system.

DESCRIPTION OF THE CONTINUOUS HEAT REGENERATIVE ADSORPTION HEAT PUMP

In recent years, we have developed a continuous heat regenerative adsorption heat pump using actived carbon-methanol. Fig.1 shows schematic of the system.

The system consists of two parts. The first part includes two adsorbers, heater and cooler, equivalent of compressor in traditional refrigerator. One adsorber discharges vapor into condenser under high temperature and high pressure while another adsorber adsorbing vapor from evaporator under low temperature and low pressure. In this way, adsorbent keeps evaporating and refrigerating, and alternatively desorbing and adsorbing condition of the two beds thus realizes continuous refrigerating. The second part includes condenser, flow control valve and evaporator, similar with the common refrigerator. After adsorbent vapor under high temperature and high pressure is cooled in condenser, and then goes through the flow control valve, it will change into liquid under low temperature and low pressure. The liquid enters into the evaporator for evaporating and refrigerating, and the evaporated adsorbent vapor will be absorbed again by the adsorber.

Heat source of the system adopts electronic boiler of 30kW, which can provide hot water from 70° to 110°. The adsorber and the condenser are cooled by cooling water. Output of cooling power is finished by two fan-coils through cycle of chilling water.

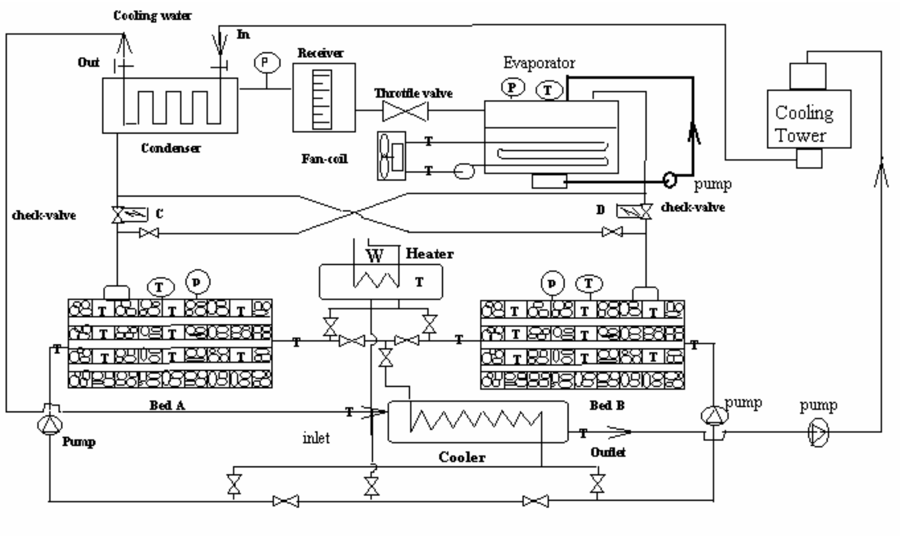


Fig.1 Schematic of the continuous heat regenerative adsorption heat pump

According to working medium, the system can be divided into four loops:

(i).Heating and cooling loop of adsorber, power of the system, supplying driving heat source for the system and discharging heat into environment; (ii).Cooling water loop, guaranteeing the systems quickly discharging heat into environment; (iii).Refrigerant loop (methanol is used as refrigerant in this system), refrigerant recycling in the loop in different conditions and providing cooling power by evaporating in the evaporator; (iv).Chilling water loop of the evaporator, ensuring output of cooling power in the evaporator and stabilizing evaporating temperature.

In the system, the adsorber adopts shell and tube heat exchanger, condenser uses plate type heat exchanger, and evaporator is spray type.

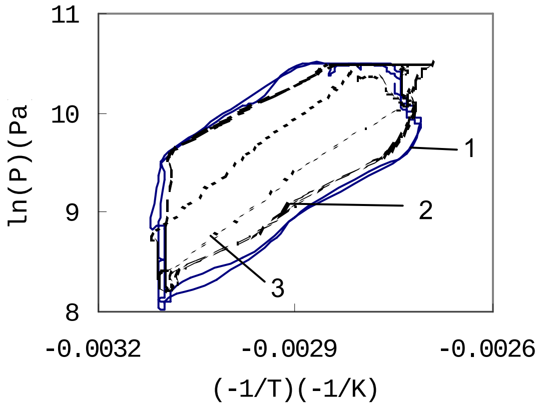
CYCLE TIME AND SYSTEM OPERATING PERFORMANCE

