SOLAR EJECTOR REFRIGERANT SYSTEM IN CHINA'S RESIDENTIAL BUILDINGS

by

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A simulation program describing the performance of solar ejector refrigerant system for air conditioning of China's residential buildings was established. Hourly performance of the system under different operate conditions, the collector efficiency, coefficient of performance, cooling capacity and cooling load were analyzed. It is found that the collector efficiency and the overall coefficient of performance increase first and then decline, and it can be concluded that the application of solar ejector refrigerant system will have a better developmental prospect in China's residential buildings.

Key words: *solar ejector refrigerant system, simulation, hourly performance*

Introduction

Compression refrigeration system consumes a large amount of high-grade energy. Hence, greater emphasis was made to replace the above system by heat-operated systems that can use abundantly available low-grade energy as the main driving source. In addition, the ejector refrigeration system (ERS) was found attractive because it requires relatively low temperature heat source [1]. ERS powered by low solar energy has been studied since the 1950s. Compared with other refrigeration systems, the ERS has some special advantages such as the simplicity in construction, high reliability, and low costs. The ERS was first developed in 1901 by Le Branc and Parson [1]. The ERS is an economic system so that it could be driven by any kinds of heat sources, such as solar energy, geothermal energy, waste heat, *etc*. Now, it is still an attractive subject because it decreases the consumption of gradually fuel resources, even if it has a low performance coefficient. In addition, compared with the conventional system, the ERS's operation and maintenance costs are low, and it has smaller working noise. So, in recent years, the solar ejector refrigerant system (SERS) has been investigated by several researchers. Selvaraju and Mani [1] studied the performance of ejector refrigeration system with working refrigerant ammonia, HFC134a, HFC152a, and HFC290. Aleksandar *et al.* [2], Yapici [3], and Petar *et al*. [4] studied the performance of various solar refrigerant systems. Alexis and Karagiannis [5] described the performance of an ERS driven by solar energy and HFC134a as working fluid based on the climate character of Athens, and pointed out that the *COP* of overall system varied from 0.014 to 0.101 under the same operation conditions and total solar radiation (536-838 W/m^2) in July; Ersoy and Yapici [6] studied the performance of SERS in the southern region of Turkey; Zheng *et al.* [7] investigated the characteristics of SERS in the Middle China region based on a numerical model. Bogdan [8] presented a numerical simulation for predicting a solar-assisted ejector air conditioning system with cold

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storage; Vidal *et al.* [9] made a theoretical study to research the hourly performance of modeling and simulation about the SERS. Gonzalez *et al.* [10] reviewed simple and hybrid jet-compression refrigeration systems. However, there are little work on the SERS using friendly refrigerants combined with climate conditions, and the study on the hourly performances of the SERS has not been archived in open literature using refrigerant ammonia. In the present study, the hourly performance of SERS has been researched in Zhengzhou, Xi'an, Taiyuan regions which are located at the middle regions of China on the basis of the previous studies by our research team [7, 11].

Description of the simulation computation program of the SERS

The entrainment ratio is the most important parameter. The bigger the entrainment ratio is, the higher the coefficient of performance (*COP*) is. The entrainment ratio was affected by many factors, such as the character of the refrigerant, the pressure of driving fluid, and so on. The flow character of ejector can be determined by thermodynamics, but the steam flow process remains very complicated, and its thermodynamic performance also needs further research. In this paper, based on a one-dimensional model, a simulation program is established through the following basic assumptions [7, 12]:

- 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.
- Ignore the inlet speed of the entrained refrigerant and mixed fluid export section of ejector.
- Refrigerant steam flow is adiabatic.
- Friction loss is defined as the efficiency of the nozzle, diffusion chamber, and the mixing chamber.
- Driving flow and the entrained refrigerant have the same molecular weight and specific heat.
- The internal flow condition of ejector is one-dimensional and steady-state flow.

The *COP* of SERS is:

$$COP = \mu \frac{q_{\mathrm{e}}}{q_{\mathrm{g}}} \tag{1}$$

where q_{e} is the heat extracted by the evaporator, and q_{g} – the heat added in the generator.

