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Enhancement of fin efficiency of a solid wire fin by oscillating heat pipe under forced convection

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ABSTRACT

Enhancement of fin efficiency of solid wire fin in a wire-on-tube heat exchanger under forced convection was examined. The solid wire fin was replaced with an oscillating heat pipe filled with R123. The unit was tested in a wind tunnel by exchanging heat between hot water flowing inside the tube and the air stream flowing across the external surface. The results showed that the fin efficiency for the case of oscillating heat pipe fin was higher than that of the conventional fin around 5% depended on the mass flow rate of air stream and the geometrical parameters of heat exchanger surface. Moreover, the model of fin efficiency was developed and the results agreed well with the experimental data.

Introduction

Wire-on-tube heat exchangers have been used in refrigeration and air-conditioning systems for many years. Hot working fluid exchanges heat with the ambient air by flowing through a serpentine tube panel attached with a small diameter solid wire.

Many research works reported on the thermal performances of wire-on-tube heat exchangers. For examples, Witzell and Fontaine [1,2] showed the thermal characteristics of a wire-on-tube heat exchanger. Tagliafico and Tanda [3] investigated the radiation and the natural convection heat transfers from a wire-on-tube heat exchanger in refrigeration appliances. Lee et al. [4] proposed a correlation for evaluating the air-side heat transfer coefficient of a wire-on-tube type heat exchanger for the Reynolds number between 50 and 900. Quadir et al. [5] used the finite element method to analyze the free convection heat transfer of a wire-on-tube heat exchanger affected by the ambient temperature and the inside refrigerant mass flow rate.

However, all of the previous works used solid metal wire as an extended surface. The heat transfer from the tube surface to the fin was only by the heat conduction. Therefore, there was a limitation due to the thermal conductivity of wire material. To overcome this problem, Nuntaphan et al. [6] proposed a new design of wire-on-tube heat exchanger. The solid wire was replaced with a closed-loop oscillating heat pipe, which was the capillary tube filled with a working fluid. The total heat transfer from the main tube surface to the fin body was the combination of the heat conduction via the capillary tube material and the heat convection via the working fluid flowing inside the capillary tube. The effectiveness of this heat exchanger increased approximately 10% compared to that of a conventional wire-on-tube heat exchanger. In case of free convection, Samana et al. [7] also found the enhancement of heat transfer when the oscillating heat pipe was used as the extended surface.

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In this study, thermal performance of a wire-on-tube heat exchanger of which the wire was replaced with an oscillating heat pipe as shown in Fig. 1 under air forced convection was investigated. The effects of some geometrical parameters on the thermal performance were included in this work.

Experimental set-up

In this work, a wire-on-tube heat exchanger was installed in a wind tunnel shown in Fig. 2. It exchanged heat between the ambient air flowing perpendicular to the tube panel and the hot water flowing inside the tube. The dimensions of heat exchangers were shown in Table 1. The volume flow rate of hot water was at 1 L/min and measured by a rotameter having $\pm$0.01 L/min accuracy. The air flow across the heat exchanger was varied between 0.02 and 1.5 kg/s and measured by a hot wire anemometer having $\pm$0.1 m/s accuracy.

The inlet temperature of hot water was varied between 40 and 80 °C while the ambient air temperature was kept constant at 25 °C. The inlet and the outlet temperatures of water and ambient air and the surface temperatures of fin and tube were measured by the set of K-type thermocouples with $\pm$0.1 °C accuracy. Note that, 50% of the total volume inside the capillary tube was filled with R123 and acted as an oscillating heat pipe.

Data reduction

For forced convection, the tube-side and the air-side heat transfer rates of the tested wire-on-tube heat exchanger could be evaluated from

$$Q_w = \dot{m}_w Cp_w (T_{wi} - T_{wo}), \quad (1)$$

$$Q_a = \dot{m}_a Cp_a (T_{ao} - T_{ai}) \quad (2)$$

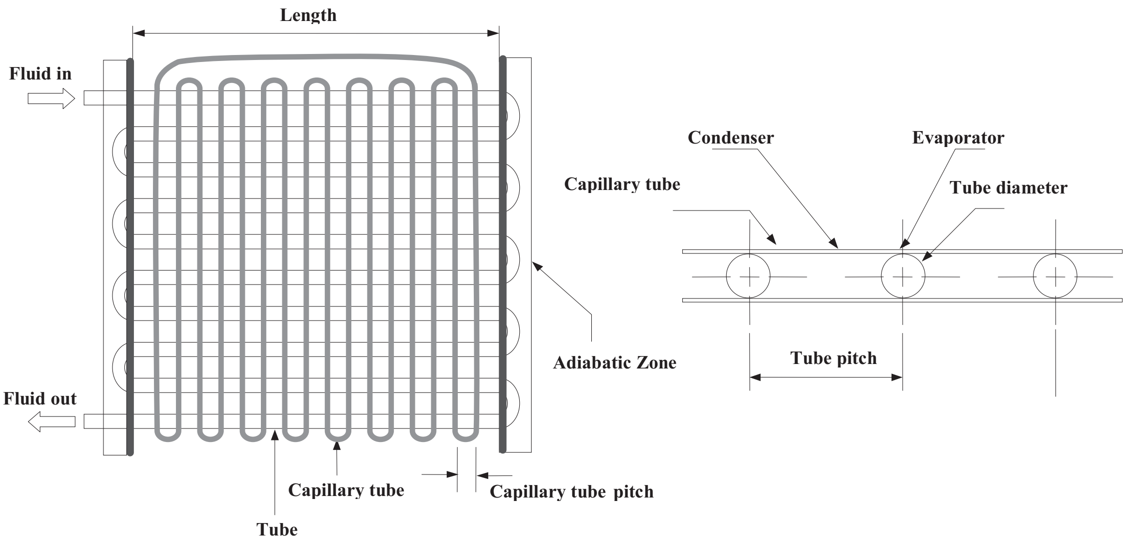

Fig. 1. Details of wire-on-tube heat exchanger with oscillating heat pipe fin.

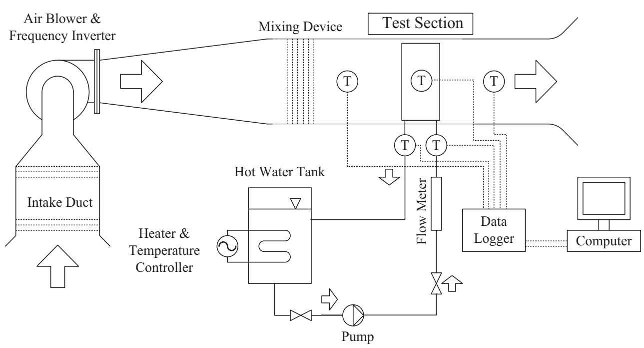

Fig. 2. A wind tunnel for heat exchanger testing.