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Analysis of Entrainment Ratio about Solar Ejector Refrigerant System

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Abstract

Based on the VB program, establish a simulation program about the solar ejector system performance. The characteristic of entrainment ratio has been analyzed when the HFC134a, R290 and R718 are adopted as working fluid respectively. It is found that the entrainment ratio of R290 is the biggest over the range of operating conditions, and the entrainment ratio of HFC134a is the middle, and the R718's is the least. The entrainment ratio of the system increases with increasing of the generator temperature and evaporator temperature, and decreases with increasing of the condenser temperature in the research of operating range, and the influence of condenser temperature on the ejector refrigerant system is more than the generator temperature and evaporator temperature. The research will provide theoretical support for solar ejector refrigeration technology optimization design and extension.

Keywords: Type your keywords here, separated by semicolons ;

1. Introduction

Along with the economic development of all countries in the world accompanied by the growing demand for energy, such as solar energy, wind energy, pollution-free clean as a renewable energy has been paid more attention by people, and in the solar energy application study, ERS has some special advantages such as the simplicity in construction, high reliability and low cost compared with other refrigeration system. So, ejector refrigeration system has also become a topic of interest for research in recent years, such as Dorantes[1] take theoretical calculation method, the application of R142b in ejector refrigerant system is studied. The performance of the solar-driven ejector refrigeration system with iso-

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butane as the refrigerant by dynamic simulation has studied[2]. Mani et al experimented on the performance of ejector refrigeration system with working refrigerant ammonia, HFC134a, HFC152a and HFC290[3~5]. The performance of an ejector cooling system driven by solar energy and HFC134a as working fluid has been described[6]. Yapici [7] has studied the character of R11 ejector system.

In relevant performance calculation about solar ejector refrigerant system, the entrainment ratio must be determined first, and then the rest performance can to be calculated. Therefore, on the basis of the predecessor's research work, using the one-dimensional pressure calculation model has established the solar ejector refrigerant system entrainment ratio calculation model, and the operation performance of the different refrigerants such as: HFC134a, R290, the R718 has been analyzed.

Nomenclature

M	Mach number
P	pressure
η_d	efficiency of diffuser
η_m	efficiency of mixing
η_n	ejector efficiency of the nozzle
μ	entrainment ratio
κ	adiabatic inflation index

2. Entrainment Ratio Calculation Model

In the performance analysis and calculation about solar ejector refrigerant system, entrainment ratio is the most key parameter, in a certain expansion ratio and compression ratio, the bigger of entrainment ratio the better. The size of the entrainment ratio is affected by many factors, such as the character of the refrigerant, the pressure of driving fluid, the entrained refrigerant and the outlet of ejector refrigerant, and the shape and size, and so on. The flow character of ejector can be determined by thermodynamic calculation theory, but in fact the steam flow process remain is very complicate, and its thermodynamic performance also need further research. In this paper, adopting the one dimensional pressure calculation model, a simulation program has been established based on the assumptions [5]:

① The driving flow is isentropic expansion on the nozzle of ejector, and the mixture of the driving flow and the entrained refrigerant is isentropic compression on diffuser of ejector.
② Ignore the inlet speed of the entrained refrigerant and mixed fluid export section of ejector.
③ Refrigerant steam flow is adiabatic.
④ Friction loss is defined as the efficiency of the nozzle, diffusion chamber, and the mixing chamber.
⑤ Driving flow and the entrained refrigerant have the same molecular weight and specific heat.
⑥ The internal flow condition of ejector is one-dimensional and steady-state flow.
⑦ Work steam and ejector fluid in 1-4 maintain between the cross section of conservation of momentum and kinetic energy conservation.

When the high pressure driving flow flows the convergent nozzle, on the basis of energy balance, it can be concluded that：

$$V_{1g}^2 = 2\cdot\eta_n(h_g - h_1) \qquad (1)$$

The Mach number of driving flow on the nozzle exit is[5]：

$$M_{1g} = \sqrt{\frac{2 \cdot \eta_n}{\kappa - 1} \cdot \left[\left(\frac{P_g}{P_1} \right)^{((\kappa-1)/\kappa)} - 1 \right]} \tag{2}$$

The Mach number of the entrained refrigerant on the nozzle exit is [5]:

$$M_{1e} = \sqrt{\frac{2}{\kappa - 1} \cdot \left[\left(\frac{P_e}{P_1} \right)^{((\kappa-1)/\kappa)} - 1 \right]} \tag{3}$$

Based on the law of momentum conservation, can be derived: $P_1 \cdot A_1 + m_g \cdot V_{1g} + m_e \cdot V_{1e} = P_3 \cdot A_3 + (m_g + m_e) \cdot V_3$

Consider the efficiency of mixing, ultimately, the critical Mach number can be derived:

$$M_3^* = \frac{\eta_m \cdot M_{1'}^* + \mu \cdot M_{1''}^* \sqrt{T_e / T_g}}{\sqrt{(1+\mu) \cdot (1 + \mu \cdot T_e / T_g)}} \tag{4}$$