Cycle time is an important operating parameter of the system. Generally, the shorter cycle time, the greater the cooling power. But if cycle time is too short, by analyzing from dynamic angle, adsorbent will have no time for heating or cooling to a certain temperature, therefore no enough temperature to finish desorption and adsorption process. Analyzed from the angle of non-balance adsorption, if adsorbent has no enough time for adsorption and desorption process, adsorber will not be able to perform its capacity. In this way, cooling power will decrease within a single cycle time, which will also influence SCP and COP. Therefore, for using the system potential to the full extent, selection of cycle time is very important. Both the cooling power and time needed for adsorption and desorption process shall be taken into consideration, which is related to heat transfer and mass transfer properties as well as performance of condenser and evaporator.

Cycle time and Clapeyron diagram of system operation

Figure 2 shows Clapeyron diagram of real operation with a 30-minute, 40-minute and 50-minute cycle time. When cycle time is 30 minutes, the system does not finish enough desorbing and adsorbing due to the limited desorption time. As the cycle time increases, the system cycle improves, with desorption and adsorption capacity increasing continuously. Claperyron diagram with cycle time of 40 minutes and 50 minutes are more similar to each other than that of 30 minutes. It is thus proved that with increasing of desorption and adsorption time, adsorber's work are closer to cycle limit under such working condition, and desorption and adsorption capacity will reach maximum as time increases. Therefore, it is foreseen that Clapeyron diagram will not change much when cycle time is greater than

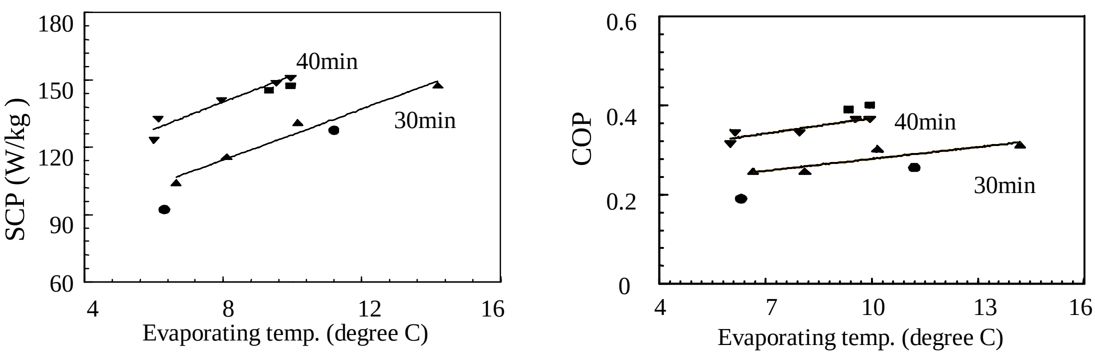
50 minutes. As far as fully using the adsorber's operating capability is concerned, it is more reasonable to select a 40-minute cycle time than a 30-minute cycle time. However, SCP is related not only to the adsorption capacity of each cycle of the adsorber, but also to cycle time, therefore, during the system operating, adsorber's adsorption capacity in each cycle shall be ensured, meanwhile, the cycle time shall be shortened as much as possible. It's in fact optimization of developing adsorber's capability and selecting cycle time. In order to obtain an optimum COP, adsorber shall be guaranteed a better operation. Condition required for improving adsorber operation guarantee a certain cycle time. But a higher SCP cannot be gained with a longer cycle time. Therefore, it is found out that though a certain cycle time guarantee a maximum SCP, it failed to guarantee a maximum COP. The method of solving the contradiction is to improve heat transfer performance of adsorber.



Cycle time: 1-50min 2-40min 3-30min
Fig.2 Cycle time and Clapeyron diagram

<u>Cycle time and COP and SCP of system operation</u>

Cycle time have effect on both SCP and COP. Fig.3 is experimental curve reflecting relationship between cycle time and SCP and COP. It is shown in the figure that cycle time for optimum SCP is 40 minutes, and in this cycle time, COP is 94.9% of its optimum value. Cycle time for optimum COP is 50 minutes, and in this cycle time, SCP is 97.6% of its optimum value.



