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EFFECTS OF FIN SPACING AND FIN HEIGHT OF CAPILLARY-ASSISTED TUBES ON THE PERFORMANCE OF A LOW OPERATING PRESSURE EVAPORATOR FOR AN ADSORPTION COOLING SYSTEM

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Abstract

Adsorption cooling systems (ACS) are a viable alternative to vapor compression refrigeration cycleswhere low-grade waste heat is abundant. When using water as a refrigerant in an ACS, the operating pressure is quite low (<5 kPa) and the performance of the system is severely affected when using conventional evaporators. This problem can be addressed by using capillary-assisted evaporators. In this study, a new capillary-assisted evaporator testbed is designed and built, and three enhanced tubes with different fin geometries (fin spacing and fin height) and a plain tube are tested under different chilled water inlet temperatures. The results show that enhanced tubes provide 1.65-2.23 times higher total evaporation heat transfer rate compared to the plain tube. Under equal inner and outer heat transfer surface area, the results also show that the enhanced tube with parallel continuous fins and higher fin height (Turbo Chil-26 FPI) has 13% higher evaporation heat transfer coefficient than that of a tube with lower fin height (GEWA-KS-40 FPI).

KEYWORDS

Capillary-assisted evaporation, enhanced tube, low-operating pressure, adsorption cooling system.

INTRODUCTION

A vapor compression refrigeration cycle (VCRC) in vehicle air conditioning (A/C) system can add up to 5-6 kW peak power draw on an internal combustion engine (ICE). Also, in an ICE of a light-duty vehicleabout 40% of the fuel's energy is wasted in the form of exhaust gas and about 30% of the fuel's energy is dissipated through the engine coolant [1]. To reduce vehicle fuel consumption and recover some of this waste heat, a waste-driven ACS can replace a conventional VCRC of light-duty vehicles. A portion of the waste heat of an ICE is sufficient to run the ACS and generate the cooling power required for the vehicle A/C applications. The substitute forthe compressor of a VCRC is an adsorber bed in which a refrigerant (adsorbate), such as water or methanol, is adsorbed at the surface of an adsorbent, such as zeolite, silica gel, or activated carbon. Most of these materials are non-toxic, non-corrosive, and inexpensive [2], which makes ACS a safe and environmentally friendly technology. Among the existing refrigerants, water has the thermo-physical properties of a suitable refrigerant, such as the highest enthalpy of evaporation (latent heat). However, the saturation pressure of water at temperatures below 100°C, where the evaporator of an A/C system operates, is below atmospheric pressure. Accordingly, an ACS that uses water as the refrigerant operates under vacuum pressure and is known as low-operating pressure (LP) evaporator.

Accumulation of liquid water in a LP evaporator creates a water column, which results in a static pressure difference between the liquid water-vapor interface and the bottom of the water column. This static pressure changes the saturation temperature and pressure of the water. As a result, cooling power generation of an ACS is drastically reduced. To have a uniform water saturation temperature, the static pressure of the water in the LP evaporator should be minimized. A practical approach to resolve this issue is capillary-assisted evaporation. Capillary-assisted flow and evaporation inside circumferential rectangular micro-grooves were studied by Xia et al.[3,4]. They immersed finned tube with outside circumferential micro-grooves into a pool of liquid to investigate the effects of immersion depth, evaporation pressure, and superheating degree on the performance of the evaporator. Their experimental results showed that the evaporation heat transfer coefficient has a positive correlation withthe evaporation pressure, and a negative correlation with the superheating and immersion depth. Wang et al.[5] developed an evaporator for a silica gel-water ACS based on the work shown in[3,4]. They claimed that the evaporation heat transfer coefficient might be about 5,000W/(m^2·K). Lanzerath et al.[6] studied a combination of finned tubes and thermal coating for capillary-assisted evaporation at low pressures. Their investigation showed a strong dependency of the total heat transfer coefficient on the water filling level. Their study also established that the combination of macroscopic fin structures and micro porous coatings yielded an evaporation heat transfer coefficient of 5,500 W/(m^2·K),which is 11 times higher than that of a plain tube [6].

High evaporation heat transfer coefficients (4,000-8,000 W/(m^2·K)) can be achieved from capillary-assisted evaporation due to the water phase change on the outer surface of the tubes. To generate cooling, this heat has to be transferred from the chilled liquid water flowing inside the tube, to the tube wall, and finally, to the refrigerant. In this process, the main thermal resistance to heat transfer is due to the low single-phase heat transfer coefficient inside the tube which is a bottle-neck in improving the overall performance of LP evaporators. Therefore, this study is focused on the overall heat transfer coefficient of LP evaporators. Three enhanced heat exchanger tubes with different fin geometries were tested under various operating temperatures and pressures to find the achievable cooling capacities and overall heat transfer coefficients, and to determine the mostsuitable tube for use in the LP evaporator of ACS.

