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Development of a New Dual-Cylinder Rolling Piston Compressor

Li Zhang
Shanghai Highly Electrical Appliances CO., LTD, China, People's Republic of, zhangli@shec.com.cn

Chunhui Liu

Ruixiong Wang

Lei Zhang

Development of a New Dual-Cylinder Rolling Piston Compressor and System

Li ZHANG*, Chunhui LIU, Ruixiong WANG, Lei ZHANG

Shanghai Highly Electrical Appliances CO., LTD.
Shanghai, China
(86-2150554560, zhangli@shec.com.cn)

* Corresponding Author

ABSTRACT

In recent years, the requirement of energy efficiency for refrigeration and air condition systems becomes more and more higher while the cost needs to be more and more lower, at the same time some new applications of refrigeration and air condition systems are emerging rapidly. All of these demands need a new compressor to meet. In this paper, a new dual-cylinder rolling piston compressor with two independent suction ports and two independent discharge ports was proposed. The structure and working principal of this compressor were described, and the performance was tested. Then simulation model was built to research the performance of the system using this kind of compressor compared with the traditional system. Simulation results showed that the COP of the system using this kind of compressor is 0.5%~4.4% higher than that of the traditional system in cooling condition, and 2.1%~3.9% higher than that of the traditional system in the heating condition.

1. INTRODUCTION

With the improvement of the living standard, the requirement of the temperature and humidity in the place of residence are also improved. The air conditioners, adjusting the temperature and humidity of the living place, are being used more and more frequently. The energy consumption of air conditioners increases quickly. At present, the proportion of building energy consumption in the social terminal energy consumption has reached 30% (Weihua Zhang, 2017). The proportion of energy consumption of air conditioners in buildings is more than 50% (Weifeng Zhu and YoudiJiang, 2013). Therefore, improving the efficiency of air conditioners is crucial to reduce the energy consumption of buildings.

The energy loss of the air condition system mainly comes from two aspects. Firstly, it is the non-isentropic compressing process in the compressor. Secondly, there is a temperature difference between the refrigerant and the air or water. Therefore, there are mainly two ways to improve the efficiency of the air condition system. One is to reduce the irreversible losses associated with the compressing process. Another is to reduce the temperature difference between the refrigerant and the air or water.

In order to reduce the temperature difference between the refrigerant and the air or water, Caoxiang et al. (2017) proposed a stepped pressures cycle. In this cycle, two or three independent compressors were used. The experimental results showed that the COP increase of dual and triple-subcycle system were achieved by 12.3% and 18.7%.But the cost of this system was higher because of the installation of more than one compressor.

In order to reduce the cost and improve the COP, this paper proposed a new dual-cylinder rolling piston compressor with two independent suction ports and two independent discharge ports.

2. THEORY OF AIR CONDITION SYSTEM

For the reverse Carnot cycle, the efficiency only depends on the temperature of the hot reservoir and cold reservoir. In the actual air condition system, the temperature of the air or water is changeable along with the heat transfer process. In this case the most efficient cycle is Lorenz Cycle. As shown in Figure 1, Lorenz cycle can be regarded as the combination of numerous reverse Carnot Cycles [3]. The COP is only determined by the mean temperatures of the hot reservoir and the cold reservoir, it can be calculated by the Equation (1).

$$COP = \frac{T_L}{T_H - T_L} \tag{1}$$

T_L is the mean temperature of the cold reservoir. T_H is the mean temperature of the hot reservoir.

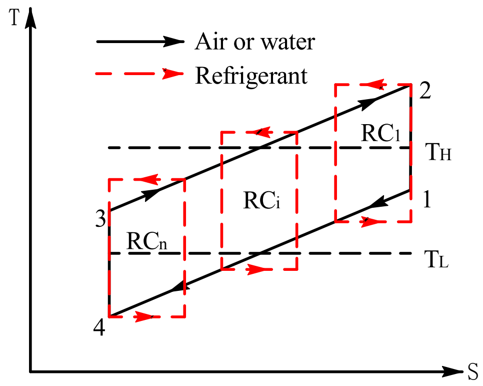


Figure 1: Lorenz Cycle

In order to approach the COP of the Lorenz Cycle, the actual cycle should be split into numerous cycles (Caoxiang et al., 2017). In fact, it could not be realized. The actual cycle could only be split into several cycles. Based on this theory, this paper proposed a new dual-cylinder rolling piston compressor with two independent suction ports and two independent discharge ports. This compressor can split an actual cycle into two subcycles to improve the COP.