Based on the performance equation, and neglected the electricity input to the pump, the overall *COP* of the system is:

$$COP_{\mathrm{o}} = \eta_{\mathrm{sc}} \cdot COP \tag{2}$$

where η_{sc} is the efficiency of an evacuated tube solar collector proposed by Sun [13], and it may be calculated by:

$$\eta_{\mathrm{sc}} = \alpha - \beta \frac{T_{\mathrm{i}} - T_{\mathrm{amb}}}{I_{\mathrm{t}}} \tag{3}$$

The cooling capacity of SERS is defined by:

$$Q_e = COP_o I_t F \tag{4}$$

where α and β are collector characteristic coefficients, and $\alpha = 0.80$, $\beta = 3.5$ for the evacuated tube collector in this research. T_i represents inlet-temperature of the collector, and it could be commonly taken as 10 °C greater than the generator temperature as an assumption. That is, $T_i = T_g + 10$ °C. I_t is the average total solar radiation, and F – the solar collector area, [m^2].

On the basis of this analysis, a simulation program was developed by using the Engineering Equation Solver (EES) and Reference Fluid Thermodynamic and Transfer Properties (REFPROP 9.0) [14, 15]. The input parameters includes T_g, T_e, T_c, and m_e, which express the generator temperature, evaporator temperature, condenser temperature, and refrigerant mass flow of evaporator respectively. The output parameters includes the maximum entrainment ratio, η_{sc} and the COP_o.

Results and discussion

The inlet and outlet water temperatures of evaporator are set to 12 °C and 7 °C, and the daily variation of the ambient dry bulb temperature T_{amb} and solar radiation at the China middle three regions are determined according to the meteorological data [16]. It can be seen that the *COP* increases with the increase of evaporator temperature, fig. 1. When the evaporator temperature is set as $T_e = 10$ °C, generator temperature $T_g = 80$ °C, and condenser temperature $T_c = 35$ °C, the *COP* of ERS equals to 0.30.

Figure 2 showed the variation of the η_{sc} of the SERS against the hours of the day in Zhengzhou on June 28th, in Taiyuan on July 31st, and in Xi'an on July 31st. From fig. 2, it can be seen that the hourly variations of overall η_{sc} on the typical day at the China middle three regions indicate similar trends. The η_{sc} increase first and then decline by the time sequence, and reaches the maximum value from 12:00 to 14:00, and it can be contributed to the influence of the ambient temperature. In addition, the average η_{sc} of Zhengzhou, Xi'an, and Taiyuan are 0.40, 0.35 and 0.14, respectively, fig. 2. The maximum η_{sc} of Zhengzhou, Xi'an, and Taiyuan can arrive at 0.52, 0.52, and 0.53, respectively.

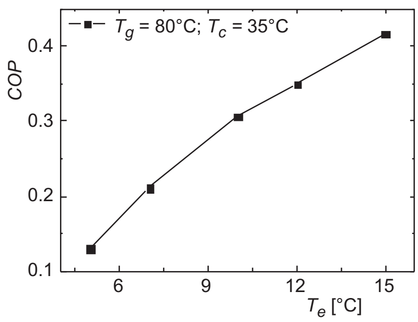

Figure 1. Variation of the *COP* and the evaporator temperature of ERS

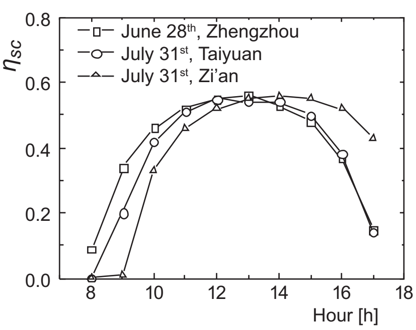

Figure 2. Hourly variation of the η_{sc} on the specific days

The COP_o of the SERS as function of the hours of the day in Zhengzhou on June 28th, in Taiyuan on July 31st, and in Xi'an on July 31st for $T_g = 80$ °C and $T_e = 5$ °C were reported in fig. 3. From fig. 3, we can see that the COP_o increase first and then decline by the time sequence, and reaches the maximum value during 12:00~14:00, and the maximum COP_o of SERS can reach about 0.16 at the different three regions. Similarly, fig. 4 depicted the

