

Research on Operating Performance of CO₂ Ground Source Heat Pump

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Abstract: According to the characteristics of the soil as the heat source and sink, the operation rules are studied on the ground source heat pump using CO₂ as a refrigerant. The methods are brought forward and discussed to make certain the operation parameters and the control strategies of the ground source heat pump. The analysis shows that the capacity regulation and the pressure control based on the inlet water temperature of the gas cooler can be a better control strategy for CO₂ ground source heat pump. And the pressure formula for operation control is also proposed. The main factors that affect the coefficient of the performance of the CO₂ heat pump are analyzed.

Keywords: CO₂ ground source heat pump, cycle performance, operating control

1. INTRODUCTION

One of the basic features of ground source heat pump is that the underground soil as the high temperature heat sink in summer and the low temperature heat source in winter, not only the operation conditions need to match the load of terminal air conditioning systems but also heat pump performance and variation of temperature of underground soil should be coupled. The operating strategy of ground source heat pump with CO₂ working fluid is different in many aspects due to different cycle type compared with conventional refrigerants heat pumps. When the CO₂ is applied in ground source heat pump, the transcritical cycle must be adopted because of the characteristics of the

underground soil temperature and the demand of supply hot water temperature for air conditioning in winter.

The objective of this work is to analyze the CO₂ ground source heat pump cycle performance and its influences to air conditioning system and ground heat exchangers in different operating conditions. The operating control strategies of the ground source heat pump are brought forward.

2. THE SCHEME OF CO₂ GROUND SOURCE HEAT PUMP

The schematic of the CO₂ transcritical cycle ground source heat pump system is shown Figure 1.

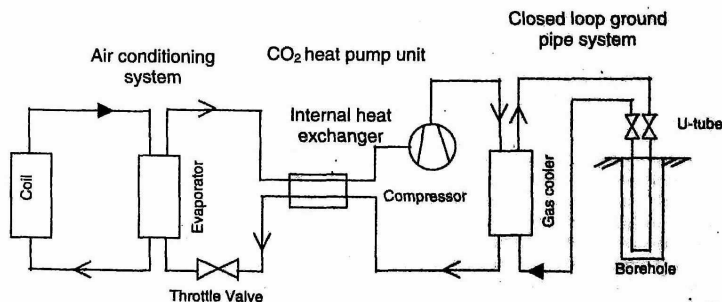


Figure 1: Schematic diagram of the CO₂ ground heat pump system(in summer)

This system is composed of three parts as follows: (1) closed loop systems with a U-tube ground heat exchanger, (2) CO₂ transcritical cycle heat pump

unit, (3) terminal air conditioning system. The ground source heat pump system uses the ground soil as a heat sink or source. The heat of gas cooler is rejected

to the ground in summer and the heat of evaporator is absorbed from the ground through the closed loop ground heat exchanger. The operating mode between summer and winter can be changed by opening or closing the valves joined the pipe systems.

The CO₂ ground source heat pump unit as shown in Figure 1 adopts a transcritical cycle type of single-stage compression with an internal heat exchanger. To determine the type of heat pump unit, the suction volume of compressor, the areas of gas cooler and evaporator must be calculated first. It is also a precondition of research on operating performance of CO₂ ground source heat pump to make certain of the capacity of these facilities.

In order to compare the system with actual R22 experimental heat pump system built in Hebei University of Engineering, the operating condition and the capacity of the CO₂ transcritical cycle heat pump unit are the same as that of R22 experimental heat

pump system. In summer, the standard refrigeration capacity of CO₂ ground source heat pump is 21.8kW, evaporating temperature is set to be 7.2°C. The outlet CO₂ temperature of gas cooler is set to be 35°C or 65°C, considering the requirement of temperature difference between the ground soil and the ground heat exchanger, also the need of the supply water temperature in air conditioning system in winter. Both of gas cooler and evaporator choose the shell and microchannel exchanger. The internal diameter of microchannel is 0.8mm. The heat transfer coefficients of CO₂ in the gas cooler and evaporator are chosen from reference^[1].

On the conditions of mentioned above, the calculated results of the suction volume of compressor and the areas of gas cooler and evaporator are shown in table 1 and table 2, the calculating processes in detail are shown in references^[2].