3. A NEW ROLLING PISTON COMPRESSOR

A new rolling piston compressor, with two independent suction ports and two independent discharge ports, was proposed. The structure of this compressor is showed in Figure 2. This new compressor has two independent compression units. Both units have their independent suction and exhaust ports. Two units are separated by a middle partition, so the refrigerant in different units will not mix when the compressor works. A common crankshaft drives the two compression units.

The first compression unit consists of the first suction port, the first cylinder, the first exhaust port and so on. The refrigerant, sucked from the first suction port, is compressed in the first cylinder and enters into the first muffler. Then the refrigerant flows into the internal volume of the shell. After cooling the motor, it is discharged out of the compressor from the first discharge port. The second compression unit consists of the second suction port, the second cylinder, the second exhaust port and so on. The refrigerant, sucked from the second suction port, is compressed in the second cylinder then discharged into a sealed cavity, after that it is discharged out of the compressor directly from the second discharge port.

When the compressor works, the lubricating oil in the compressor could leak into the cylinders through the clearances between moving parts. For the first cylinder, the refrigerant carries the oil droplets into the interior of the compressor and those oil droplets finally sink to the bottom of the compressor due to the gravity and separation effect coming from the motor and the cavity above the motor. But for the second cylinder, the oil droplets are carried into the sealed cavity and then directly discharged from the second discharge port. When the compressor works for some time, more and more oil droplets will leave the compressor, which would lead to mechanical failures due to the lack of the lubricating oil. In this paper a new scheme was proposed to solve this problem shown in Figure3. An oil separator was used in this scheme. The oil separator has three pipes. The inlet pipe connects the second discharge port of the compressor, and the outlet pipe connects the condenser. The oil return pipe connects the first suction port of the compressor. In order to control the mass flow rate through the oil pipe, a throttling capillary is installed in the oil return pipe. This oil separator can separate the oil from the refrigerant coming from the second compression unit. Driven by the pressure difference, the oil could flow back to the first suction port. Then, the oil droplets finally return back to the compressor. By using this method, the problem of lacking lubricating oil could be solved.

