2014

Experimental Study on Performance of Two-phase Ejector Refrigeration Cycle System with Two-throat Nozzle

Li Qian Ren
Tianjin University of Commerce, People's Republic of China, renliqian2011@163.com

Xian Min Guo
Tianjin University of Commerce, People's Republic of China, xmguo@tjcu.edu.cn

Xin Wei Guo
Tianjin University of Commerce, People's Republic of China, 605500616@qq.com

Tian Long Li
Tianjin University of Commerce, People's Republic of China, olitianlongo@sina.com

Experimental Study on Performance of Two-throat Nozzle Ejector and Two-phase Ejector Refrigeration Cycle System

Liqian REN [1], Xianmin GUO [2]*, Xinwei GUO[3], Tianlong LI [4]

Tianjin Key Laboratory of Refrigeration Technology, Tianjin University of Commerce, Tianjin, China
[1] Phone: +0086 22 26669660, E-mail: renliqian2011@163.com

[2] Phone/Fax: +0086 22 26686268, E-mail: xmguo@tjcu.edu.cn

[3] Phone: +0086 22 26669660, E-mail: 605500616@qq.com

[4] Phone: +0086 22 26669660, E-mail: olitianlongo@sina.com

ABSTRACT

The two-phase ejector refrigeration cycle (TPERC) system with a two-throat nozzle ejector was investigated experimentally, and the entrainment ratio of the ejector and the COP of the system were compared with those of the ejector with Laval nozzle and its TPERC system respectively. The experimental results indicate that under the working condition of the evaporating/condensing temperatures 1℃/45℃, the entrainment ratio of the two-throat nozzle ejector with different geometric size is greater than that of the Laval nozzle ejector, the maximum increment of the entrainment ratio is about 18%, and the COP of the TPERC system with two-throat nozzle ejector is greater than that of the TPERC system with Laval nozzle ejector, the maximum increment of the COP is about 12%. Under the fixed evaporating temperature 1℃, the entrainment ratio of the two-throat nozzle ejector and the Laval nozzle ejector achieve the maximum as the condensing temperature is 45℃. Under the fixed condensing temperature 50℃, the entrainment ratio of the two types of ejectors achieves the maximum as the evaporating temperature is 3℃.

1. INTRODUCTION

At present, the expansion work in the refrigeration cycle can be recovered by using two methods. One is to replace the expansion valve with expander (Xia et al., 2013) and run the fan or compressor with the output power of the expander. There are many technical problems, such as wet expansion in the impeller and reliability of the expander, to be solved. Another is to use the ejector instead of expansion valve (Sumeru et al., 2012). The refrigerant expands in the nozzle and the high pressure energy is converted into kinetic energy. The high velocity flow at the outlet of the nozzle entrains the refrigerant steam from the evaporator and the mixture is diffused subsequently. In the ejector the high pressure energy of the refrigerant is recovered and the suction pressure of the compressor is increased, so the performance of the refrigeration cycle is improved.

A lot of studies on the performance of the TPERC system and the ejector were reported. Chaiwongsa and Wongwises (2007) studied the effects of the throat diameter on the performance of the ejector. Nakagawa et al. (2010) investigated the effect of the mixing length on the ejector system performance experimentally. The results showed that the mixing length had significant effect on the entrainment ratio, the magnitude and profile of the pressure recovery. Liu and Groll (2013) established the empirical correlations to estimate the ejector component efficiencies at different ejector geometries and operation conditions. The system simulation model predicted the COP and the cooling capacity within ±8% and ±12% of the measured one, respectively. Wang and Deng (2012) established the mathematical model of the ejector with contrivable back pressure in a transcritical CO_2 ejector-expansion refrigeration cycle and analyzed the effects of the ejector back pressure and outlet velocity on the system. Yazdani et al. (2012) provided the capability through pragmatic integration of multiple separately validated sub-models for mass and energy transfer between phases, two-phase sonic velocity, and real-fluid properties with an underlying commercial CFD simulation through user-defined functions.

In all of the published literatures about TPERC system the Laval nozzle ejector were used. In this paper a new type of two-throat nozzle ejector was introduced, and the performance of the ejector with different geometric size in TPERC system under the variable working conditions were investigated experimentally.

