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ABSTRACT

Heat pump technology has been rapidly developed recently as a clean and efficient heating method. Continuous capacity modulation of heat pumps is necessary for enhancing room thermal comfort and reducing start-stop losses. A novel capacity modulation method for the scroll compressor heat pump system based on refrigerant injection and refrigerant release is proposed. The experiments indicate the refrigerant injection increases the heating/cooling capacity by 21.9%/21.4% and enhances the heating COP/cooling EER by 5.6%/9.0% when the glycol inlet temperature of condenser and evaporator is fixed at 40℃ and 0℃, respectively. The tests also show the refrigerant release decreases the heating/cooling capacity by 26.6%/31.4% and enhances the heating COP/cooling EER by 16.0%/8.4% when the condensing and evaporating temperature fix at 40℃ and 1.7℃, respectively. To sum up, the technology combining refrigerant injection and refrigerant release is a remarkable capacity modulation method for heat pump systems with scroll compressors, which can modulate the capacity continuously within a wide range as well as increase its energy efficiency ratio.

1. INTRODUCTION

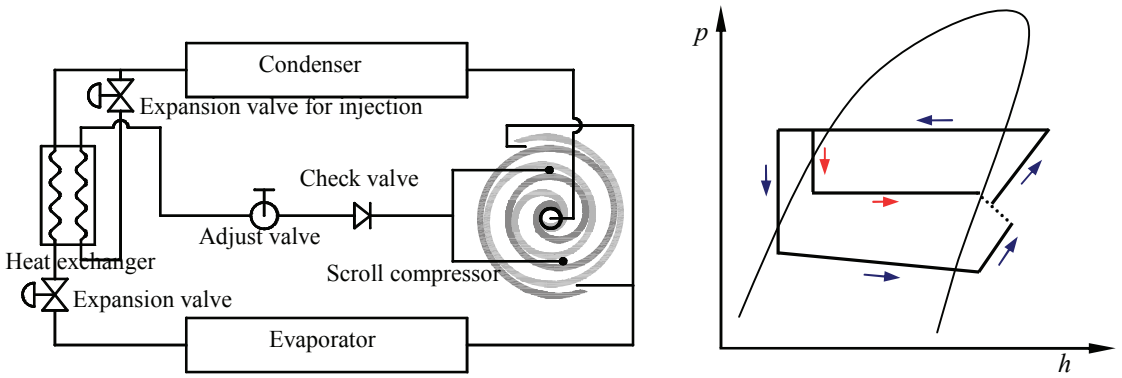
Because of possible energy savings and emission reduction, heat pump technology has been rapidly developed recently as a clean and efficient heating method. For space heating, the heating requirement varies in a large range due to the change of indoor and outdoor situations, so the ability of continuous capacity modulation is necessary for enhancing room thermal comfort and reducing start-stop losses. Moreover, increasing the energy efficiency of heat pump system under off-design conditions is the main way to increase the seasonal performance of the system because field surveys show that the system is operated under off-design conditions for most of the operating time. So continuous capacity modulation method considering the energy efficiency under off-design conditions will largely accelerate the development and promote the application of heat pump systems.

Much research has been done for capacity control of the heat pump and different methods are proposed, such as hot gas bypass, suction pressure modulation, suction valve control, and so on. For heat pump systems with scroll compressors, frequency conversion and digital scroll technology are often utilized. However, these methods above either achieve the capacity reduction only or sacrifice the system efficiency.

Actually, refrigerant injection and refrigerant release technologies are remarkable capacity modulation methods for heat pump systems with scroll compressors, which can modulate the capacity as well as increase the energy efficiency under off-design conditions.

2. REFRIGERANT INJECTION TECHNOLOGY

For upward capacity modulation, refrigerant injection technology is an effective method. Figure 1 shows the heat pump system of scroll compressor with refrigerant injection technology. This system is constituted by the main circuit and the injection circuit. The main circuit is made up of a scroll compressor, a condenser, an expansion valve and an evaporator orderly, which is just a conventional heat pump. The injection circuit includes an expansion valve, a heat exchanger, an adjust valve and a check valve. One end of the injection circuit locates on two injection ports of the fixed scroll plate of the scroll compressor and the other connects with the outlet of the condenser.