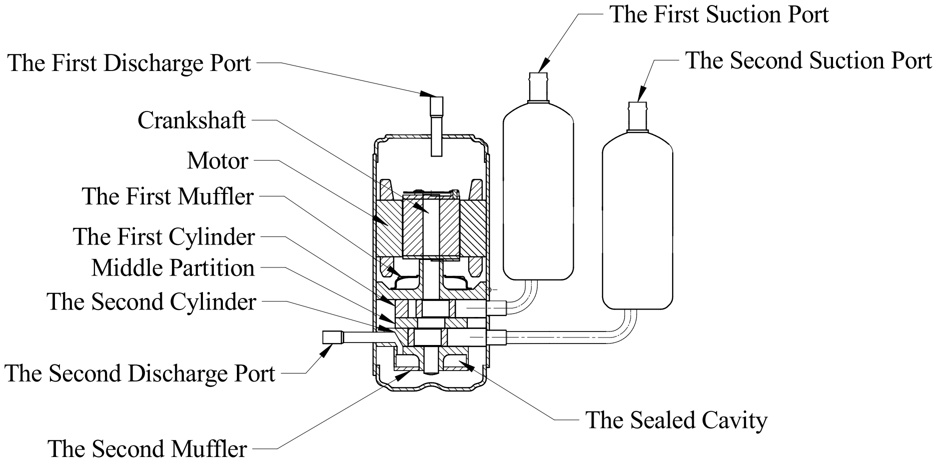


Figure 2: The structure of the new rolling piston compressor

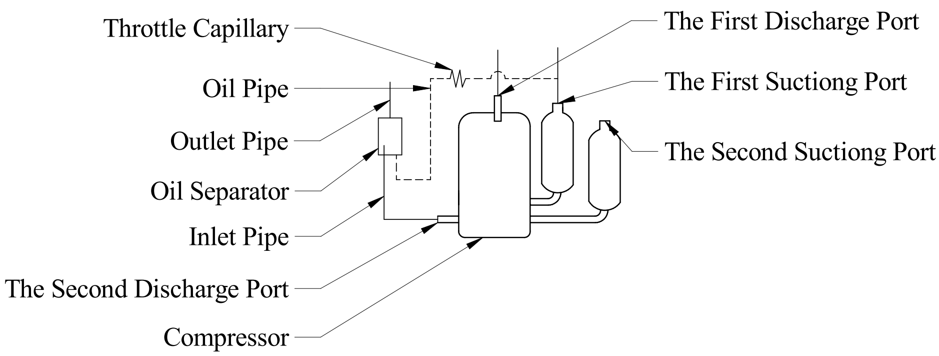


Figure 3: A schematic view applying the new compressor

4. THE SIMULATION OF THE DUAL-LOOP SYSTEM AND TRADITIONAL SYSTEM

In order to know the performance of a dual-loop air condition system applying this new compressor, a system simulation model was built. At the same time, a traditional air condition system simulation model was built too as a comparison.

4.1 The Performance Model of the Compressor

To build a system simulation model, a compressor performance model for the new compressor and traditional compressor is needed. So the performance at different operating conditions of this new compressor and a traditional dual-cylinder compressor with the same displacement was tested at a compressor performance test rig (calorimeter). Based on the test data, a mathematical model using AHRI polynomial equation was built.

4.2 The Simulation Model of the Dual-loop System and Traditional System

In order to simulate the performance of a air conditioner system, a parameterized mathematical model of the air conditioner was built, which mainly includes：

- The indoor and outdoor heat exchangers of the air conditioner were modeled, and the appropriate heat exchange correlations were used.

  The C.C.Wang model was used for heat exchange of the air-side. The Shah-Tang model was used for the heat exchange of the condensation side. The Kattan-Thome-Favrat mode（Kattan, N., Thome, J.R. and Favrat et al.1998）was used for boiling heat exchange of the evaporation side.

- The mathematical models of fan and EEV（electronic expansion valve）were established. The fan adopts efficiency model, and the orifice valve model was used for the EEV, which includes the physical and mathematical models according to the two-phase flow characteristics of refrigerant.

Based on this model, the performance of a dual-loop system using the new compressor was simulated. Figure 4 shows the schematic of the simulation model which consists of the first loop and the second loop. The first suction port and the first discharge port connect an evaporator and a condenser separately, forming the first loop. The second suction port and the second discharge port connect another evaporator and condenser separately, forming the second loop. For the condenser side, the air flow firstly enters into the condenser in the second loop, and it is heated by the refrigerant. Then it enters into the condenser in the first loop. For the evaporator side, the air flow firstly enters into the evaporator in the first loop, and it is cooled by the refrigerant. Then it enters into the evaporator in the second loop.

As a comparison, a simulation model was also built for a traditional air conditioner. Figure 5 shows the schematic of the simulation model. In this model, the heat transfer area of the condenser and the evaporator, the volume flow of the air and the expansion valve are same as the dual-loop system, the compressor is a traditional dual-cylinder compressor with the same displacement as the new compressor, and its performance model was built at section 4.1.

