INTER-COOLER IN SOLAR-ASSISTED REFRIGERATION SYSTEM
Theory and Experimental Verification

by

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An inter-cooler in the solar-assisted refrigeration system was investigated experimentally and theoretically, and the theoretical prediction was fairly in good agreement with the experimental data. The influence of pipe diameter, tooth depth, and spiral angle of inter-cooler on the performance of the refrigerant system was analyzed. It was concluded that heat transfer is influenced deeply by the structure parameters of inter-cooler, and the heat transfer capacity increases with tooth depth and spiral angle increasing, and decreases with tooth apex angle increasing.

Key words: *solar-assisted refrigeration system, inter-cooler, simulation, experimental*

Introduction

In the utilization of solar energy technology, the solar-assisted ejector refrigeration system has been used popular for its simple structure, fewer moving parts and low cost. Abdulateef *et al.* [1] studied the development history and recent progress of solar-driven ejector refrigeration systems; Chidambaram *et al.* [2] researched the field of solar cooling techniques, solar collectors, storage methods and their integration; Gonza *et al.* [3] presented the latest developments of the ejector compression refrigeration and hybrid ejector compression refrigeration systems. Mohamed *et al.* [4] investigated the feasibility of solar assisted air-conditioning in an office building under Tripoli weather conditions.

Recent extensive works were carried out in the optimization design of solar hybrid refrigeration system. Zheng *et al.* [5], and Dorantes *et al.* [6] studied the dynamic thermal behavior of solar ejector-compression refrigeration system. Sun [7], and Huang *et al.* [8, 9] proposed and studied a combined-cycle refrigeration system that comprises a conventional refrigeration system and an ejector-cooling cycle, and the results showed that the coefficient of performance (*COP*) of the combined-cycle refrigeration system is higher than a single-stage refrigeration system.

From the literature discussed, it is confirmed that the solar hybrid refrigeration system would widely be used in the future because of dealing with unstable and low *COP* of simple solar ejector refrigeration system, and a simulation model about the inter-cooler has been established in this paper, and the performance of the solar-assisted ejector refrigeration system were analyzed.

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Simulation model

An inter-cooler simulation model was established and the following assumptions are made for analysis:
- the refrigerant flow mass rate and temperature in the inter-cooler are evenly distributed, the refrigerant flow is also 1-D,
- the physical property of refrigerant and tube wall is constant,
- the pressure drop and the resistance of the inter-cooler are negligible, and
- the inter-cooler and condenser flow are in countercurrent during steady-state.

The heat transfer capacity about refrigerant in condenser side $Q_{c,int}$ is given by:

$$Q_{c,int} = m_{c,int}(h_{c,int,in} - h_{c,int,out}) \tag{1}$$

The heat transfer capacity about refrigerant in evaporator side $Q_{e,int}$ can be described:

$$Q_{e,int} = m_{e,int}(h_{e,int,out} - h_{c,int,in}) \tag{2}$$

The heat balance equation of inter-cooler is defined:

$$Q_{c,int} = \gamma Q_{e,int} \tag{3}$$

where, $m_{c,int}$ [kgs^{-1}], is the refrigerant mass flow of condenser side, $m_{e,int}$ [kgs^{-1}], – the refrigerant mass flow of evaporator side, $h_{c,int,in}$ and $h_{c,int,out}$ [kJkg^{-1}] – the import and export enthalpy of condenser side, and $h_{e,int,in}$ and $h_{e,int,out}$ [kJkg^{-1}] – the import and export enthalpy of evaporator side.

Leakage heat coefficient γ is between 0.92 and 1.0.

Based on the analysis, designed and developed a steady distribution parameter simulation model. More detail information about simulation model are in [10].

Results and discussion

Figure 1 depicts the validation of simulation model with R134a as refrigerant. The simulated performance is compared with that of experimental data available in the literature [10]. The variation of simulated results in this case also is in good agreement with that of the experimental data.

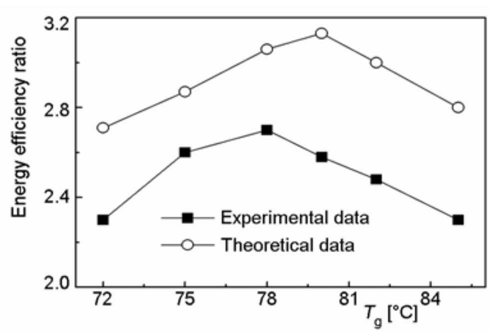

Figure 1. Validation of simulation model

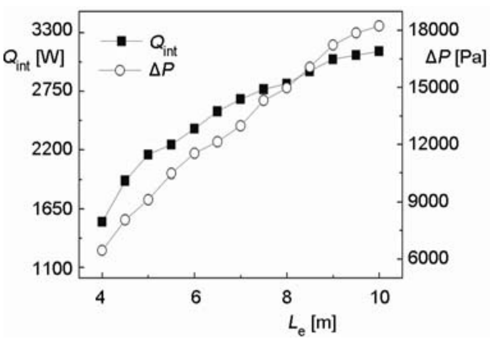

Figure 2. Variation of Q_{int}, and ΔP with L_e

Figure 2 shows the effect of the L_e of inter-cooler on the Q_{int} and ΔP, where L_e is the tube length, Q_{int} – the heat transfer capacity, and ΔP – the pressure drop. It can be seen that the Q_{int} and ΔP increases with L_e increasing, and it can also be found that the optimal tube length of inter-cooler is between 6 m and 9 m.