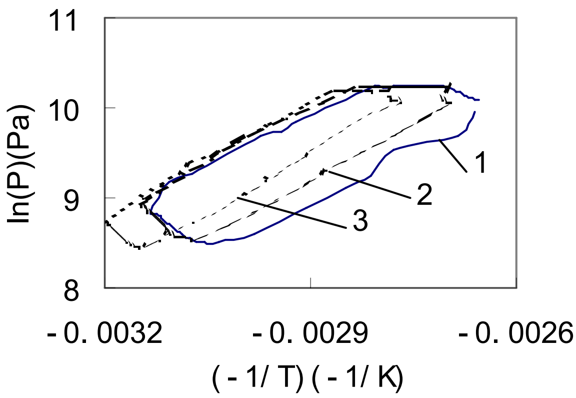
Cycle time: ●—20min ▲—30min ▼—40min ■—50min
Fig.3 Cycle time and SCP and COP

<u>HEAT SOURCE TEMPERATURE AND SYSTEM OPERATING PERFORMANCE</u>

Desorption temperature is another important operating parameter. Generally, the higher heat source temperature is, the quicker the temperature increasing speed of adsorber and the higher desorption temperature is, therefore, the greater cooling power in the same cycle time is. But there is an optimum heat source temperature for optimum COP.

<u>Heat source temperature and Clapeyron diagram of system operation</u>

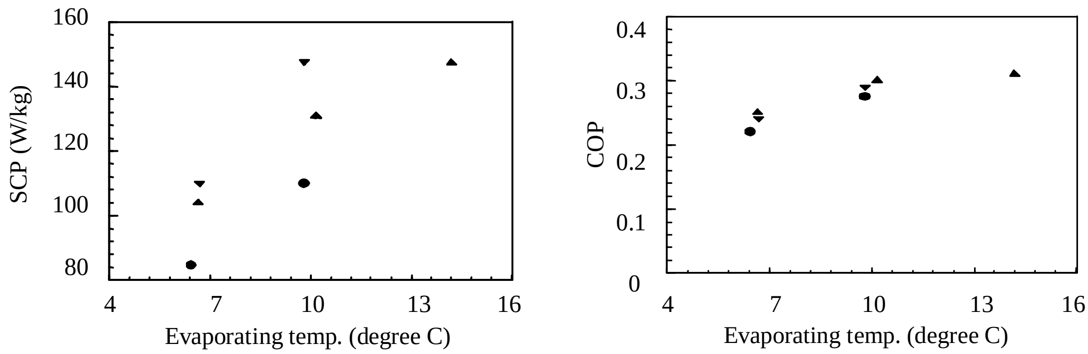
Analyzed from a dynamic angle, increase of heat source temperature mainly improves temperature of adsorber and heating speed, therefore, in the same cycle time, increases desorption temperature of the system, increases desorption capacity and thus adsorption capacity. In other words, heat source temperature improves adsorber's capability. Clapeyron diagram of the real operation is shown in Fig.4, including operation curve when heat source temperature is 90°, 100° and 110°. In this figure, it is shown that increase of heat source temperature reduces desorption pressure of adsorber and realizes enough desorbing. It is thus realizes a function equivalent of that when extending desorption time. In this way, as heat source temperature increases, adsorber improves its operating. Comparing curve 2 in Fig.2 and curve 1 in Fig.4, it is found out that adsorber’s performance in 30-minute cycle time and under heat source temperature of 110□ is close to that in 40-minute cycle time and under heat source temperture of 100□, which fully indicates that increasing heat source temperature has effect on increasing adsorber's performance.



1-110°C 2-100°C 3-90°C
Fig.4 Heat source temperature and Clapeyron diagram

<u>Heat source temperature and COP and SCP</u>

The increase of heat source temperature makes adsorber working better in the same cycle time, which will definitely increase SCP. However, the increase of heat source temperature also increases system's heating capacity and not necessarily increases COP. Fig.5 shows SCP and COP of system operation under different heat source temperature. From curves in the figure, it can be seen that as heat source temperature increases, SCP will gradually increases. But for COP there is an optimum value. Under such conditions desorption temperature for maximum COP is 100°.