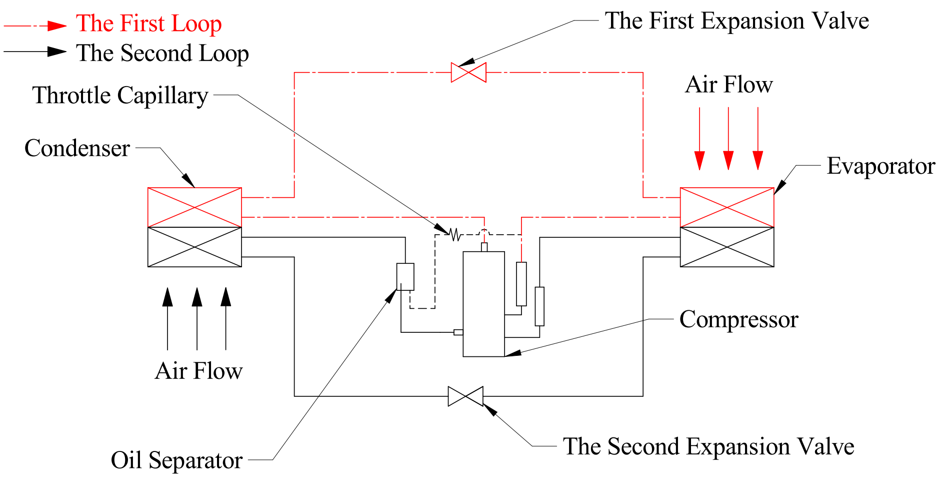


Figure 4: The schematic of the simulation model applying the new compressor

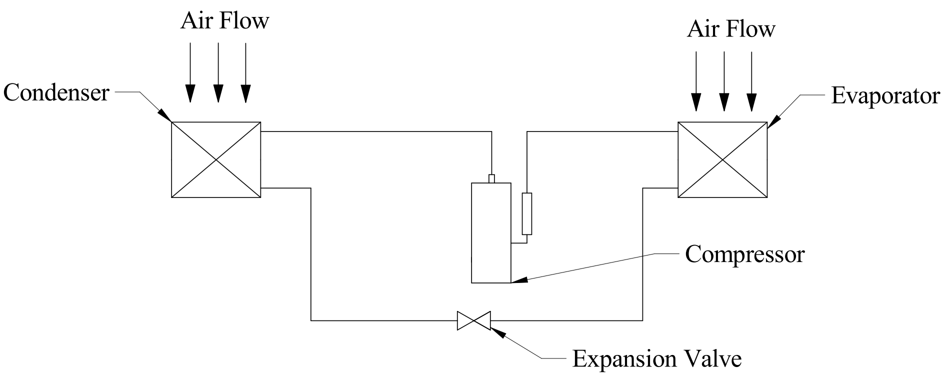


Figure 5: The schematic of simulation system applying the traditional compressor

4.3 Operating Conditions

In order to compare the performance of the dual-loop system and the traditional system, different operating condition need to be set for the simulation models. Table 2 shows the detailed parameters of the operating conditions.

Table 1: Simulation conditions of the system

Conditions	Indoor temperature （dry bulb / wet bulb）(℃)	Outdoor Temperature (℃)	Relative humidity
Heating	20/15	-3, 2, 7, 12, 17	87%
Cooling	27/19	30, 32.5, 35, 37.5, 40	40%

Both the new compressor and the traditional compressor are variable frequency compressors. But during the simulation, the rotational speed is set as constant. Table 2 shows some detail parameters of compressors.

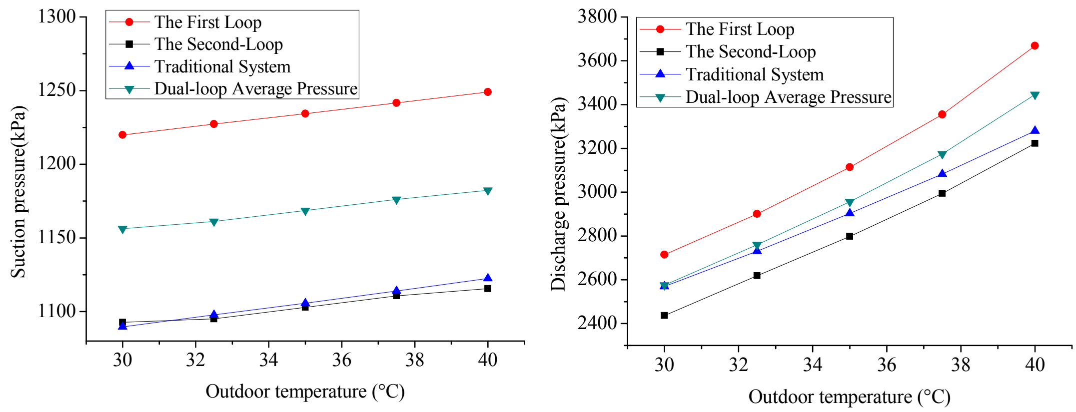
Table 2: Parameters of those compressors

Content	Cooling condition	Heating condition
Refrigerant	R410A	
Rotational speed(rpm)	3000	4800