(a) Configuration schematics (b) Schematic p-h diagram

Figure 1. Scroll compressor refrigeration system with refrigerant injection

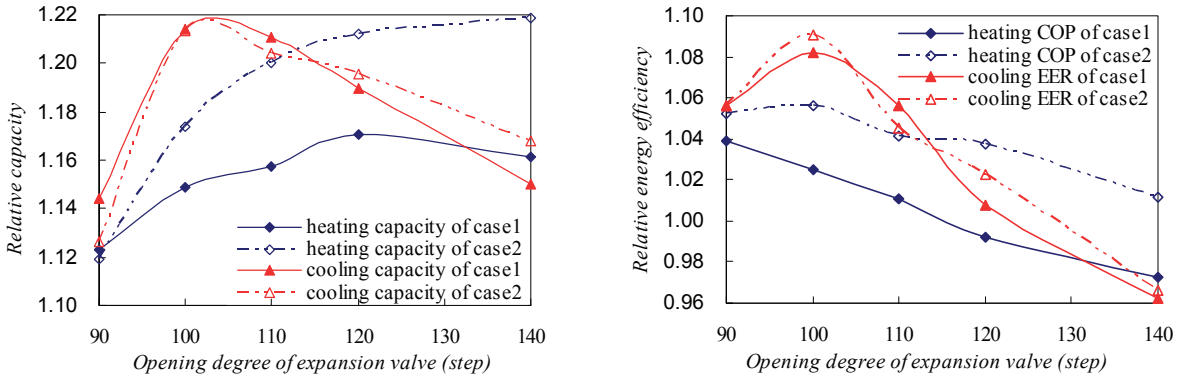
When the capacity of the heat pump matches the requirement, the adjust valve in the injection circuit turns off and the injection circuit is out of work. In this case, the system just operates as an ordinary heat pump. Once the capacity supplied by the heat pump is not enough for the requirement, the adjust valve turns on and adjusts with the expansion valve for injection according to the capacity needed. In this case, part of the refrigerant at the outlet of condenser will be throttled by the expansion valve of the injection circuit, then be heated by the refrigerant of main circuit in the heat exchanger and inject into the compressor chamber finally.

As a result, the refrigerant mass flow through the condenser is increased, which raises the heating capacity of the heat pump. The cooling capacity is also increased because the enthalpy at the inlet of evaporator is reduced through the heat transfer with the injection refrigerant in the internal heat exchanger. Furthermore, because extra refrigerant is injected into compression chamber and compressed, the pressure at the end of compression process is increased, which decreases the under-compression loss thereby improving the efficiency of compressor. In addition, the refrigerant injection can decrease the discharge temperature and thereby ensure the safety of the compressor.

A lot of research (Beeton *et al*., 2003; Ma *et al*., 2003; Park *et al*.,2002; Winandy *et al*., 2002; Yang *et al*., 2009) has been conducted on the refrigerant injection system. Some experiments (Wang, 2006;Wang *et al*., 2009) are carried out to prove the effect of refrigerant injection and the results are showed in Figure 2. The glycol inlet temperatures of the evaporator and the condenser are 5℃and 30℃ respectively for case 1. For case 2, the corresponding temperatures are 0℃ and 40℃ respectively. In the experiment, the adjust valve turns on fully, and the expansion valve for injection is adjusted from 90 steps to 140 steps.

It can be seen from Figure 2 that the refrigerant injection not only increases the heating and cooling capacity effectively but also enhances the energy efficiency ratio of the heat pump system with a scroll compressor. The largest enhancements of heating and cooling capacity are 21.9% and 21.4% and the largest enhancements of heating

COP and cooling EER are 5.6% and 9.0%, respectively. The increases of heating capacity and COP for case 2 are larger than case 1, which indicates that refrigerant injection has a better effect on heating under bigger pressure ratio condition.



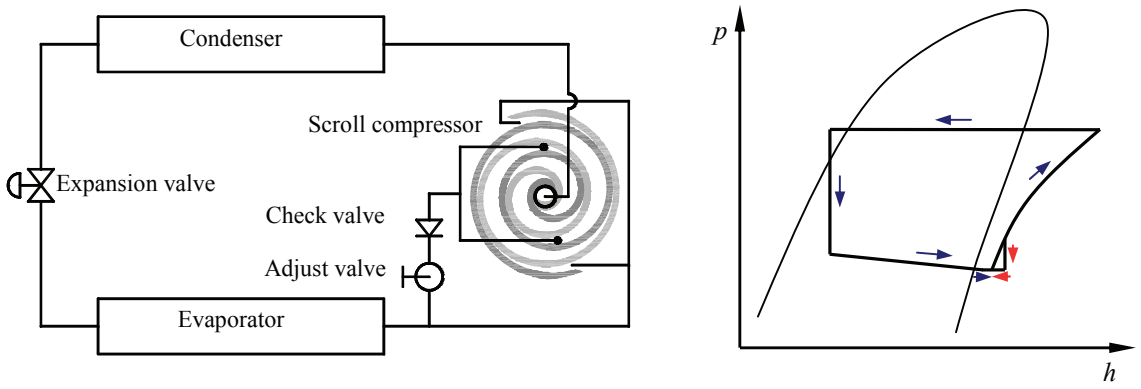
(a) Heating and cooling capacity (b) EER/COP

Figure 2. Effect of refrigerant injection on the performance of a heat pump system with a scroll compressor

Generally, the refrigerant injection technology is proved to be a practical and effective method for increasing capacity and enhancing efficiency of heat pumps with scroll compressors under large compression ratio conditions.