The relationship of between actual Mach number and critical Mach number [5]:

$$M^* = \sqrt{\frac{M^2 (\kappa + 1)}{M^2 (\kappa - 1) + 2}} \tag{5}$$

The Mach number of steam mixed flow behind of the shock is:

$$M_4 = \sqrt{\frac{M_3^2 + 2/(\kappa - 1)}{2\kappa M_3^2 / (\kappa - 1) - 1}} \tag{6}$$

The pressure increase of steam mixed flow on the shock is:

$$\frac{P_4}{P_3} = \frac{1 + \kappa \cdot M_3^2}{1 + \kappa \cdot M_4^2} \tag{7}$$

The pressure increase of steam mixed flow on the diffuser is:

$$\frac{P_c}{P_4} = \left[\frac{\eta_d (\kappa - 1)}{2} M_4^2 + 1 \right]^{(\kappa/(\kappa-1))} \tag{8}$$

The performance coefficient of solar ejector refrigerant system is：

$$COP = \mu \frac{q_e}{q_g} \tag{9}$$

3. Calculation Program

On the basis of the above analysis, a computer simulation model has been developed by VB program, and the thermal physical of refrigeration can be got by Refprop7.0 software. The input includes T_g , T_e , T_c and m_e , which express the generator temperature, evaporation temperature, condenser temperature and refrigerants flow of evaporator respectively. The output is the optimal entrainment ratio, and the program flow can be seen from figure 1.

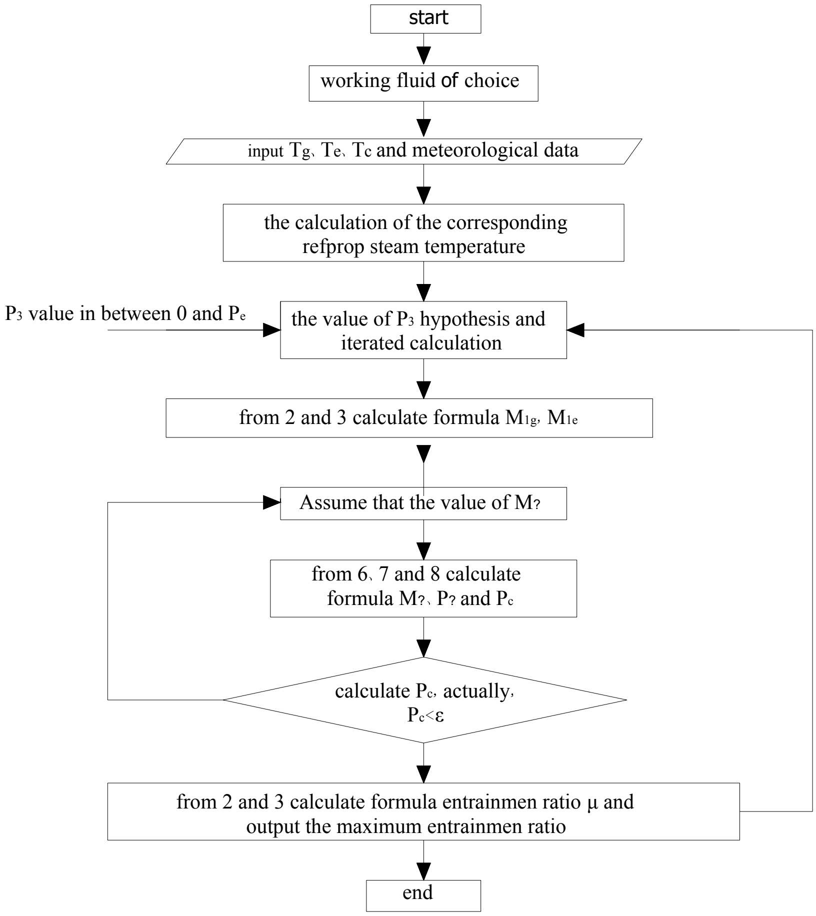

Fig. 1. Simulation flow chart for ejector performance analysis

4. Result and Discussion

In order to understand the character of entrainment ratio of solar ejector refrigerant system, this paper selects R290, HFC134a and R718 as refrigerant, and research the change trend of entrainment ratio under different condenser temperature, the evaporation temperature, and generator temperature.

Fig.2 shows the changes of the entrainment ratio with generator temperature when the R718, HFC134a, R290 as refrigerant under the condition of evaporation temperature and condenser temperature constant. Fig.2 shows the effect of entrainment ratio for different generator temperature, and it is known that the entrainment ratio increases with the increasing generator temperature in research condition, when the refrigerant is R718, the entrainment ratio fluctuates between 0.10 and 0.22, and is between 0.23 and 0.45 for HFC134a, and is between 0.24 and 0.46 for R290. The average entrainment ratio for different refrigerant is 0.15, 0.33, 0.35 in turn.