5. SIMULATION RESULTS AND DISCUSSION

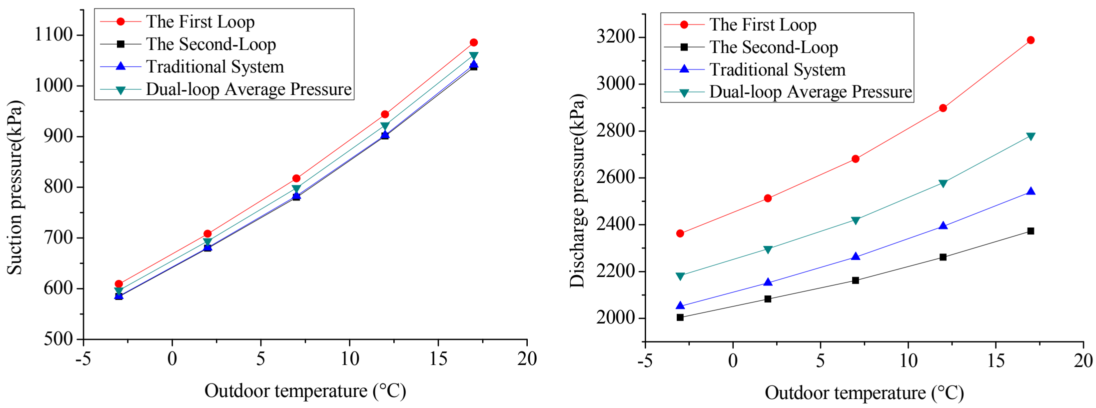
5.1 Suction Pressure and Discharge Pressure

Figure 6 and Figure 7 show the variation of suction pressure and discharge pressure of the dual-loop system compared with the traditional system under cooling and heating condition. With the increasing of outdoor temperature, the suction pressure and the discharge pressure of the dual-loop system and traditional system increase in cooling and heating condition. Both the suction pressure and the discharge pressure of the traditional system are lower than the dual-loop average pressure. The suction pressure and discharge pressure of the traditional system are between that of the first loop and the second loop. The reason is that the mean temperature of air is different between the dual-loop system and the traditional system. Higher mean temperature of the air could result in higher pressure of the refrigerant. For the evaporator, the air temperature decrease along with the heat transfer process. The air firstly enters into the evaporator in the first loop, and is cooled by the refrigerant. Then it enters into the evaporator in the second loop. Therefore, the mean temperature of the first loop is higher than that of the traditional system, while the mean temperature of the second loop is lower than that of the traditional system. For the condenser, the air temperature increase along with the heat transfer process. The air firstly enters into the condenser in the second loop and is heated by the refrigerant. Then it enters into the condenser in the first loop. Therefore, the mean temperature of the first loop is higher than that of the traditional system, while the mean temperature of the second loop is lower than that of the traditional system.