3. REFRIGERANT RELEASE TECHNOLOGY

In order to decrease the capacity and enhance the efficiency of the scroll compressor refrigeration system under small compression ratio conditions, a refrigerant release technology is proposed (Wang *et al.*, 2007). As shown in Figure 3, the system with refrigerant release is constituted by the main circuit and the release circuit. The main circuit includes a scroll compressor, a condenser, an expansion valve and an evaporator as a conventional heat pump. The release circuit is a bypass channel for refrigerant release with one end connecting with the release port on fixed scroll plate and the other connecting with the suction pipe. A check valve and a adjust valve are settled on the release circuit for stopping the reverse flow and adjusting the release flow rate.

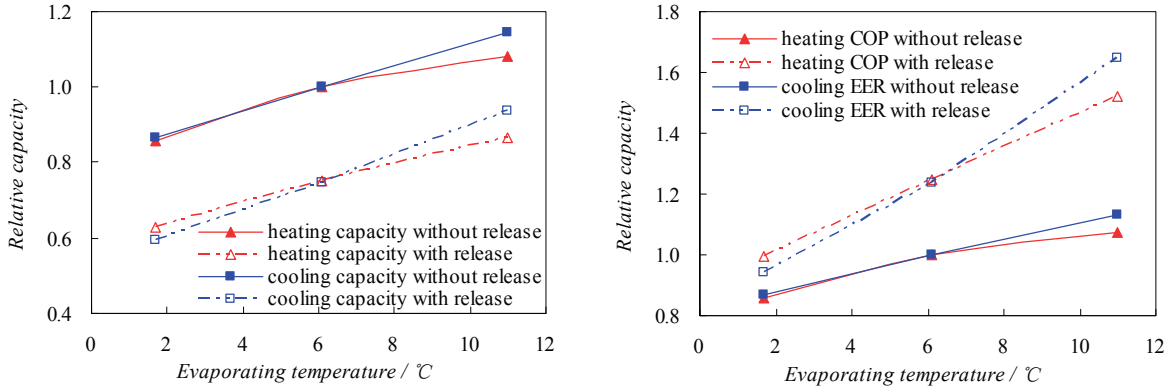


(a) Configuration schematics (b) Schematic p-h diagram

Figure 3. Scroll compressor refrigeration system with refrigerant release

When the capacity of heat pump matches the requirement, the adjust valve in the release circuit turns off and the release circuit is out of work. In this case, the system just operates as an ordinary heat pump. Once the capacity supplied by heat pump exceeds the requirement, the adjust valve opens and adjusts according to the capacity needed.

In this case, part of the refrigerant in the compression chamber will release through the release channel back to the inlet of the compressor driven by the pressure difference. As a result, the refrigerant mass flow through the condenser and evaporator is decreased, which cuts down the heating/cooling capacity of the heat pump. Furthermore, the effective compression length of scroll compressor is shortened because of the refrigerant release, and the inner compression ratio is reduced, which decreases the over-compression loss. The check valve can prevent the reverse flow of the refrigerant from inlet of the compressor into the compression chamber.



(a) Heating and cooling capacity (b) Energy efficiency ratio

Figure 4. Effect of refrigerant release on the performance of a heat pump system with a scroll compressor

Experiment is carried out to prove the effect of refrigerant release. In the experiment, the condensing temperature is fixed at 40℃, the evaporating temperature is set at 1.7℃, 6.1℃ and 11.0℃ respectively, and the adjust valve keeps open fully. The results are showed in Figure 4. For comparison, the results are expressed in relative value, and the benchmark is the point at evaporating temperature 6.1℃ without refrigerant release.

Figure 4(a) represents the effect of refrigerant release on the heating and cooling capacity of the system. It can be found that the refrigerant release decreases the heating and cooling capacity effectively. Under different evaporating temperature, the heating capacity decreases by 18.2%~31.4% and the cooling capacity decreases by 20.2%~26.6% compared with the capacity without refrigerant release. Because the adjust valve opens fully in the experiment, the decreases of the capacity here reach their maximum. Therefore, based on the experiment data, the capacity of the heat pump can be modulated within 68.4%~100% continuously with the regulation of the adjust valve.

