

Energy and Exergy Analysis of a Refrigeration System with Vapor Injection Using Reciprocating Piston Compressor

Hao-jie TANG^a, Shu-xi ZHENG^b, Yu-tao YANG^c, Chao WANG^d, You-xin ZHAO^e and Su-yan HE^{f,*}

School of Mechanical and Electrical Engineering, Qingdao University, Qingdao 266071, China

^a646149553@qq.com, ^b893471488@qq.com, ^c359662164@qq.com, ^d2859630915@qq.com,

^e18753296188@139.com, ^fhesuyan67829@sina.com

*He SuYan

Abstract—Vapor injection systems have been used on scroll compressor and rotary compressor. Literature about the use of vapor injection on reciprocating piston compressor are rare. In order to increase the application range of the piston compressor, based on the single stage circulatory system, a reciprocating piston compressor with injected quasi two-stage compression system was proposed. The experiment device with vapor injection is built by modifying the reciprocating piston compressor. Analysis of exergy losses and exergy efficiency of the system are carried out. The results show that the intermediate injection system can reduce exergy loss system and expand the application range of reciprocating piston compressor.

Keywords-reciprocating piston compressor; Intermediate injection; exergy destruction; exergy analysis

I. INTRODUCTION

In recent years, with the continuous development of the refrigeration industry, compressor technology is also improved. Piston compressor with power less than 16HP was crowded out by the progressively expanded scroll compressor; In low temperature applications, more than 40HP piston compressor section was supplanted by the small screw compressor. Although the high and low temperature market was occupied by other models, the piston compressor in the range of 16HP-40HP still has a high performance-price ratio, faced with high challenge, piston compressors are competitive in the future market.

Compared with the two stage compression refrigeration system, the quasi two stage compression system was greatly simplified, the various compressor quasi two stage compression cycle can adapt to the changing work conditions. Heating and cooling capacity and efficiency are improved when compressors are off-design conditions. The performance of the system is stable, and easy to increase the refrigerating capacity and COP after a simple transformation of the original machine [1-3].

However, the quasi-two-stage compression cycle with vapor injection has been widely used in the screw compressors and scroll compressors systems [4-8]. Literature about piston compressor with vapor injection are rare. The paper presents a refrigeration cycle of piston compressor with vapor injection (PCVI). The single stage refrigeration compression cycle (SSRC) is regarded as the

contrast. The two systems are compared and analyzed.

II. CYCLE SYSTEM DESCRIPTION

The schematic diagram of experiment device is showed in Fig.1, and the pressure enthalpy diagram of the system is expressed in Fig.2. The baseline single stage refrigeration cycle was 1-2-4-5-1, the main difference between the PCVI and the SSRC was that the high pressure refrigerant liquid from the condenser was divided into two ways, refrigeration loop 4'-5-1-2'-1 and injection loop 4-6-7, the 7-9-8 was refrigerant and refrigeration vapor mixing process, the 1-9-2' was a compression process. Part of refrigerant with medium temperature and high pressure from the condenser outlet was injected into the cylinder compression stroke of the reciprocating piston compressor in order to achieve the effect of quasi-two-stage compression.

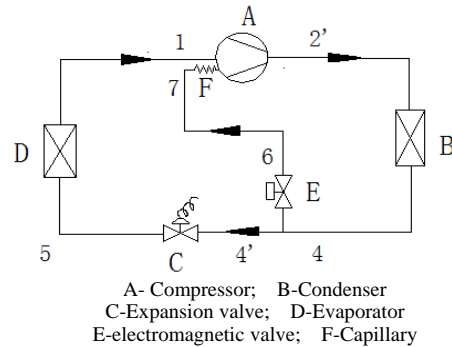


Figure 1. Schematic diagram of the experiment device

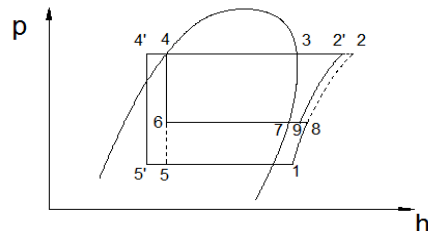


Figure 2. Pressure-enthalpy diagram of the PCVI and SSRC

III. THERMAL ANALYSIS OF THE SYSTEM

The refrigeration system uses R134a as the refrigerant, tests are carried out under the condition of atmosphere pressure 0.1MPa, relative humidity 75%, power 220V/50HZ±5%. Two sets of data were recorded by measuring the normal operation of the contrast (SSRC) and the system with vapor injection (PCVI).

The following assumptions were made for the energy analysis and exergy analysis:

1) Each circulation component is in a stable state and the flow is steady;

2) The variation of potential energy and kinetic energy of refrigerant at the inlet and outlet were negligible;

3) Throttling process is the isoenthalpy process. Pressure drop and heat losses of refrigerant in the cycle were neglected.

The energy analysis method based on the first law of thermodynamics is used to evaluate the performance of the total refrigeration system. The result is showed in table 1.

TABLE I. REFRIGERATION PARAMETER OF SSRC AND PCVI.

System	q	W	Q	COP
SSRC	165.1	440.0	595.7	1.35
PCVI	169.8	484.0	579.3	1.20

As can be seen from Table 1, the PCVI improved the unit refrigeration capacity, but because of the refrigerant injection process without economic heat exchanger, the total refrigeration capacity was reduced. Intermediate injection of the refrigerant compressor caused a slight increase in compressor power leading to the COP of IRC declined.