Table 1 : Calculation Results of Theoretic Suction Volume of CO₂ Compressor

Discharge Pressure bar	Discharge Temperature °C	Outlet Temperature °C	Suction Volume m ³ /h	Flow rate kg/s	Refrigeration kW	Input Power kW	COP
93.34	92.0	37.5	6.51	0.151	21.80	6.74	3.23

Table 2: Calculation Results of Areas of Evaporator and Gas Cooler

Evaporator			Gas Cooler		
Temperature Difference °C	Water Flow rate kg/s	Area m ²	Temperature Difference °C	Area kg/s	Area m ²
3.99	0.988	0.696	10.13	0.219	0.436

Note: The areas above are inner areas of microchannel

In summer, the circulation water in the ground heat exchanger can obtain a rather larger temperature glide through gas cooler of the CO₂ ground source heat pump unit. Under the condition of meeting the amount and temperature difference of heat transfer between the water in the ground pipe and soil, the outlet temperature of CO₂ gas cooler still remains a relative lower level. Therefore the coefficient of performance of CO₂ ground source heat pump cycle may maintain a relative higher level.

3. OPERATING PERFORMANCE OF THE CO₂ GROUND SOURCE HEAT PUMP IN SUMMER

When CO₂ ground source heat pump unit is in summer operating condition the air conditioning chilled water system and evaporator are coupled. The evaporating temperature remains constant 5°C in the analysis of the operating performance. The change of inlet or outlet water temperature of ground heat exchanger will affect the outlet temperature of gas cooler, and the optimum operating pressure of the ground source heat pump, the coefficient of performance, discharge heat. The refrigeration capacity will change accordingly.

3.1 operating performances in different inlet water temperature of gas cooler

The water flow in the gas cooler is constant with 0.219kg/s. The calculated results of the operating performances in different inlet water temperature of gas cooler with the change of operating pressure are shown in Fig.2 and Fig.3. As shown in figure 2, the discharge heat and the refrigeration capacity have a tendency to rise with the raise of operating pressure in the same inlet water temperature. When the operating pressure is low, discharge heat rises quickly with the change of the pressure. When the pressure is high, the trend of rising is slowed down. At the same time, it can be found out that the lower the inlet water temperature of gas cooler is, the larger discharge heat and refrigeration capacity are. With the raise of the operating pressure, the difference of discharge heat in different inlet water temperature lessens.

Figure 3 shows that the change of the temperature of outlet water and outlet CO₂ of gas cooler with the change of operating pressure in different inlet water temperature. It is indicated that the outlet water temperature of the gas cooler has a tendency to rise with the increasing operating pressure in the same inlet water temperature, yet the outlet CO₂ temperature of the gas cooler has a few change. In the lower operating pressure, when the inlet water

temperature is high, the outlet water temperature is lower. When the operating pressure rises to some a point, the outlet water temperature whose inlet water temperature of gas cooler is high is higher than that of the gas cooler whose inlet water temperature is low.

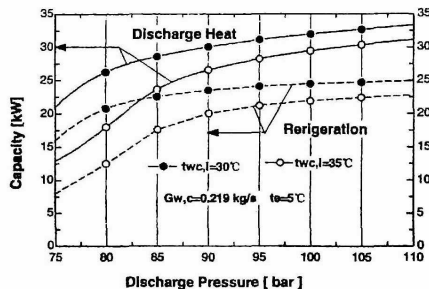


Figure 2: Relation of capacity to discharge pressure in different inlet water temperature

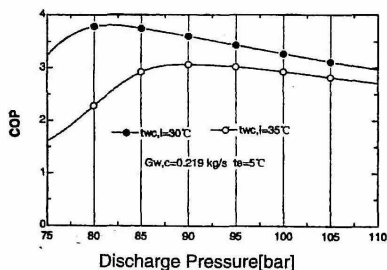


Figure 4. Effect of inlet water temperature on

Figure 4 shows that the change of COP of CO₂ heat pump unit in different inlet water temperature. The coefficient of performance has a maximum in the same inlet water temperature with the change of the operating pressure, which is the optimum controlled operating pressure in this inlet water temperature.

The coefficient of performance and the optimum controlled operating pressure are different in different inlet water temperature. The lower the inlet water temperature is, the higher the coefficient of performance and the lower optimum controlled operating pressure are.