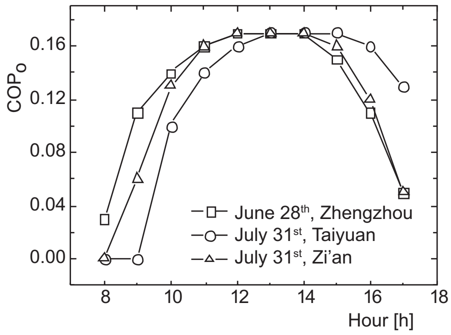

Figure 3. Hourly variation of the COP_o on the specific days

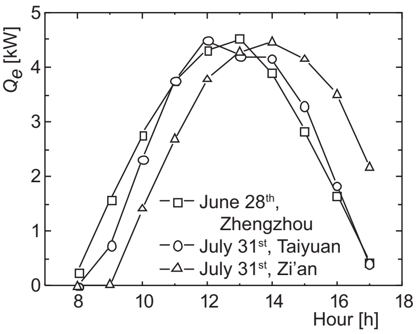

Figure 4. Hourly variation of the cooling capacity on the specific days

hourly variation of the cooling capacity of SERS at the China middle three regions on the typical days. Combined with a villa, the area of which is equal to 200 m^2, and the evacuated tube collector area is 30 m^2. Figure 5 showed the variation of the cooling load against the hour in Zhengzhou on June 28th, in Taiyuan on July 31st, and in Xi'an on July 31st respectively. It can be seen that, the cooling load increases by the time sequence, and the hourly variation of cooling load in the three regions on the typical days indicates similar trends.

Figure 6 illustrated the relation between *P* and hour on the specific days at the China middle three regions. *P* represents the ratio of the cooling capacity of the SERS to the cooling load that the villa needed. It can be noticed that the SERS can provide 54, 111, and 38 percent cooling load for the residential building, respectively, during 8:00-17:00 at the three regions on the typical days. It can be concluded that the application of SERS will have a favorable prospect in the middle region of China.

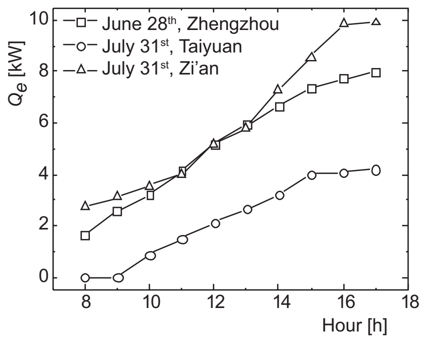

Figure 5. Hourly variation of the cooling load on the specific days

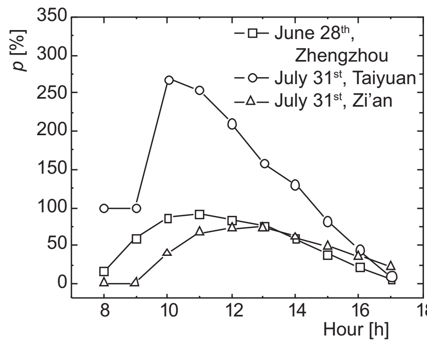

Figure 6. Hourly variation of the *P* on the specific days

Conclusions

Based on the character of residential building, this paper established a simulation program about the SERS on the basis of climate character of the Xi'an, Zhengzhou, and Taiyuan regions which are located at the middle region of China, and the system performance of SERS was investigated. The simulation results show that the collector efficiency increase first and then decline by the time sequence and the maximum η_{sc} of Zhengzhou, Taiyuan, and

Xi'an can reach 0.52, 0.52, and 0.53, respectively. The hourly variations of COP_o on the typical days at the China middle three regions indicate similar trends. The COP_o increase first and then decline by the time sequence, and can arrive at the maximum value during 12:00~14:00. When the evacuated tube collector area equals to 30 m^2 and the residential building area equals to 200 m^2, the SERS can supply 54, 111 and 38 percent cooling load for the residential building respectively during 8:00~17:00 at the China middle three regions on the typical days, and it can be concluded that the application of SERS will have a favorable prospect in the middle region of China.

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