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Optimal Performance of an Endo-reversible Solar Driven Sorption Refrigeration System

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Abstract:
This article deals with the thermodynamic optimization of a solar driven sorption refrigeration system. An externally irreversible but internally endo-reversible model has been emp loyed to analyze the optimum conditions of a sorption cooling system driven by a solar collector. The operating conditions for maximum refrigeration load are determined. It is shown that the system gives its highest capacity if the thermal conductances of the heat exchangers are distributed properly. Results also show that optimum refrigeration load increases with the increase of collector stagnation and required room temperature increase and decreases as the ratio of collector size to the cumulative size of all four heat exchangers increases. It may also see that the optimal thermal conductance of the evaporator expands with the expense of the optimal thermal conductance of solar collector as collector stagnation temperature, refrigerated room temperature increase.

1. Introduction

In recent years, heat driven sorption refrigeration system have drawn considerable attention due to its lower environmental impact and large energy saving potential. Another interesting feature of this system is that, the chiller/heat pump can be operated by thermal heat such as waste heat from industries or by solar heat. From this context, a number of researchers investigated the performance of sorption heat pumping/ refrigeration system driven by waste heat or by renewable energy sources. Among these, for solar cooling, worked by Pons and Guilleminot(1986), Zhang and Wang (1997) for automobile cooling and Saha et. al (2000), Alam et. al. (200a,b) for waste heat utilization. While the feasibilty of the system performance has been studied, the investigation on optimum design of a heat driven refrigeration system is scare. In 1993, Sokolov and Hersagal (1993) apply optimization techniques to optimize the system performance of a solar driven year round ejector refrigeration. Vargas *et. al.* (1996) investigated the optimal condition for a refrigerator driven by solar collector considering the three heat transfer irreversibilites. Later, Chen and Schouten (1998) discussed the optimum performance of an irreversible absorption refrigeration cycle in which three external heat transfer irreversibilities have been considered.

Recently, Alam et. al. (2001) modeled and optimized a solar driven endo-reversible adsorption refrigeration system by considering the four heat transfer irrevesibilities. In that article, authors showed that the maximum refrigeration effect could be achieved by allocating the heat exchangers inventory properly. They also showed that the optimal thermal conductance of the heat exchangers that take heat from the heat source is almost equal to the thermal conductance of the heat exchangers that release to the external ambient. In the present study, the model of Alam et. al. (2001) has been utilized to investigate the optimum refrigeration load in different conditions. The primary objective of this study is to determine the optimum allocation of thermal conductancee between the collector and evaporator.

2. Mathematical Model

The main components of a solar driven sorption refrigeration system are a solar collector, a desorber, a sorber, a condenser and an evaporator, as shown in Fig. 1. In a sorption cycle, the working fluid execute a cycle and exchange heat to the heat exchange equipment of the system. During the cycle, desorber receives the heat load, Q_H, from the heat source (solar collector) at temperature, T_H, while evaporator seizes heat load, Q_{EVA}, from the refrigeration space at temperature, T_L; the condenser and evaporator release heat transfer, Q_{CON} and Q_A respectively to the external ambient at temperature, T_0. In this analysis, it is assumed that there is no heat loss between the solar collector and the desorber and no work exchange occurs between the refrigerator and its environment.

According to Alam et. al. (2001), the system can be described by the following non-

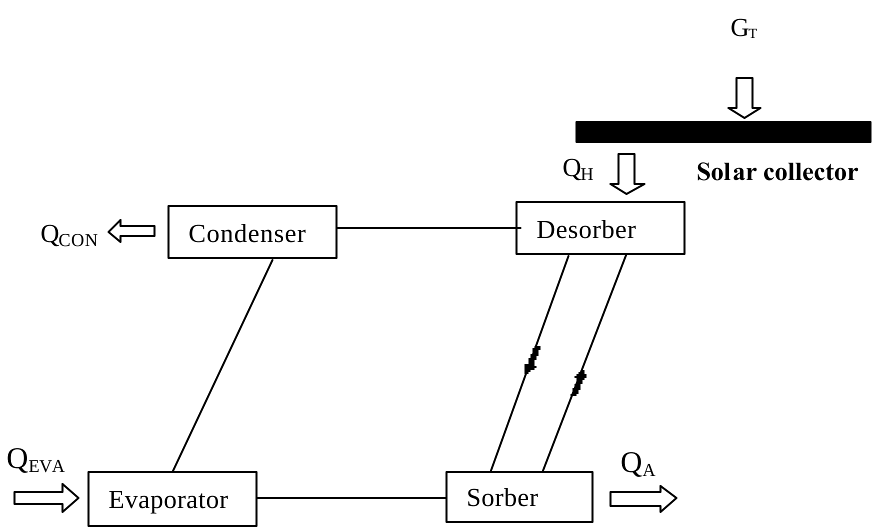

Fig.1 Schematic of a solar driven sorption refrigeration system

dimensionless mathematical model.