As shown in Figure 3 and Figure 4, when the operating pressure is higher than the optimum control pressure, the coefficient of performance of the system descends slowly in the nearby regions of the optimum pressure, but the discharge heat of the gas cooler and the refrigeration capacity of the system increases quickly. Therefore, the coefficient of the performance of the system and the heat transfer of the ground heat exchanger and the cold load of the air conditioning system should all be considered at the same time in order to determine the suitable operating pressure in CO₂ ground heat pump system in summer.

Figure 3 also shows that when the water flow of the gas cooler is constant, the lower the inlet water temperature is, the lower the outlet CO₂ temperature of gas cooler is in the whole range of the operating pressure.

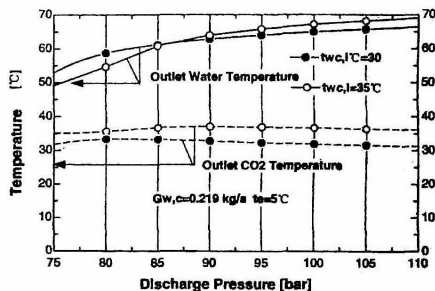


Figure 3: Relation of outlet temperature of water and CO₂ to discharge pressure in different inlet water temperature

3.2 operating performance in different inlet water flow of gas cooler

When the inlet water temperature of the gas cooler is constant with 35°C, in different water flow rate of gas cooler, the calculated results of the operating performance of the CO₂ ground source heat pump system with the change of operating pressure are shown in Figure 5 and Figure 6.

As shown in Figure 5 and Figure 6, the water flow rate of the gas cooler has a little influence to the discharge heat and the refrigeration capacity of the CO₂ ground source heat pump system. Generally speaking, the larger the water flow is, the larger the discharge heat and the refrigeration capacity are. The variation range of the outlet water temperature is bigger than that of discharge heat with the water flow rate of gas cooler. The larger the flow rate is, the lower the outlet water temperature of gas cooler is. The outlet CO₂ temperature of gas cooler is essentially same in different cooling water flow rate.

The outlet water temperature lower in high water flow than that in low water flow is due to the discharge heat rising a little with the increasing of the cooling water flow.

Corresponding to the change rule of the discharge heat with the outlet CO₂ temperature, the coefficient of performance of CO₂ ground source heat pump unit grows up with the increasing of cooling water flow, but the variation extent is a little. The influence of cooling water flow on the optimum pressure is also weak. The optimum pressure is all almost near the 90bar in three groups of cooling water flow as follows: 0.219kg/s, 0.24kg/s and 0.26kg/s.

It has been indicated above that the influence of cooling water flow on performance and discharge heat and refrigeration capacity is a little, but on outlet water temperature of gas cooler and mean water temperature of ground heat exchanger is a large. Therefore, to determine the cooling water flow in summer operating condition, one hand the relations

between the coefficient of performance and the refrigeration capacity should be considered; on the other hand the requirements of discharge heat and temperature difference between circulation water of the ground heat exchanger and ground soil should be considered also.

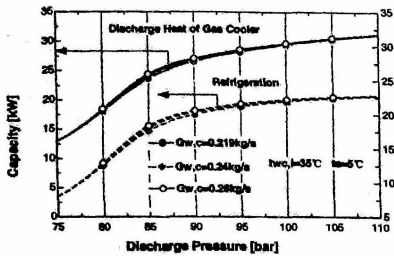


Figure 5: Relation of capacity to discharge pressure in different inlet water flow rate

4. THE OPERATING CONTROL STRATEGY OF CO₂ GROUND SOURCE HEAT PUMP

Because of the characteristics of transcritical cycle and the u-tube ground heat exchanger, to meet the needs of cold load of air conditioning system and discharge heat of the ground heat exchanger, it should be considered at first that regulate the operating pressure of CO₂ ground source heat pump according to the inlet water temperature or outlet CO₂ temperature of gas cooler. To a given CO₂ ground source heat pump, the inlet water temperature of gas cooler has a corresponding relation to outlet CO₂ temperature. Considering that it will be easier to set a sensor on the side of water than on the side of CO₂ in gas cooler, it is suitable to regulate capacity and control operating pressure based on inlet water temperature of gas cooler.