The variation of entrainment ratio for different evaporation temperature is shown in Fig.3. As shown in Fig. 3, the entrainment ratio increases with the increasing evaporation temperature in research condition when the generator temperature and condenser temperature, and when the refrigerant is R718, the entrainment ratio fluctuates between 0.15 and 0.46, and is between 0.36 and 0.68 for HFC134a, and is between 0.38 and 0.68 for R290. The average entrainment ratio for different refrigerant is 0.29, 0.51, 0.53 in turn.

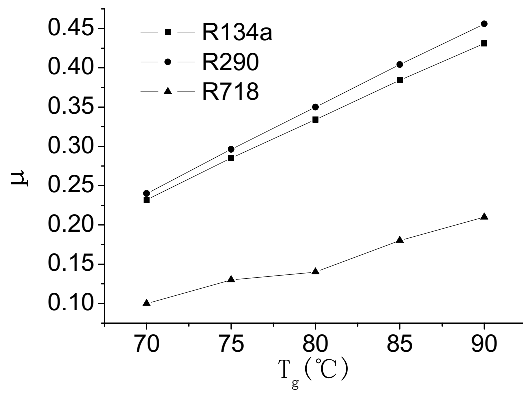

Fig.2. Effect of entrainment ratio for different generator temperature(evaporation temperature equal 7℃， and condenser temperature equal 32℃)

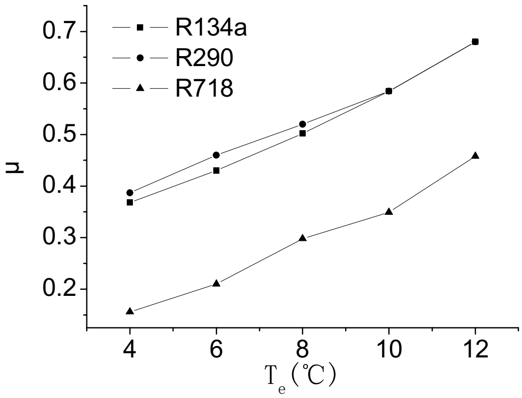

Fig.3. Effect of entrainment ratio for different evaporation temperature (generator temperature equals to 85℃， and condenser temperature equals to 32℃)

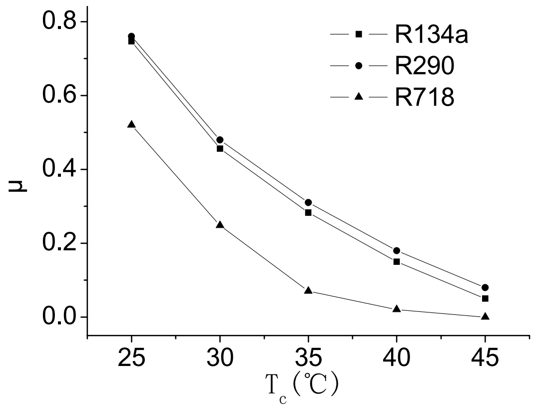

Fig.4 Effect of entrainment ratio for different condenser temperature when evaporation temperature equals to 7℃， and generator temperature equals to 85℃)

The variation of entrainment ratio for different condenser temperature is shown in Fig.4. As shown in Fig. 4, the entrainment ratio decreases with the increasing condenser temperature in the scope of research condition when the generator temperature and evaporation temperature is constant. When the refrigerant is R718, the entrainment ratio fluctuates between 0.00 and 0.52, and is between 0.05 and 0.75 for HFC134a, and is between 0.08 and 0.76 for R290. The average entrainment ratio for different refrigerant is 0.17, 0.34, and 0.36 in turn. In addition, it still can be found that when condensing temperature reaches a critical value, the entrainment ratio will appear reach 0, and the reason may help to the inherent critical condensing characteristics of ejector.

In addition, through the comparison among of the figure 2~figure 4, it is known that the change of condenser temperature have the most influence on the entrainment ratio. The condenser temperature increase 1, and the entrainment ratio can increase more than 30%, far outweigh the evaporation temperature and generator temperature. So, when the system designs, should try to minimize the fluctuation of condenser temperature, and make the system works within in a relatively stable condition.

5. Conclusion

Through to the analysis of the solar ejector refrigerant system, based on VB program, an entrainment ratio calculation model has been established, and the comprehensive research is conducted about the evaporation temperature, condenser temperature and generator temperature. The effect of the entrainment ratio for the refrigerant is R290, HFC134a, and R718 respectively, and the results can be summarized as follows：

1. The entrainment ratio increases with the increasing evaporation temperature and generator temperature, and decreases with the increasing condenser temperature in research condition.
2. The calculation results show that, when the solar ejector refrigerant system adopts the HFC134a, R290, and R718 as refrigerant, under the same condition, R290 entrainment ratio is the most, HFC134a is middle and the R718 is the minimum.
3. The influence of condenser temperature changes on the ejector refrigerant system is greater than the evaporation temperature and generator temperature, and when designs the solar ejector refrigerant system, will try to reduce the fluctuation of condenser temperature.

Acknowledgements

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