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Development of hybrid solar-assisted cooling/heating system

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ABSTRACT

A solar-assisted ejector cooling/heating system (SACH) was developed in this study. The SACH combines a pump-less ejector cooling system (ECS) with an inverter-type heat pump (R22) and is able to provide a stable capacity for space cooling. The ECS is driven by solar heat and is used to cool the condenser of the R22 heat pump to increase its *COP* and reduce the energy consumption of the compressor by regulating the rotational speed of the compressor through a control system. In a complete SACH system test run at outdoor temperature 35 °C, indoor temperature 25 °C and compressor speed 20–80 Hz, and the ECS operating at generator temperature 90 °C and condensing temperature 37 °C, the corresponding condensing temperature of the heat pump in the SACH is 24.5–42 °C, cooling capacity 1.02–2.44 kW, input power 0.20–0.98 kW, and cooling COP_c 5.11–2.50. This indicates that the use of ECS in SACH can effectively reduce the condensing temperature of the heat pump by 12.6–7.3 °C and reduce the power consumption by 81.2–34.5%. The SACH can also supply heat from the heat pump. At ambient temperature from 5 °C to 35 °C, the heating COP_h is in the range 2.0–3.3.

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1. Introduction

The ejector cooling system (ECS) using low boiling point refrigerant is suitable for solar cooling application due to its simple design and low cost. Huang et al. [1,2] has shown that the *COP* of an ECS using R141b, with a proper design of ejector and system structure, can reach 0.54 at generator temperature 84 °C, condenser temperature 28 °C, and evaporator temperature 8 °C. This makes the ECS become competitive to the sorption (absorption or adsorption) system that is much more complicated in design and more expensive [3–12].

In the ECS, the condenser temperature must be lower than the critical condensing temperature (critical point) to obtain a high performance. Fig. 1 shows the double-choking phenomenon of ECS [1,2]. Therefore, the ejector should be operated at critical mode in order to obtain a better performance. If the ECS was driven by solar energy, it always requires a back-up system to make up the heat required to keep a constant cooling capacity for space cooling during cloudy or rainy periods (Fig. 2). Heat supplied by fossil fuel or electricity was generally adopted. This however causes a problem of additional investment of heaters and low efficiency in heat supply.

The present study intends to develop a hybrid solar-assisted ejector cooling/heating system (SACH) in which a conventional inverter-type air-conditioner (heat pump) made of variable-speed compressor is connected in series with a solar ejector cooling system (see Fig. 3). The solar ejector cooling system is used to cool the condenser of the air conditioner to reduce the condensing temperature and increase the *COP* to reduce the power consumption of the compressor when solar irradiation is available. The cooling load is directly supplied by the inter-type heat pump. During cloudy or rainy periods or at night, the SACH will provide the entire cooling load from the heat pump as usual. The SACH can also produce hot water by the heat pump year round to supply heat, in addition to the direct heat supply from the solar collector. This will make the solar cooling/heating system more economical. The present paper reports the experimental results of this study.

2. Experimental setup

2.1. System configuration of SACH

The SACH consists of three major parts: a pump-less ejector cooling system, a solar collector system, and an inverter-type heat pump with variable-speed compressor. Fig. 4 is the schematic diagram of a practical SACH. A small SACH prototype using an inverter-type air-conditioner (heat pump) with rated cooling capacity 2 kW was built and tested in the present study. The cooling capacity of the ejector cooling system (ECS) is 700 W rated at condenser temperature 32 °C, generator temperature 90 °C, and evaporator temperature 7 °C. Table 1 shows the specification of the air conditioner used in the SACH. The overall system design specification is shown in Table 2.