In initial start stage of the CO₂ ground source heat pump in summer, the inlet water temperature of the gas cooler is lower because of the soil temperature around the u-tube ground heat exchanger at a relatively lower level. In order to meet the need of larger discharge heat in start stage and the demand of higher discharge pressure in transcritical cycle, it must be done to limit minimum operating discharge pressure of compressor.

$$\left. \begin{aligned} p &= 85 \\ p &= 48.38 + 0.4289t_{wc,i} + 0.02374t_{wc,i}^2 \\ p &= 110 \end{aligned} \right\} \begin{aligned} t_{wc,i} &\leq 31.3^\circ\text{C} \\ 31.3^\circ\text{C} &< t_{wc,i} \leq 42.7^\circ\text{C} \\ t_{wc,i} &> 42.7^\circ\text{C} \end{aligned} \quad \text{bar} \quad (1)$$

As shown in Figure 7, when the control strategy above is put in practice, the discharge heat to the ground changes greatly in lower inlet water

temperature of gas cooler, and the heat to the ground and refrigeration do not change much with the inlet water temperature of gas cooler and the optimum

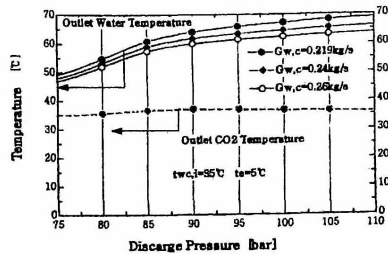


Figure 6: Relation of outlet temperature of water and CO₂ to discharge pressure in different inlet water flow rate

With the heat pump going on running, the heat rejected to the ground will increase continuously. Both the inlet water temperature of gas cooler and outlet CO₂ temperature will rise. During the times the operating pressure should maintain the minimum discharge pressure. When the outlet CO₂ temperature of gas cooler gets to the point at which the optimum pressure calculated by the formula given in reference [9] equals to the minimum discharge pressure set to the actual CO₂ ground source heat pump system in start stage, the operating pressure should be determined by the formula given in document [3] with the inlet water temperature rising. If the inlet water temperature and outlet CO₂ temperature rise continuously, the optimum operating pressure will rise also. The operating pressure must limit a maximum for safety of the unit and stability of the lubricating system.

Considering the demand of larger heat to ground in the initial operating stage, the minimum operating pressure can be set at 80-85bar. For operating safety, the discharge temperature of CO₂ compressor should not exceed 120 °C, so the maximum operating pressure can be set at 110bar.

According to the minimum and maximum operating pressure, through the cycle characteristics analysis and datum fitting, the formula of the operating pressure of CO₂ ground source heat pump for capacity control based on inlet water temperature of the gas cooler is given as follows:

temperature of gas cooler, and the heat to the ground and refrigeration do not change much with the inlet water temperature of gas cooler and the optimum

pressure in normal operating conditions, which is in correspondence with the heat transfer characteristics of ground heat exchanger. From the point of view of capacity control method, it is much easier to use CO₂ as working fluid than to use conventional working fluids in ground source heat pump.

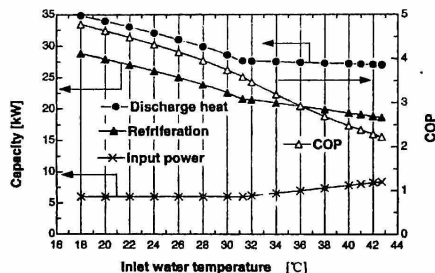


Figure 7: Relation of capacity and COP to inlet water temperature

In winter, the control method in evaporator side of CO₂ ground source heat pump is not different at all with that of conventional working fluids ground source heat pump in the couple of evaporator and ground heat exchanger. But CO₂ transcritical cycle can produce higher temperature supply water, which can easily meet the requests for hot water temperature needed in different heating systems and can easily match the changing heat source needed in air conditioning systems. The CO₂ ground source heat pump can completely meet the needs of the heat load of air conditioning system that changes with weather by regulating the operating pressure.

5. CONCLUSIONS

Because of different cycle ways, the remarkable difference between the CO₂ ground source heat pump and conventional refrigerants ground source heat pump is the regulating and controlling methods to adapt the changes of external high and low temperature heat source. In the condition to satisfy the request of discharge heat in summer, the outlet CO₂ temperature of the gas cooler can still keep on a relatively lower level, so the coefficient of performance of CO₂ heat pump is close to conventional working fluids ground source heat pump. The operating pressure and capacity control of CO₂ ground source heat pump can be determined by inlet water temperature of the gas cooler, which is more flexible and feasible in practice.

ACKNOWLEDGMENTS

This research was supported by the Natural Science Foundation of Hebei (502388).

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