$$\overline{Q}_H = B(\tau_{st} - \tau_H) \tag{1}$$

$$\overline{Q}_H = y(\tau_H - \tau_{HC}) \tag{2}$$

$$\overline{Q}_A = z(\tau_A - 1) \tag{3}$$

$$\overline{Q}_{CON} = (1 - x - y - z)(\tau_{CON} - 1) \tag{4}$$

$$\overline{Q}_{EVA} = x(\tau_L - \tau_{LC}) \tag{5}$$

$$\overline{Q}_H + \overline{Q}_{EVA} = \overline{Q}_{CON} + \overline{Q}_A \tag{6}$$

$$\frac{\overline{Q}_H}{\tau_H} + \frac{\overline{Q}_{EVA}}{\tau_L} = \frac{\overline{Q}_{CON}}{\tau_{CON}} + \frac{\overline{Q}_A}{\tau_A} \tag{7}$$

Where the following group of non-dimensional transformation are imposed,

$$\tau_H = \frac{T_H}{T_0}, \tau_{LC} = \frac{T_{LC}}{T_0}, \tau_L = \frac{T_L}{T_0}, \tau_{CON} = \frac{T_{CON}}{T_0}, \tau_A = \frac{T_A}{T_0}, \tau_{HC} = \frac{T_{HC}}{T_0}$$
$$\overline{Q}_H = \frac{Q_H}{UAT_0}, \overline{Q}_{EVA} = \frac{Q_{EVA}}{UAT_0}, \overline{Q}_{CON} = \frac{Q_{CON}}{UAT_0}, \overline{Q}_A = \frac{Q_A}{UAT_0}, \; B = \frac{bA_C G_T}{UA} \tag{8}$$

Here B is the size of the collector relative to the cumulative size of the four heat exchangers and x, y and z are conductance allocation ratios, defined as

$$x = \frac{(UA)_{EVA}}{UA}, \qquad y = \frac{(UA)_H}{UA}, \quad \text{and} \quad z = \frac{(UA)_A}{UA} \tag{9}$$

According the constraint property of thermal conductance UA in equation (11), the thermal conductance distribution ratio for the condenser can be written as,

$$v = \frac{(UA)_{CON}}{UA} = 1 - x - y - z \tag{10}$$

Here, it is assumed that sum of all thermal conductances are fixed,

$$UA = (UA)_H + (UA)_A + (UA)_{CON} + (UA)_{EVA} \tag{11}$$

3. Optimization Techniques

To maximize the refrigeration load, $\overline{Q}_{EVA}$, one needs to solve the nonlinear set of Equations (1)-(7). Newton-Raphson's method with appropriate initial guesses was employed for solving the above set of non-linear equations. The Newton's method has been employed to maximize $\overline{Q}_{EVA}$ by optimizing $t_{H,}$ x, y and z and varying some selected parameters to generate the results shown in Figs. 2-4. The convergence criteria for both maximization technique and solving nonlinear set of equation is taken as $|R|_2 \leq 10^{-7}$. Where, $|R|_2$ stands for the Euclidean norm of the residual vector. The results obtained by this numerical method are presented and discussed in the following section.

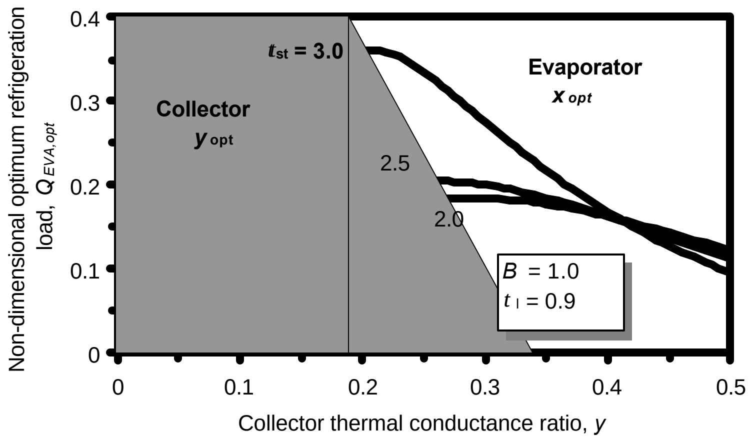

Fig.2 Effects of collector stagnation temperature on refrigeration load

Results and Discussion

It is reported that the sorption refrigeration system can be operated by mid to lower driving heat source temperatures, T_H (60 ~ 200 ºC), for producing refrigeration load temperatures, T_L, between –15 ºC and 15 ºC [Alam et. al (2001)]. In terms of non-dimensional form, these ranges can be estimated, respectively, as 1.1-1.5 for the driving heat source temperature and 0.8-0.95 for the refrigeration load temperature. Therefore, the dimensionless collector stagnation temperature, τ_{st}, has been varied from 1.1 to 1.5, and the dimensionless refrigeration space temperature, τ_L, has been set from 0.8 to 1. Alam et. al.(2001) showed that half of the total thermal conductance is distributed between the thermal conductances of collector and evaporator. From this viewpoint, this paper investigates the proper allocation of thermal conductances between the collector and evaporator. The optimum allocation of thermal conductances between collector and evaporator are indicated by shaded and non shaded parts in Figs.2-4.