Figure 3 depicts the variation of the Q_{int} and ΔP with the D_{w1} of inter-cooler, where D_{w1} is the outer diameter of inner tube. It can be seen that the flow mass rate of refrigerant and the ΔP increase rapidly with the D_{w1} increasing. The optimal D_{w1} should be designed between 9 mm and 11 mm.

Figure 4 shows the variation of heat transfer capacity with the D_{w2} when the D_{w1} is constant, and the micro-fin tube has been chosen as heat transfer tube in the inter-cooler, where D_{w2} represents inner diameter of outer tube. It is evident that the Q_{int} decreases, and ΔP is unchanged with the D_{w2} increasing. It can be concluded that the optimal range of the inner diameter of outer tube is between 30 mm and 36 mm.

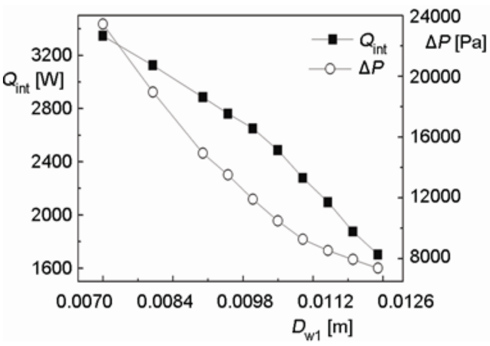

Figure 3. Variation of Q_{int}, and ΔP with D_{w1}

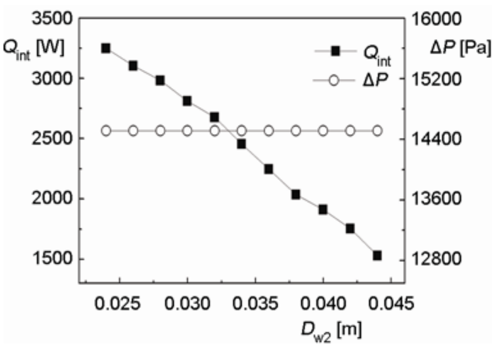

Figure 4. Variation of Q_{int} with D_{w2}

Figure 5 illustrates the variation of Q_{int} with $m_{c,int}$ under different h_f, where h_f represents tooth depth. The variation of Q_{int} with $m_{c,int}$ under different β is shown in fig. 6, where β represents spiral angle. It is found that the inter-cooler heat transfer capacity increases with the tooth depth and spiral angle increasing.

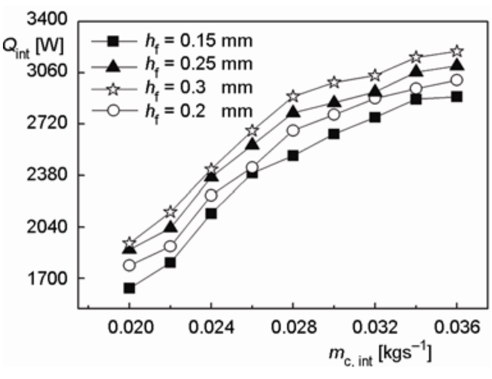

Figure 5. Variation of Q_{int} with $m_{c,int}$, under different h_f

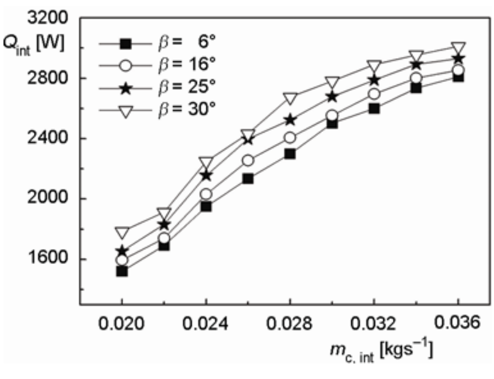

Figure 6. Variation of Q_{int} with $m_{c,int}$, under different spiral angle

Conclusion

A simulation model about inter-cooler of solar refrigeration system was established, and the performance of inter-cooler was also studied. The heat transfer character is influenced deeply by the structure parameters of inter-cooler, and it can be concluded that the heat transfer capacity increases with tooth depth and spiral angle increasing, and decreases with tooth apex angle increasing. The optimal length of the heat transfer tube, outer diameter of inner tube, inner diameter of outer tube of inter-cooler have been achieved.

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