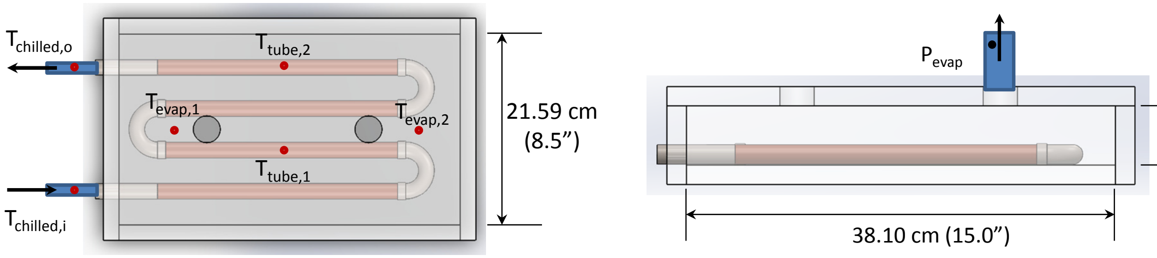
EXPERIMENTAL DETAILS

A representation of capillary-assisted evaporation is shown in Fig. 1. An enhanced tube with small fin spacing on its outside surface is in contact with a pool of liquid. Due to capillary action, the liquid rises upward and covers the entire outside surface of the tube. Chilled liquid water provided by a temperature control system (TCS) is circulated inside the tube and heat is transferred to the thin liquid filmon the outside of the tube, leading to evaporation.

A capillary-assisted LP evaporator was designed and built as shown in Fig.2. The evaporator tube consisted of a four-pass arrangement with a total length of 1.54 m. Capillary evaporation took place at the free surface of the tube helping to maintain the evaporation heat transfer rate as the water level decreases. The tube was placed horizontally at the bottom of the box to minimize the water height as shown in Fig.2b. Type T thermocouples (Omega, model #5SRTC-TT-T-36-36) with accuracy of ±0.1°C, and a pressure transducer with 0-34.5 kPa operating range (Omega, model #PX309-005AI) and ± 0.4 kPa accuracy were used to monitor and record the temperature and pressure variations at the locations shown in Fig.2.

(a) (b)

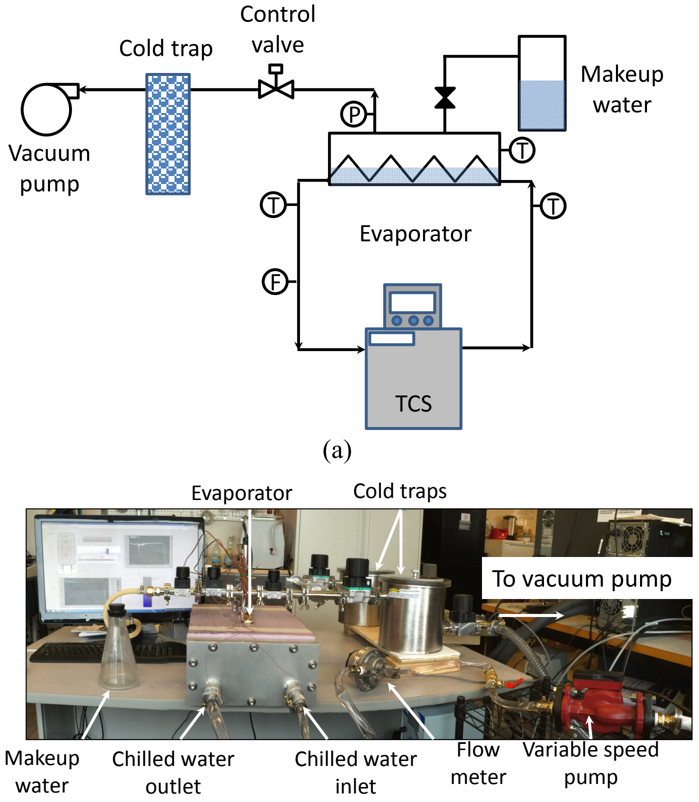
Fig. 1. Capillary-assisted evaporation: (a) side view, and (b) cross-sectional view.



(a) (b)

Fig.2. Capillary-assisted evaporator built for testing different enhanced tubes: (a) top view, and (b) side view.

A schematic diagram of the experimental setup is shown in Fig.3. The experimental test bed was designed to measure the cooling capacity and overall heat transfer coefficient of the evaporator. The setup consisted of a TCS and a variable speed pump to provide a constant temperature chilled water to the evaporator at different mass flow rates. A control valve was used to regulate the pressure inside the evaporator. A vacuum pump and cold trap were used to mimic the adsorber bed of ACS. The cold trap, filled with a dry ice and isopropyl alcohol solution, was used to protect the vacuum pump from the water vapor coming from the evaporator. The operating conditions during the experiments are summarized in Table 1. Once the evaporator was evacuated using the vacuum pump, the evaporator was filled with the makeup water (1,200 g) to immerse the evaporator tube in water. When all the temperatures and pressure inside the evaporator became constant, the control valve was opened and adjusted until the evaporator pressure reached the specific value listed in Table 1. No water was added during the course of the experiment, so the water level dropped until all of the water in the chamber evaporated.The tests were conducted for three types of enhanced tubes with different fin structures and one plain tube as a benchmark as listed in Table 2.



(a)

(b)

Fig.3. (a) Schematic of the experimental setup and (b) the actual setup.

Table 1. Operating conditions for the experiments.

Parameter	**Values**
Chilled water inlet temperatures	10°C/ 15°C/ 20°C
Chilled water flow rate	2.4-2.7 kg/min
Evaporator pressure	0.5 kPa @ 10°C 0.6 kPa @ 15°C 0.8 kPa @ 20°C
Amount of water filled inside the evaporator for each experiment	1200 g