Fig.2 shows the effect of collector stagnation temperature on the optimum refrigeration load. It can be seen that the optimum refrigeration load, Q_{EVA} increases with the increase of collector stagnation temperature. This is accord with the real situation. Because, the system can be operated effectively with the high heat source temperature, which leads the cooling load to increase. This figure also depicts the optimal allocation between the thermal conductance ratios of collector and evaporator. From Fig. 2, it can also be observed that optimum evaporator thermal conductance is proportional to collector stagnation temperature while optimum collector thermal conductance is inversely proportional to collector stagnation temperature.

The effects of dimension collector size B on the optimal refrigerator load are depicted in Fig. 3. It can be seen that an increase in dimensionless collecdtor size, B leads the optimal refrigeration load to increase. Actually an increase in collector size leads the system to supply heat effectively, which causes the system to increase the refrigeration load. It can

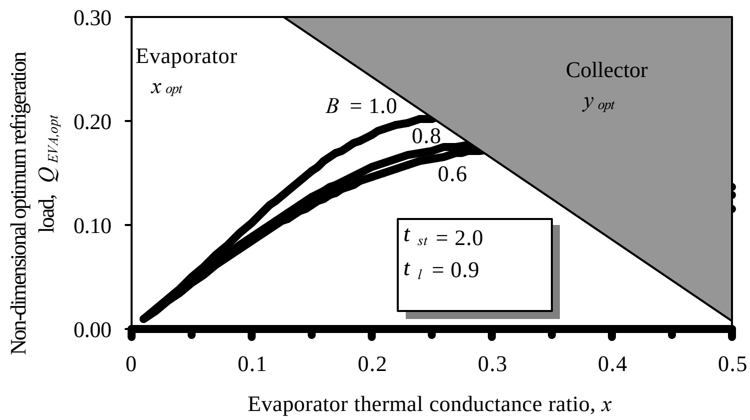

Fig.3 Effects of non-dimensional collector size on refrigeration load

also be observed that evaporator thermal conductance $\frac{(UA)_{CON}}{UA}$ decreases as well as collector thermal conductance $\frac{(UA)_{H}}{UA}$ increases as collector size, B increases.

The effects of refrigeration space temperature on the optimum refrigeration load are illustrated in Fig. 4. An increase in optimum refrigeration load has been observed with the increase of refrigeration space temperature. From the same figure it is seen that the optimum share of thermal conductance of collector is higher than the optimum share of thermal conductance of evaporator if the non-dimensional refrigeration space temperature is below 0.9. Therefore, it can be noted that the optimum share of evaporator thermal

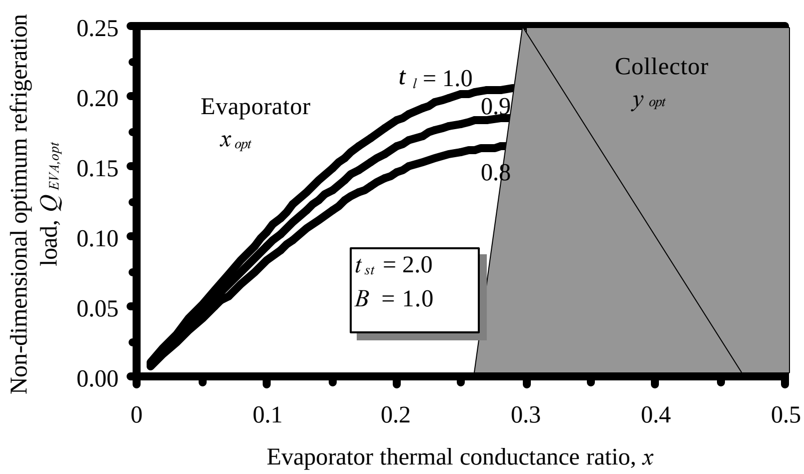

Fig.4 Effects of non-dimensional refrigeration space temperature on refrigeration load

conductance is directly proportional to refrigeration space temperature, while the optimum share of collector thermal conductance is inversely proportional to refrigeration space temperature.

5. Conclusion

A Thermodynamic optimization of a solar driven sorption refrigerator is presented in this study. An end-reversible model has been considered to determine the optimum conditions of a solar driven sorption cooling system. From this study it can be concluded that an increase in τ_{st} or τ_L leads to increase in refrigeration effect. It may also concluded that optimum $(UA)_{EVA}$ gains with the expense of $(UA)_H$ as τ_{st}, τ_L, increase as well as B decreases.

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