2. EXPERIMENTAL SETUP

The diagram of the experimental setup is shown in figure 1. The refrigeration system is consists of the compressor, evaporators, condenser, two-throat nozzle ejector, gas-liquid separator, liquid separator and other accessories. R134a is used as refrigerant. This system can be used for experiments of the TPERC system or the traditional refrigeration cycle system by controlling the state (open or close) of the valves No.1-5 (Pei et al., 2013). The working process of the system was detailed in the reference of Pei et al. (2013).

All the measuring points of the pressure, temperature and flow rate are marked in figure 1. The precision of the platinum resistance temperature sensor and the pressure sensor are ±0.1 ℃ and ±0.1 %FS, respectively. The mass flow rate of R134a and the flow rate of water are measured by using the mass flow meter (±0.1%R) and the turbine flow meter (±0.5%R), respectively. The power consumption of the compressor is measured in terms of a power transducer (±0.5%).The cooling water of the condenser is supplied by the water chiller, of witch the temperature is adjusted by the electric heater. The chilled water from the evaporator is heated and the temperature of the chilled water at the inlet of the evaporator is adjusted by the electric heater. The flow rates of both the cooling water and the chilled water are controlled by adjusting the rotation speed of the water pumps. The refrigeration capacity can be calculated by the water temperature deference between the inlet and outlet of the evaporator and the mass flow rate of the chilled water, also can be got by the enthalpy difference between the refrigerant inlet and outlet of the evaporator and the mass flow rate of the R134a, then the COP can be calculated with the compressor power consumption. The entrainment ratio can be determined with the mass flow rate of the main flow and the secondary flow into the ejector.

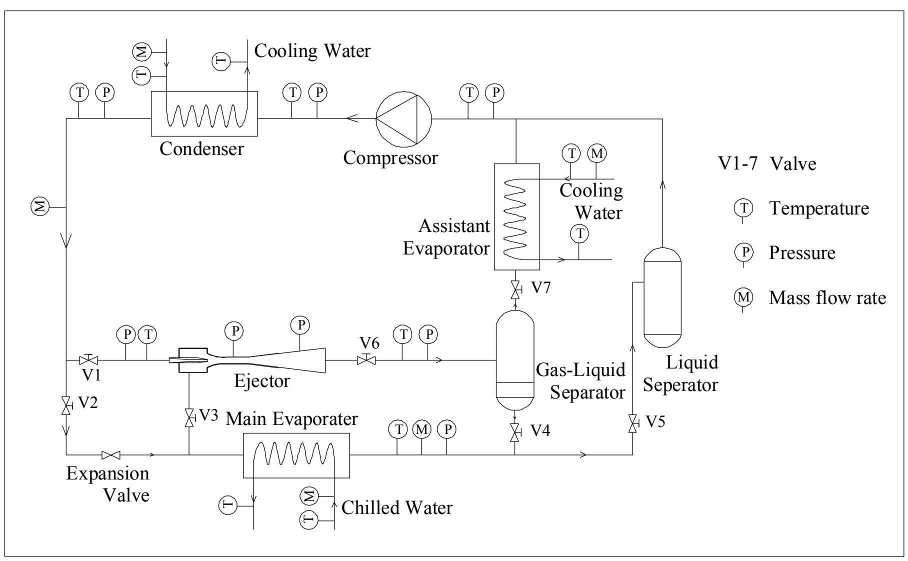

Figure 1: Diagram of experimental setup of TPERC System

Figure 2 is the schematic diagram of the two-throat nozzle ejector. In the traditional ejector, the difference between the vapor and liquid velocities at the outlet of the Laval nozzle is very large resulting from the great difference between vapor and liquid density and large droplet diameter of the liquid refrigerant, witch lead to lower entrainment ratio of the Laval nozzle ejector [2]. In the two-throat nozzle ejector, the two Laval nozzle is set serially. The gas-liquid refrigerant mixture from the first Laval nozzle flow into the second negative throat nozzle and the liquid refrigerant droplets are broken into smaller one. The refrigerant velocity can achieve sonic at the second throat and then supersonic in the expansion section of the second nozzle. It can be expected that the performance of the ejector with the two-throat nozzle is improved.