(a) Suction Pressure (b) Discharge Pressure

Figure 6: Cooling condition

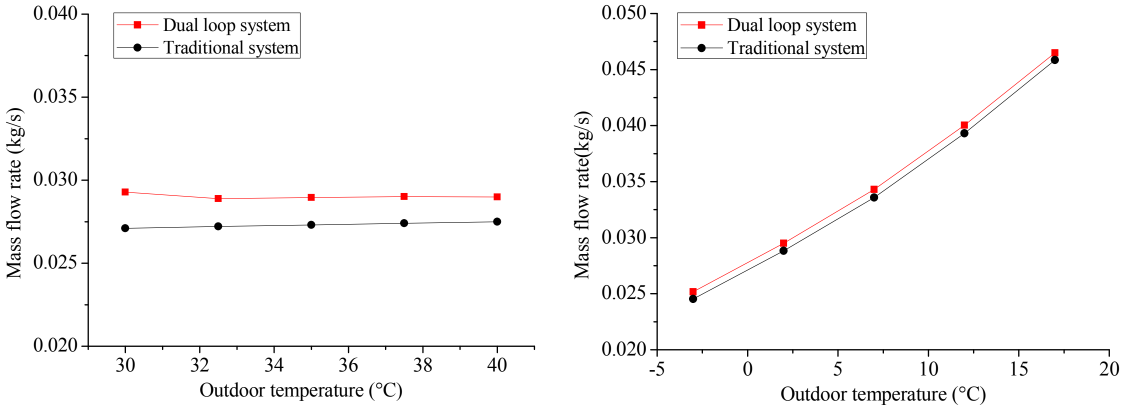


(a) Suction Pressure (b) Discharge Pressure

Figure 7: Heating condition

5.2 Mass Flow Rate

Figure 8 shows the variation of mass flow rate of the dual-loop system compared with the traditional system under cooling condition and heating condition. With the increasing of the outdoor temperature, the mass flow rate of the dual-loop system and traditional system increase in both cooling condition and heating condition. The mass flow rate of the dual-loop system is higher than that of the traditional system in both cooling condition and heating condition. The reason is that the average suction pressure of the dual-loop system is higher than that of the traditional system, while the displacement of the two type compressor is same. The suction pressure determines the refrigerant density in the suction port. The higher of the suction pressure results in the higher of the refrigerant density. Therefore, the mass flow rate of the dual-loop system is higher than that of the traditional system. The mass flow rate of the dual-loop system is 5.4% ~8.0% higher than that of the traditional system in cooling condition and1.4%~2.5% higher than that of the traditional system in heating condition.

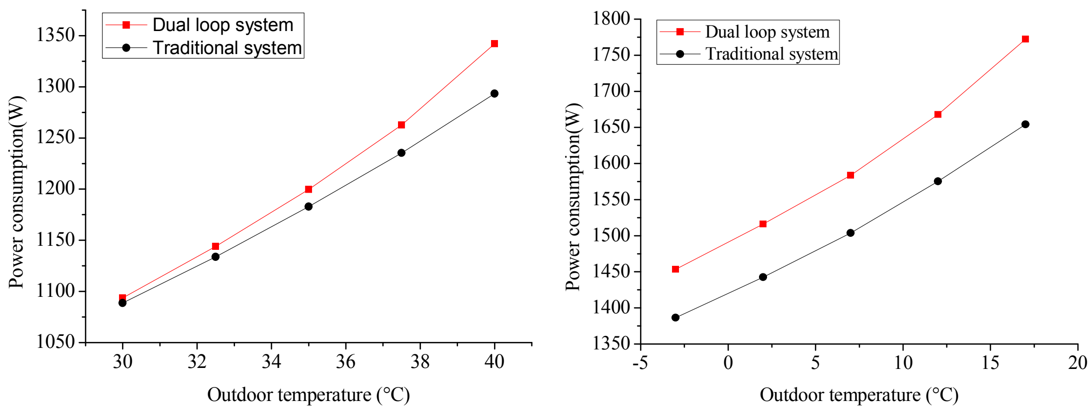


(a) Cooling condition (b) Heating condition

Figure 8: Mass flow rate

5.3 Power Consumption

Figure 9 shows the variation of power consumption of the dual-loop system compared with the traditional system under cooling condition and heating condition. With the increasing of the outdoor temperature, the power consumption increase in both cooling condition and heating condition. The power consumption of the dual-loop system is higher than that of the traditional system in both cooling condition and heating condition. The reason is that mass flow rate of the dual loop system is higher than that of the traditional system. Compressing more refrigerant means the compressor consumes more power. The power consumption of the dual-loop system is 0.5~3.8% higher than that of the traditional system in cooling condition and 4.8%~7.1% higher than that of the traditional system in heating condition.