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Nomenclature

COP	coefficient of performance
COP_c	coefficient of cooling performance
COP_{ej}	coefficient of ejector cooling performance
COP_h	coefficient of heating performance
P_c^*	critical condenser pressure, MPa
P_{co}	condenser pressure of limiting condition, MPa
$q_{c,e}$	cooling capacity, kW
$T_{c,c}$	condensing temperature of heat pump, °C
W_c	power consumption of inverter-type air conditioner kW

Greek symbol

ω	entrainment ratio

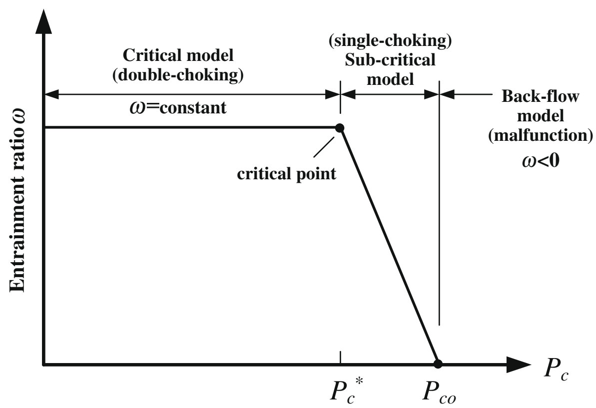

Fig. 1. Double-choking phenomenon of ECS.

A test performed for a commercial inverter-type air-conditioner shows that the cooling *COP* increases at a rate about 0.12 per °C condensing temperature drop. This means that 20 °C reduction in condensing temperature will increase *COP* by 2.4, about twice the original *COP* or save about 50% compressor power consumption.

To work as a heat pump for heating, the condenser of the R22 heat pump is connected to a 100 L hot water tank inside which a condenser coil made of 30 m copper tube (OD 10 mm) is immersed.

A schematic of the experimental system is shown in Fig. 5. The system was installed with 36 T-type thermocouples with an uncertainty of ±0.7 °C, and five pressure transducers with a ±1% uncertainty (see Fig. 5). The power consumption of the compressor was measured by a power meter within a ±1.5% uncertainty.

2.2. Pump-less ejector cooling system

The pump-less ejector cooling system was developed by Huang et al. [5,13] by combining the concept of heat-driven pump (HDP)

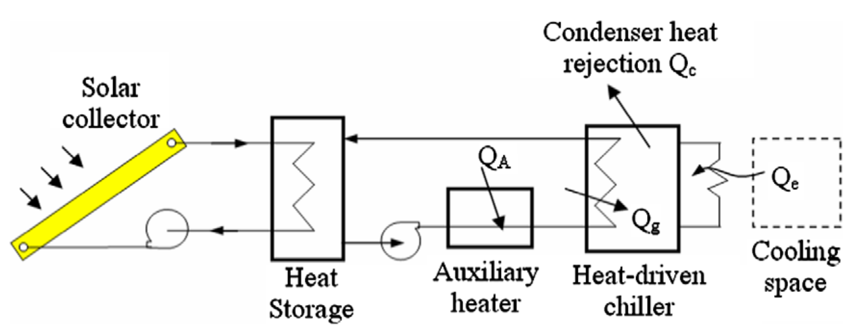

Fig. 2. Conventional solar cooling system.

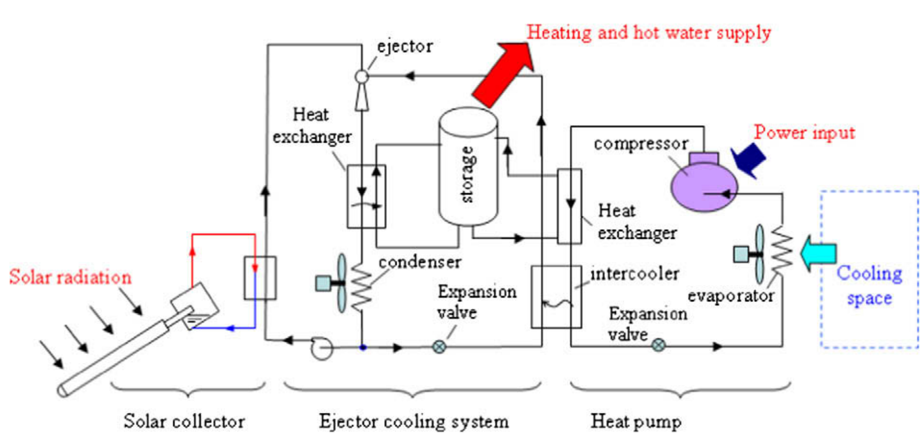

Fig. 3. Hybrid solar-assisted cooling/heating system (SACH).

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