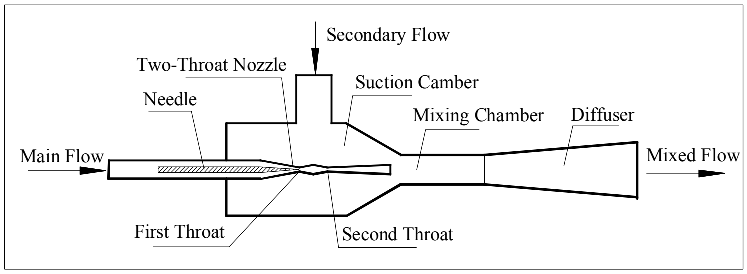

Figure 2: Schematic diagram of two-throat nozzle ejector

3. EXPERIMENTAL RESULTS AND ANALYSIS

In order to verify the performance and the factors affecting the performance of the two-throat nozzle ejector, a series of experiments for the ejectors with different dimensional two-throat nozzles and the Laval nozzles under different working conditions were conducted. The experimental prototype of the ejector was designed as a removable nozzle. For all of the experiments the ejector was the same except the nozzle. The cross-sectional throat area of the experimental nozzles is shown in the table 1. The diffuse angle of the expansion section for all of the nozzles is 3°.

Table 1: Cross-sectional throat area of experimental nozzles

Prototype Number		No.1	No.2	No.3	No.4	No.5
Laval nozzle			2.55 mm^2	2.84 mm^2	3.14 mm^2	3.46 mm^2
Two-Throat Nozzle	**First Throat**	2.27 mm^2	2.55 mm^2	2.84 mm^2	3.14 mm^2	3.46 mm^2
	Second Throat	2.27 mm^2				

3.1 Effect of Cross-Sectional Throat Area of Nozzle

The COP of the TPERC system and the entrainment ratio of the ejector with different cross-sectional throat area of the nozzles under the working condition of the evaporating/condensing temperatures 1℃/45℃ are shown in the figure 3.

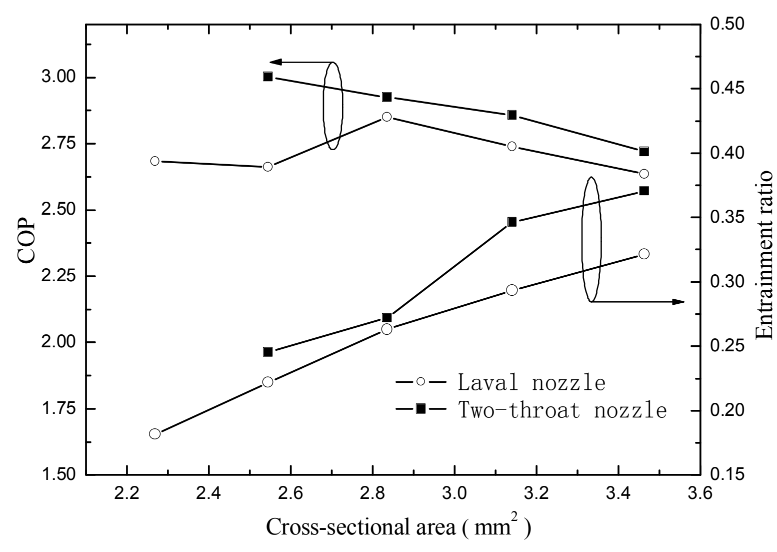

Figure 3: System COP and entrainment ratio of ejector with throat area of nozzle

As shown in figure 3, the entrainment ratio of both the two-throat nozzle ejector and the Laval nozzle ejector increases with the increase in the cross-sectional throat area, but the entrainment ratio of the two-throat nozzle ejector is greater than that of the Laval nozzle ejector, and the maximum increment of the entrainment ratio is about 18%. The COP of the TPERC system with the Laval nozzle ejector achieves the maximum value as the cross-sectional throat area is about 2.84mm^2. The COP of the TPERC system with two-throat nozzle ejector decreases with the increase in the cross-sectional throat area of the nozzle, and is greater than that of the TPERC system with the Laval nozzle ejector. The maximum increment of the system COP is about 12%. This is because that the use of the two-throat nozzle in the ejector improves the entrainment ratio of ejector, as well as the refrigerating capacity of the system, and the power consumption of the TPERC system with two-throat nozzle ejector is almost the same to that of the TPERC system with the Laval nozzle ejector.