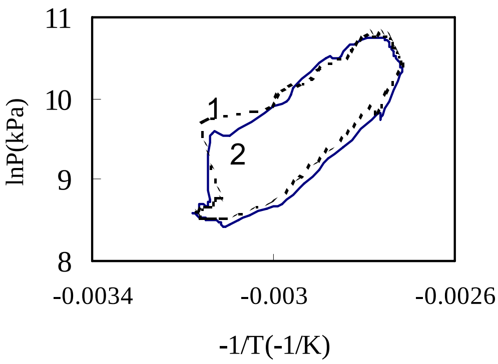


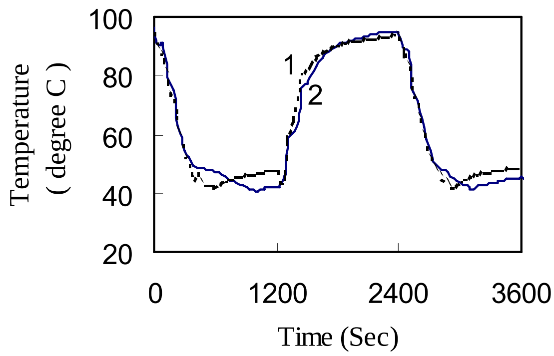
heat source temperature: ▼—110° ▲—100° •—90°
Fig.5 Heat source temperature and SCP and COP

<u>STROKE OF FLOW CONTROL VALVE AND SYSTEM OPERATING PERFORMANCE</u>

In the adsorption heat pump system, flow control valve is in the middle of condenser and evaporator, controlling refrigerant flow from condenser to evaporator. It is one of the main parts keeping the system working continuously. If the stroke of flow control valve is too wide, condenser and evaporator will have passage to each other and thus influence evaporating pressure; if the stroke is too narrow, flowing of refrigerant will be influenced and thus desorption capacity reduced. Therefore, a proper stroke of flow control valve is demanded. A 2mm needle valve is adopted here with a controlled stroke range of 10mm. For the purpose of knowing the influence of stroke of flow control valve on system operating performance, stroke are changed to various extent, and comparing experiment under two groups of working conditions are carried out. The experimental data is shown in Fig.6, Fig.7, Fig.8 and Fig.9. Hereafter working condition with 2mm stroke is referred to as working condition 1 and working condition with 5mm stroke is referred to as working condition 2.

From Clapeyron diagram in Fig.6, it can be seen that in desorption process of the adsorber, working condition 2 has a greater desorption capacity. In Fig.7 of temperature increasing curves of adsorber, curves of working condition 2 is slower that that of working condition 1. Besides, in Fig.8 of condenser cooling water inlet and outlet temperature, condenser cooling water takes away more cooling capacity for working condition 2. All the above indicates that in working conditions with a wider stroke of flow control valve, system's desorption capacity is greater. The reason is that the opening of flow control valve causes the flowing of refrigerant, which emptying the condenser's room and thus improves desorption process. In this way, it laid a good foundation for adsorption process in the next cycle. From Fig.6 of comparison of adsorber's temperature decrease curves, it can be seen that starting speed of temperature decrease under working conditon 2 is slower than that under working condition 1, which proves that at beginning adsorption capacity under working condition 2 is greater, in fact it is because that the adsorber has a better desorbing in the previous cycle. But the opening of flow control valve connects condenser with evaporator, which has a certain influence on evaporating pressure. From changing tendency of da section in Clapeywon diagram of Fig.6, it can be seen that without opening of the valve, pressure at point shall be lower than present value. Increase of the pressure is caused by connection between condenser and evaporator. If this pressure increases too much, some cooling power will be offset. Moreover, it may surpass the increase of cooling power caused by improvement of desorption process. Therefore, opening of flow control valve shall be appropriate. In experiment under working condition 2, condenser's pressure increases evaporator's pressure, but a small increase, therefore opening of flow control valve increases cooling power of system operation. From cooling power of Fig.9, it can be seen that cooling power is greater than that under working condition 2.

