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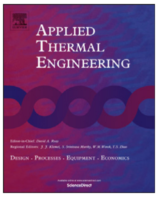

Research paper

Experimental and numerical investigation of an air-to-water heat pipe-based heat exchanger

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HIGHLIGHTS

- An air-to-water thermosyphons based heat exchanger has been investigated.
- The developed CFD model has been validated experimentally.
- A good agreement was achieved between CFD and experiment.
- Effect of multi-air-pass on the working temperature of thermosyphons was reported.

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ABSTRACT

An experimental and analytical investigation was conducted on an air-to-water heat exchanger equipped with six wickless heat pipes (thermosyphons) charged with water as the working fluid. The flow pattern consisted of a double pass on the evaporator and condenser sections. The six thermosyphons were all made from carbon steel, measured 2 m in length and were installed in a staggered arrangement.

The objectives of the reported experimental investigation were to analyse the effect of multiple air passes at different air inlet temperatures (100–250 °C) and air mass flow rates (0.05–0.14 kg/s) on the thermal performance of the heat exchanger unit including the heat pipes. The results were compared with a CFD model that assumed the heat pipes were solid rods with a constant conductivity. The conductivity of the pipes was extracted from modifications of correlations available in the literature based around the theory of Thermal Resistance. The results proved to be very accurate within 10% of the experimental values.

1. Introduction

Heat pipe-based heat exchangers are finding increased usage in a variety of applications due to new environmental policies to reduce exhaust temperatures and the carbon footprint of many industries [1,2]. These devices uniqueness derives from the use of heat pipes, responsible for increasing the heat exchanger's reliability, flow separation, ease of operation, system efficiency and reducing the overall manufacturing and maintenance cost. A heat pipe is essentially a superconductor [3], consisting of a sealed and evacuated tube partially filled with a working fluid. The working fluid is responsible for the device's high heat transfer capabilities as when faced with a temperature difference it enters a state of evaporation/condensation, allowing large quantities of heat to be transferred at an essentially constant temperature.

Heat pipe-based heat exchangers find use in a wide variety of industries, such as space [4], computing and electronics [5], ventilation and air conditioning (including dehumidification devices) [6], solar energy systems [7], water desalination [8], and nuclear systems [8,9], from temperatures below zero degrees [10], to as high as 950 °C [11], depending on the materials composing the pipe and the working fluid used.

The basic operation of a wickless heat pipe (thermosyphon) relies upon a difference in temperature between both ends of the pipe. Upon coming into contact with a heat source, the working fluid inside the pipe evaporates, transporting the heat to the top of the pipe. When this vapour makes contact with the cooler wall of the pipe at the top, it condenses, releasing its latent heat and

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changing phase to liquid that will flow back to the evaporator due to the gravity effect to complete the working cycle [12].

There is a particular characteristic that can change a heat pipe's working principle and that is the existence or lack of a wick structure. Heat pipes that are used in the thermal management of electronic components have a built-in wick structure that allows them to work against the force of gravity, due to capillary pressure being exerted on the fluid. Heat pipes applied in industrial heat exchangers are devoid of a wick in order to keep costs. A schematic of a wickless heat pipe can be seen in Fig. 1. Wickless heat pipes are technically named two-phase closed thermosyphons or gravity-assisted heat pipes and are the ones used in the experiment described in this paper.

The heat exchanger under study is equipped with two phase closed thermosyphons which involves two air passes across the evaporator and two water passes using a baffle at the condenser side. A heat pipe-heat exchanger is usually divided in three parts: evaporator, adiabatic section and condenser, which coincide with the parts of the heat pipe as can be seen in Fig. 1. In the evaporator of the heat exchanger under investigation, the hot air passes through the pipes, in the evaporator section, twice in what is effectively called “two passes”, as can be seen in Fig. 2. One of the advantages of having two passes in the evaporator section is to balance the heat pipes' working temperatures as the hot air will go through the first half of the evaporator and then cover the second half but by contacting the later rows first. This will lead to more balanced working temperatures inside the thermosyphons throughout the heat exchanger. In addition, and for the same hot air mass flow rate, forcing the hot air to flow through two passes will lead to higher convective heat transfer coefficient from the air to the pipes when compared with the lower velocity hot air if it passes through the pipes in one pass. The same enhancement in the heat transfer coefficient is achieved in the water side by using a baffle to allow the water to flow around the condenser ends of the thermosyphons faster (see Fig. 3); hence higher convective heat transfer coefficient from the condenser to the water flow [13]. In order to determine the heat transfer coefficient on the shell sides, there are widely accepted correlations derived from empirical studies, as noted by Incropera & DeWitt [14]. The flow in the condenser section makes contact with the pipes linearly and according to the numbering of the pipes, as seen in Fig. 3.