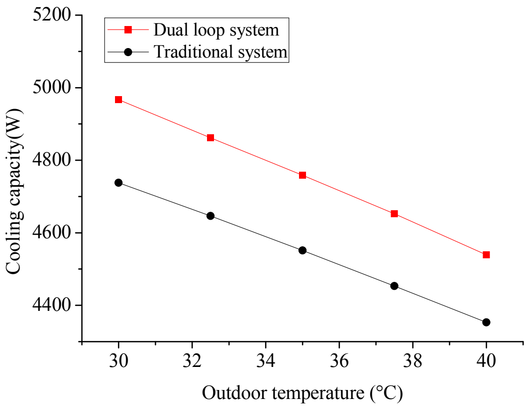


(a) Cooling condition (b) Heating condition

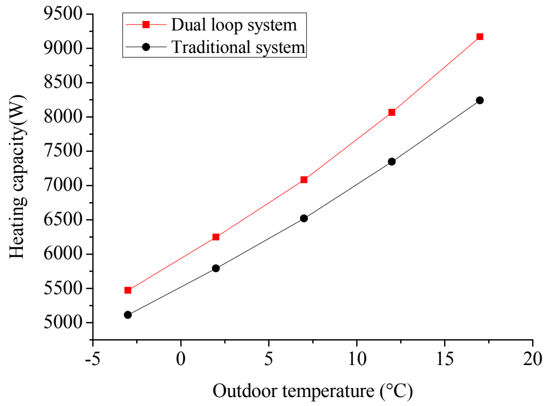
Figure 9: Power consumption

5.4 Cooling and Heating Capacity

Figure 10 shows the variation of cooling capacity and heating capacity of the dual-loop system compared with the traditional system under cooling condition and heating condition. With the increasing of the outdoor temperature, the cooling capacity decrease, while the heating capacity increase. Both the cooling capacity and heating capacity of the dual-loop system is higher than that of the traditional system in cooling condition and heating condition. The reason is that mass flow rate of the dual loop system is higher than that of the traditional system. The cooling capacity of the dual-loop system is 4.3~4.8% higher than that of the traditional system and the heating capacity of the dual-loop system is 7.0~11.3% higher than that of the traditional system.



(a) Cooling condition

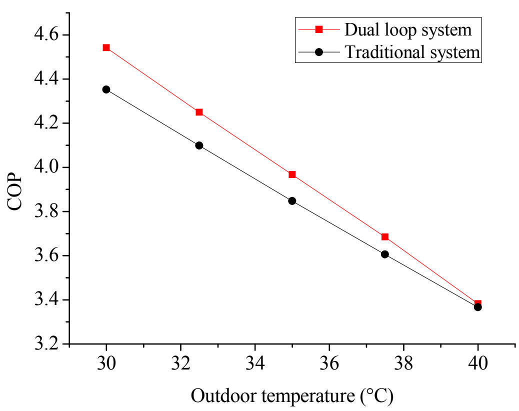


(b) Heating condition

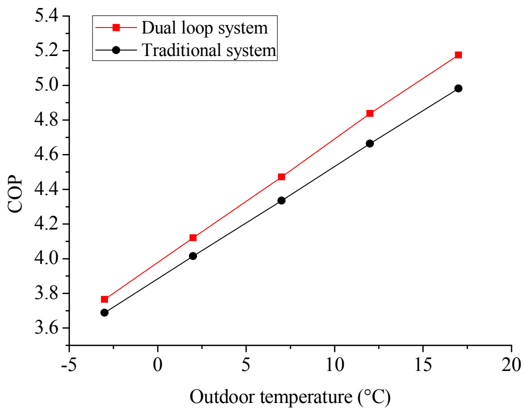
Figure 10: Cooling capacity and heating capacity

5.5 COP

Figure 11 shows the variation of COP of the dual-loop system compared with the traditional system under cooling condition and heating condition. With the increasing of the outdoor temperature, the COP decreases in cooling condition, while the COP increases in heating condition. The COP of the dual-loop system is higher than that of the traditional system in cooling condition and heating condition. It shows that the dual-loop system is more efficient than the traditional system. The COP of the dual-loop system is 0.5%~4.4% higher than that of the traditional system in cooling condition and 2.1%~3.9% higher than that of the traditional system in heating condition.



(a) Cooling condition



(b) Heating condition

Figure 11: Cooling capacity and heating capacity

6. CONCLUSIONS

A new dual-cylinder rolling piston compressor with two independent suction ports and two independent discharge ports was proposed, and this compressor was applied in a dual-loop system. Through building the simulation model of the dual-loop system and the traditional system, this paper came to the following main conclusions. The COP of the dual-loop system is 0.5%~4.4% higher than that of the traditional system in cooling condition and 2.1%~3.9% higher than that of the traditional system in heating condition.

NOMENCLATURE

The nomenclature of the equation during the text:

T	temperature	(K)

Subscript

H	High
L	Low

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