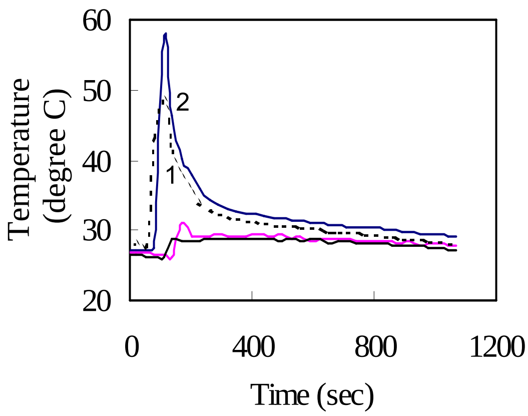


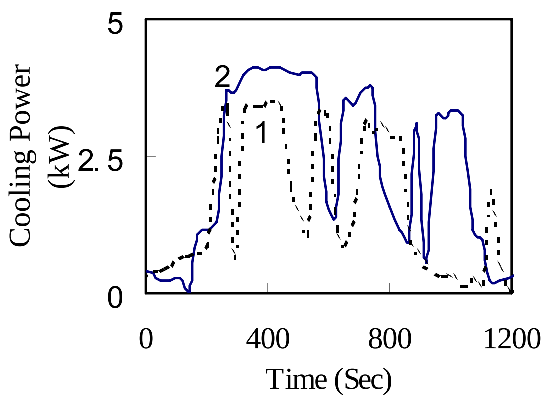


Stroke of flow control valve: 1-2mm 2-5mm

Fig.6 Influence of the stroke of flow control valve on Clapeyron diagram

Fig.7 Comparison of adsorber temperature increasing curves





Stroke of flow control valve: 1-2mm 2-5mm

Fig.8 Comparison of inlet and outlet temperature of condenser cooling water

Fig.9 Cooling power vs. time for different stroke of flow control valve

COOLING WATER TEMPERATURE AND SYSTEM OPERATING PERFORMANCES

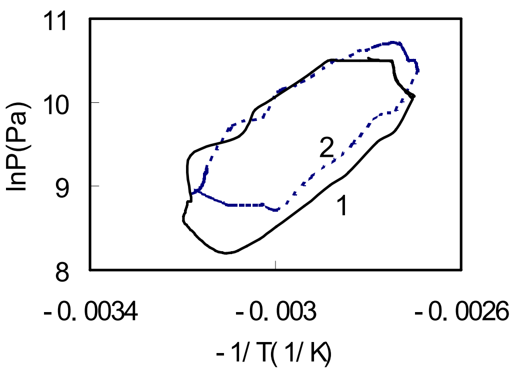
Adsorption temperature is closely related to inlet temperature of adsorber cooling water. Generally, the lower inlet temperature of the cooling water, the quicker adsorber's temperature decreasing speed is and the lower adsorption temperature becomes, therefore the greater cooling power in the same cycle time is.

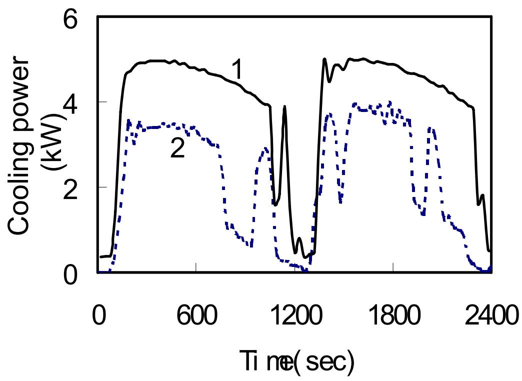
Cooling water temperature and Clapeyron diagram of system operation

Fig.10 shows comparison of real operation under different cooling water temperatures. From Fig.10, it can be seen that increase of cooling water temperature results in increase of adsorption temperature, and at the same time causes increase of desorption pressure. It is because that cooling water temperature influences not only adsorption temperature but also condensing temperature, therefore, adsorption capacity in adsorption process is influenced, so is the desorption process.

Cooling water temperature and cooling power

Changing of system's adsorption and desorption capacities results in changing of cooling power of system operation. Fig.11 shows the comparison of cooling power under two different temperature of cooling water. With the increase of cooling temperature, cooling power will decrease. Therefore, cooling water temperature has greater influence on cooling power.





1-21° 2-27° $T_{heat,s}$=100°, t_{cycle} =40min, t_{reg}=2min

Fig.10 Cooling water temperature and Clapeyron diagram in real operation

Fig.11 Cooling water temperature and cooling power

CONCLUSION

In real system, cycle time, heat source temperature, stroke of flow control valve and cooling water temperature have great influence on exerting of adsorber's operating capacity and system operating process. Corresponding to a certain cycle time, both COP and SCP have a certain optimum valve. Increase of heat source temperature improves operating capacity of adsorber, but causes decrease of COP. Opening of flow control valve causes the flow of refrigerant, helping emptying condenser room and improves desorption process. But a wide opening will also cause increase of pressure in evaporator. Therefore, proper opening of flow control valve will improve desorption process and system operating performance. Increase of cooling water temperature will cause system operating performance decrease.

To sum up, appropriate parameters can bring the system's operation potential into fully play.

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Nomenclature

$T_{heat,s}$ Heat source set temperature [degree C]; T_{cool} Cooling water temperature [degree C]; T_e Evaporating temperature [degreen C]; T_{cycle} Cycle time [min]; T_{reg} Heat recovery time [min]

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