In the experiment, the resistance of the bypass channel is quite large due to the adjust valve and the check valve, which limits the release refrigerant mass flow and weakens the capacity modulation. Once the resistance of the bypass channel gets smaller by optimization, the modulating range of the heat pump will enlarge greatly.

Figure 4(b) illustrates the effect of refrigerant release on the energy efficiency ratio of the system. It can be found that the refrigerant release enhances the efficiency level largely, and the higher the evaporating temperature is, the bigger the increase of EER and COP is. The heating COP and cooling EER rise by 41.8% and 45.4%, respectively, at a fixed evaporating temperature of 11℃, which indicates the great potential for energy saving of refrigerant release besides capacity modulation.

Generally, refrigerant release can not only adjust the capacity of the heat pump system with scroll compressor effectively, but also enhance the efficiency of the system under small compression ratio conditions remarkable.

4. BIDIRECTIONAL CAPACITY MODULATION METHOD

Since the refrigerant injection and refrigerant release technologies can achieve upward and downward capacity modulation of heat pumps with scroll compressors respectively, the combination of refrigerant injection and release is available for bidirectional capacity modulation of scroll compressor heat pump system.

Figure 5 illustrates the novel capacity modulation method for scroll compressor heat pump combining the refrigerant injection and release technologies. Actually, it is the integration of figure 1 and figure 3, and the two check valves on the injection and release circuit are replaced by a switch valve for injection and release for easier installation.

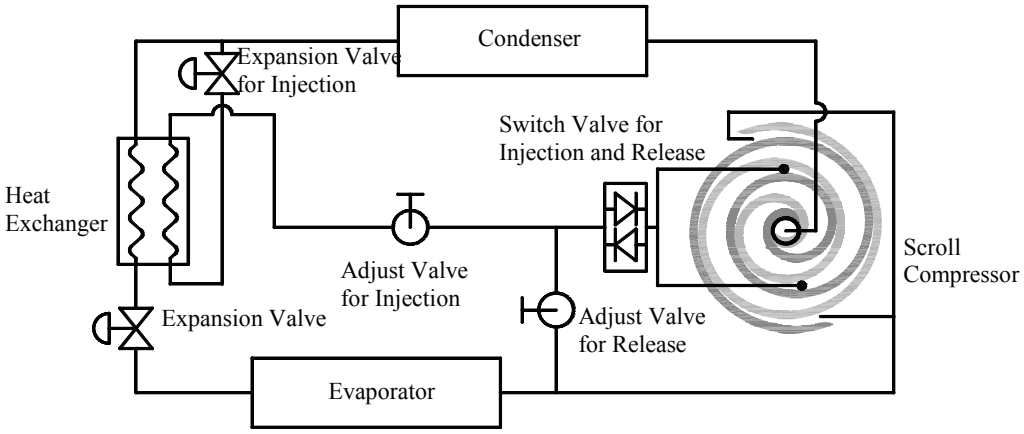


Figure 5. Novel capacity modulation method for heat pumps with scroll compressors combining refrigerant injection and release

Bidirectional capacity modulation can be achieved easily with this method. When the capacity of heat pump matches the requirement, the adjust valves for injection and release both keep closed, and the system just operates as an ordinary heat pump. When the capacity supplied by heat pump is not enough for the requirement, the adjust valve for injection turns on and the refrigerant injection circuit will be involved to increase the capacity. Through adjusting the expansion valve and the adjust valve the capacity can be regulated exactly to meet the demand. When the capacity supplied by heat pump exceeds the requirement, the adjust valve for refrigerant release turns on and the refrigerant release process works. Through adjustment of the valve the capacity of the heat pump also can be decreased to the appropriate value. In addition, the refrigerant injection and release method will not sacrifice the energy efficiency of the heat pump but increase it to a certain extent.

In the experiment above, the maximum modulating range of the capacity is about 70% to 120% by refrigerant injection and release. However, the modulating range will be larger and the modulating capability will be more excellent after the improvement and optimization of valves and pipes of the injection and release circuit. It can be predicted that the capacity of the heat pump will be adjusted from 50% to 130% under common conditions by this method, and the energy efficiency ratio will be enhanced by 5% to 40% additionally.

5. CONCLUSIONS

A novel capacity modulation method for heat pump systems with scroll compressors based on refrigerant injection and refrigerant release is proposed in the paper. The experiments indicate that the maximum modulating range of the capacity is about 70% to 120% by this new technology. After the improvement and optimization of valves and pipes of the injection and release circuit, the capacity modulating range will be enlarged. The technology combining refrigerant injection and refrigerant release is a remarkable capacity modulation method for heat pump systems with scroll compressors, which can modulate the capacity continuously within a large range as well as increase its energy efficiency ratio.

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