3.2 Effect of Condensing Temperature

Figure 4 shows the variation of the system COP and the entrainment ratio of the ejector in terms of the nozzle prototype No.5 (Tab. 1) with the condensing temperature under the working condition of evaporating temperature 1℃.

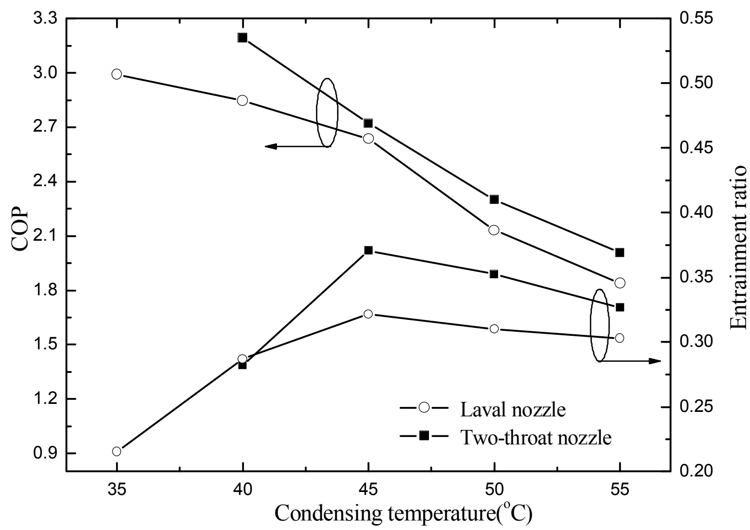

Figure 4: Variation of system COP and entrainment ratio of ejector with condensing temperature

It can be seen in the figure 4 that the COP of the TPERC system with both the two types of nozzle ejector decreases with the increase in the condensing temperature, and the COP of the system with the two-throat nozzle ejector is greater than that with the Laval nozzle ejector. This is caused by the increase in the power consumption of the compressor. The variation trend of the entrainment ratio of the ejector with the condensing temperature is different from that of the system COP, the entrainment ratio of both the two-throat nozzle ejector and the Laval nozzle ejector achieves the maximum value as the condensing temperature is 45℃, and the entrainment ratio of the two-throat nozzle ejector is greater than that of the Laval nozzle ejector. This is because of the increase in the pressure difference between the inlet and outlet of the nozzle with the increase in the condensing temperature. As the condensing temperature is less than 45℃, the pressure difference is small, so the shock wave in the ejector is weak and the outlet velocity of the nozzle, as well as the entrainment ratio, increases with the increase in the pressure difference. When condensing temperature is higher than 45℃, the shock wave moves into the nozzle, and the pressure difference is higher, the shock wave is stronger, so the entrainment ratio decreases with increase in the condensing temperature.

3.2 Effect of Evaporating Temperature

Under the working condition of condensing temperature 50℃, the variation of the system COP and the entrainment ratio of the prototype ejector No. 5 (Tab. 1) with evaporating temperature is shown in figure 5.

As shown in the figure 5, the entrainment ratio of both the Laval nozzle ejector and the two-throat nozzle ejector achieves the maximum value as the evaporating temperature is 3℃ under the working condition of condensing temperature 50 ℃. The explanation about this trend is similar to the above effect of the condensing temperature. The COP of the system with two types of ejectors increases with the increase in the evaporating temperature under the fixed condensing temperature. Both the entrainment ratio and COP of the system with two-throat nozzle ejector is higher than those of Laval nozzle ejector.

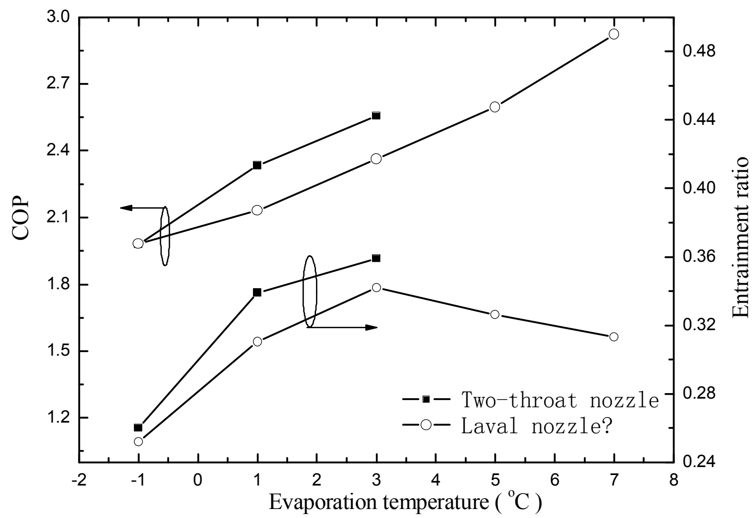

Figure 5: Variation of system COP and entrainment ratio of ejector with evaporation temperature