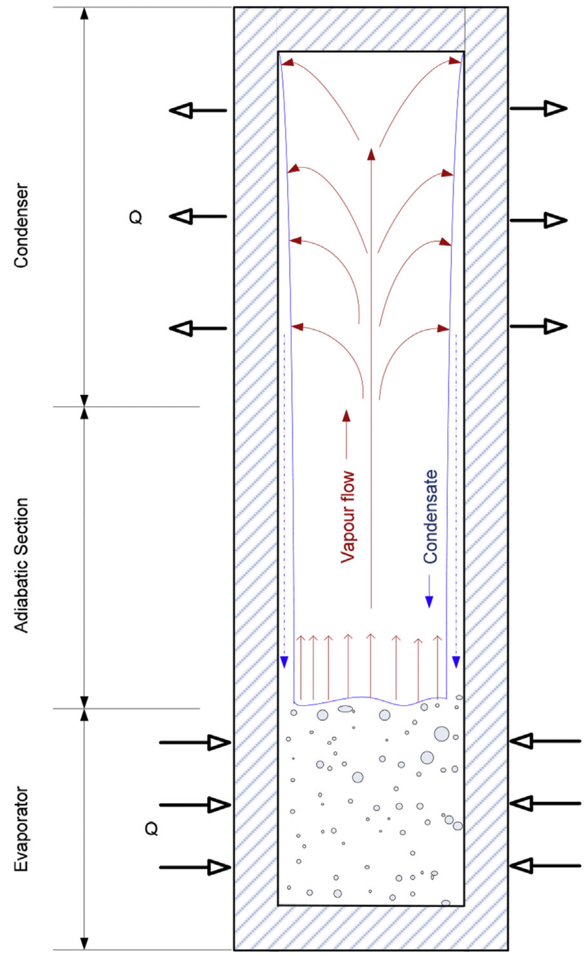

Fig. 1. Schematic of a working two-phase closed thermosyphon.

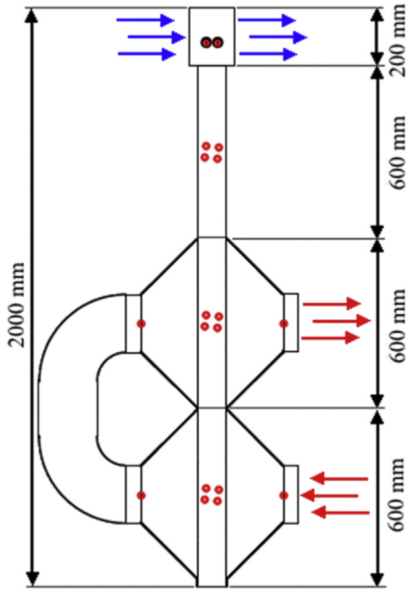

Fig. 2. Schematic representation of the heat pipe heat exchanger thermocouple locations (each red dot represents a K-type thermocouple) and dimensions (all in mm). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Danielewicz et al. [15] have conducted an investigation of an air-to-air heat exchanger and produced a correlation which allowed the prediction of multiple variables related to heat exchanger performance based on the inlet conditions. A similar principle was used in this investigation; the experimental results were compared and validated through Computational Fluid Dynamics. Jouhara and

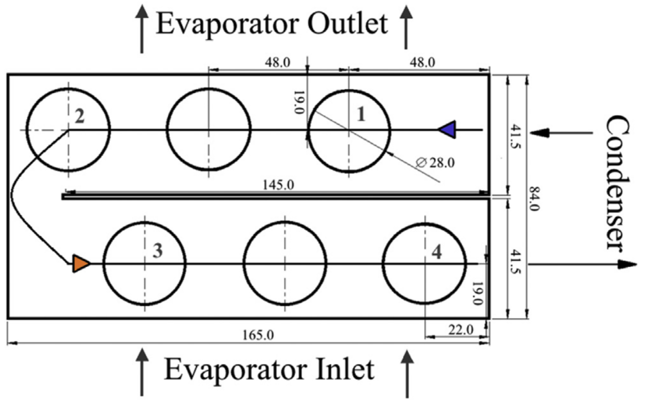

Fig. 3. Top down view of a cross section of the condenser section. The pipes numbered are the pipes with thermocouples on their surface.