In order to further evaluate the intensity of the irreversibility at every cycle component, the exergy analysis is employed in the study to further explore the thermodynamic performance of the two systems [9-11].

A. For Compressor Process

The SSRC

$$Ex_{d.com} = T_0(s_2 - s_1) \quad (1)$$

The PCVI

$$Ex_{d.com} = T_0(s_2' - s_1) \quad (2)$$

B. For Condenser Process

The SSRC

$$Ex_{d.con} = h_2 - T_0s_2 - (h_4 - T_0s_4) \quad (3)$$

The PCVI

$$Ex_{d.con} = h_2' - T_0s_2' - (h_4' - T_0s_4') \quad (4)$$

C. For Expansion Process

The SSRC

$$Ex_{d.exp} = T_0(s_5 - s_4) \quad (5)$$

The PCVI

$$Ex_{d.exp} = T_0(s_5' - s_4') \quad (6)$$

D. For Evaporation Process:

The SSRC

$$Ex_{d.eva} = T_0(s_1 - s_5) - (h_1 - h_5) \frac{T_0}{T_0^*} \quad (7)$$

The PCVI

$$Ex_{d.eva} = T_0(s_1 - s_5') - (h_1 - h_5') \frac{T_0}{T_0^*} \quad (8)$$

Total exergy destruction:

$$Ex_{d.t} = Ex_{d.com} + Ex_{d.con} + Ex_{d.exp} + Ex_{d.eva} \quad (9)$$

Exergy efficiency:

$$\eta_{Ex} = 1 - \frac{Ex_{d.t}}{W_{com}} \quad (10)$$

The results of exergy analysis of the two systems were shown in exergy flow diagram Fig. 3, when the condensing pressure was 0.58MPa.

Fig.3 shows that the compression destruction of SSRC system accounted for 20.3% of the compressor exergy input. In order to minimize the energy consumption, energy saving should be the compression process. The compressor destruction and the evaporator destruction of the system PCVI are reduced, while condenser destruction and expansion destruction of the system PCVI are raised. Since the the throttling process of PCVI system did not use methods such as an economic heat exchanger or an ejector, the heat recovery and other methods to reduce the throttle loss [12]. The exergy destruction of expansion process is raised in the PCVI system, thus leading to the exergy efficiency reduction of the system.

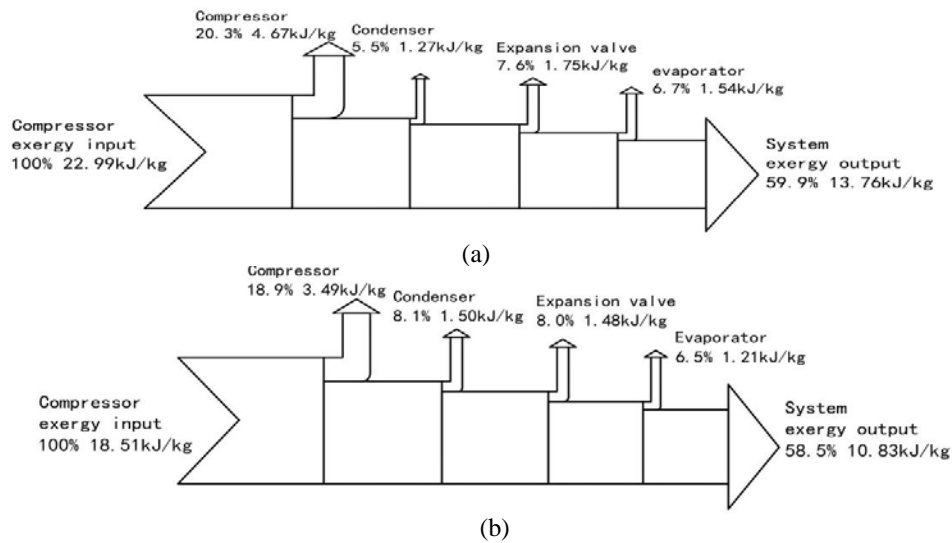


Figure 3. Exergy flow diagrams for the SSRC (a) and PCVI (b)

IV. CONCLUSION

The PCVI system reduced total system exergy destruction, especially the compression exergy destruction. The PCVI system expanded the use range of the piston compressor, and improved the performance of compressor in low temperature and high temperature conditions. The system has only one compressor, which makes the system institutions simple, easy to maintenance. The system should be more widely used. Because no measures are taken to reduce the throttling losses in the present study, further improvement of the PCVI system will be carried out in the next work.

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Nomenclature			
q	unit refrigeration capacity (kJ/kg)	P	pressure (Pa)
W	compressor power (W)	h	enthalpy (kJ/kg)
Q	refrigeration capacity (W)	S	entropy (kJ/kg·K)
COP	coefficient of performance	T	temperature (K)
E_x	exergy rate of fluid (kJ/kg)		Subscripts
E_{xd}	exergy destruction (kJ/kg)	com	compressor
η_{Ex}	exergy destruction percentage	con	condenser
T_0	environment temperature	exp	expansion
T_0^*	refrigeration temperature	eva	evaporator
SSRC	single stage refrigeration compression cycle	1-9	state points of refrigerant
PCVI	refrigeration cycle of piston compressor with vapor injection	d	destruction