4. CONCLUSIONS

The two-phase ejector refrigeration cycle system with a two-throat nozzle ejector was investigated experimentally, and the entrainment ratio of the ejector and the COP of the system were compared with those of the ejector with Laval nozzle and its TPERC system respectively, the conclusions as follow can be obtained:

- The experimental results indicate that under the working condition of the evaporating/condensing temperatures 1℃/45℃, the entrainment ratio of the two-throat nozzle ejector with different geometric size is greater than that of the Laval nozzle ejector, the maximum increment of the entrainment ratio is about 18%. The entrainment ratio of the two types of ejectors increases with the increase in the cross-sectional throat area. The COP of the TPERC system with the two-throat nozzle ejector is greater than that of the TPERC system with the Laval nozzle ejector, and the maximum increment of the system COP is about 12%.
- Under the working condition of the fixed evaporating temperature 1℃, the entrainment ratio of the two types of ejectors achieves the maximum as the condensing temperature is about 45℃, the entrainment ratio of the two-throat nozzle ejector increases by 15.2% compared to that of the Laval nozzle ejector.
- Under the working condition of the fixed condensing temperature 50℃, the entrainment ratio of the two-throat nozzle ejector achieves the maximum as the evaporating temperature is about 3℃ and increases by 5.1% compared to that of the Laval nozzle ejector.

REFERENCES

Chaiwongsa, P., Wongwises, S., 2007, Effect of Throat Diameters of the Ejector on the Performance of the Refrigeration Cycle Using a Two-phase Ejector as an Expansion Device, *Int. J. of Refrigeration,* vol. 30: p601-608.

Liu, F., Groll, E., A., 2013, Study of Ejector Efficiencies in Refrigeration Cycles, *Applied Thermal Engineering*, vol. 52: p360-370.

Nakagawa, M., Marasigan, A., R., Matsukawa, T., et al. 2010, Experimental Investigation on the Effect of Mixing Length on the Performance of Two-Phase Ejector for CO2 Refrigeration Cycle with and without Heat Exchanger, *Int. J. of Refrigeration*, vol. 30(1): p1-10.

Pei, W., Guo, X., Wang S., et al. 2013, Effects of Geometric Parameter on Performance of Ejector and Two-Phase Ejector Refrigeration System, *J. of Refrigeration*, vol.34(1):65-68.

Sumeru, K., Nasution, H., Ani F., N., 2012, A Review on Two-Phase Ejector as an Expansion Device in Vapor Compression Refrigeration Cycle, *Renewable and Sustainable Energy Reviews,* vol. 16(7):p4927- 4937.

Takeuchi, H., Nishijima, H., Ikemoto, T., World's First High Efficiency Refrigeration Cycle with Two-Phase Ejector: "Ejector Cycle", 2004, *SAE World Congress,* Paper 2004-01-0916, Detroit, MI, USA.

Wang, F., Deng J., 2012, Critical Back Pressure of Transcritical Carbom Dioxide Refrigeration Cycle with Ejector, *J. of Xi'an Jiaotong University*, vol. 46(9):66-70.

Xia, C., Zhang, W., Bu, G., et al, 2013, Experimental Study on a Sliding Vane Expander in the HFC410A Refrigeration System for Energy Recovery, *Applied Thermal Engineering,* vol. 59: p 559-567.

Yazdani, M., Alahyari, A., A., Radcliff, T., D., Thomas D.Radcliff. 2012, Numerical Modeling of Two-Phase Supersonic Ejectors for Work-Recovery Applications, *Int. J. of Heat and Mass Transfer,* vol.55:5744-5753.

ACKNOWLEDGEMENT

The financial support of this work by National Natural Science Foundation of China (No.51176142) is gratefully acknowledged.