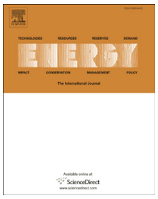
Energy xxx (2017) 1–18

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy



Performance evaluation of a multi-pass air-to-water thermosyphon-based heat exchanger

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ARTICLE INFO

Article history:
Received 17 January 2017
Received in revised form
16 March 2017
Accepted 20 April 2017
Available online xxx

Keywords:
Heat pipe
Thermosyphon
Heat exchanger
CFD
Effectiveness

ABSTRACT

The project reported in this paper used CFD as a tool to investigate the effect of multi-pass on the shell side heat transfer of a heat exchanger system. The heat exchanger system is equipped with six vertical thermosyphons transferring thermal energy from a heat source (air) to a heat sink (water). The CFD model has been experimentally validated. The two-phase change processes inside the thermosyphons were not modelled during the simulation. Instead, the thermosyphons were treated as solid rods with a constant thermal conductivity, which was calculated theoretically by applying the thermal resistance analogy with the aid of convection, boiling and condensation correlations found in the literature. The heat source consists of multiple air passes on the evaporator section of the thermosyphons and two water passes on the condenser section. Three different arrangements on the evaporator section were investigated with one, two or three shell passes and the thermal performance compared for the three configurations. The investigation was performed at various inlet conditions: a range of air inlet temperatures (100, 150, 200 and 250 °C) and mass flow rates (0.05, 0.08, 0.11 and 0.14 kg/s). The water inlet conditions were kept constant (a temperature of 15 °C and a mass flow rate of 0.08 kg/s). The overall rate of heat transfer was obtained by both CFD and a theoretical model, and the results lay within 15% of the experimental data. The numerical predictions demonstrated that the $k-\varepsilon$ Realizable turbulence model is a reliable tool for predicting heat transfer and fluid flow in such heat exchangers.

1. Introduction

It is generally accepted that throughout history, especially after the industrial revolution, humans have had a negative impact on the environment. A clear increase in the earth's average temperature has been observed for some years and the world's leading climate scientists believe that this rise in temperature is directly related to mankind's activities [1], such as the burning of fossil fuels, deforestation and livestock farming. Those activities produce gases which act in a similar way to the glass in a greenhouse, permitting short-wavelength solar radiation to be incident on the earth's surface but absorbing long-wavelength infra-red radiation from the earth, thereby increasing global temperatures. Gases produced by human activities include, in particular, carbon dioxide, methane, nitrous oxide and fluorinated gases. Carbon dioxide is the major greenhouse gas (GHG), which contributes 64% of man-made global warming and its concentration in the atmosphere is currently 40% higher than when industrialisation began [2]. Other GHGs contribute less to global warming: 17% for methane and 6% for nitrous oxide, although they are more efficient at absorbing infra-red radiation than carbon dioxide.

Average global temperatures have been observed to have risen by about 0.85 °C in the past 150 years (50% of the rise in the past 20 years) and they are still subject to further increases. If they exceed 2 °C, there is a risk of dangerous changes in human and natural systems [2] and actions have been taken by the United Nations Framework Convention on Climate Change (UNFCCC). The objective was to level off GHG emissions in this decade and to reduce them by 50% compared to 1990 levels by 2050. In order to achieve a reduction in GHGs, the European Union (EU) has imposed some policies including the increased use of renewable energy sources

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http://dx.doi.org/10.1016/j.energy.2017.04.111

Please cite this article in press as: Mroue H, et al., Performance evaluation of a multi-pass air-to-water thermosyphon-based heat exchanger, Energy (2017), http://dx.doi.org/10.1016/j.energy.2017.04.111

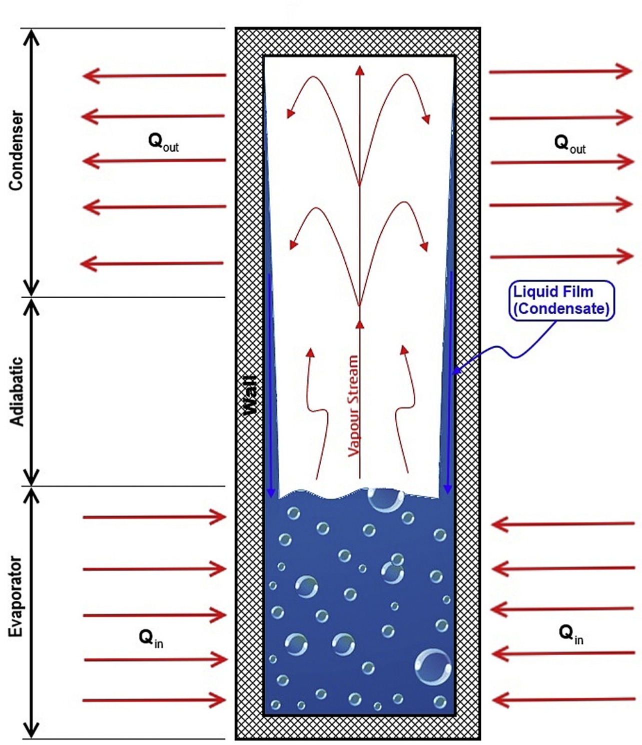

Fig. 1. Thermosyphon schematic.

and a continual improvement in the energy efficiency of a wide range of systems [3]. EU leaders have also set several targets to be met by 2020. These targets were proposed in 2007 and agreed in 2009, including a 20% reduction in GHG emissions, 20% of energy to come from renewables and a 20% improvement in energy efficiency.

Companies involved in building services and process industries have therefore been forced to design more sustainable and energy efficient systems [4–6] to meet the EU targets. Exhaust gases generated from such activities release both GHGs and waste heat to the atmosphere and they are a significant contributor to global warming. Waste heat could be recovered and/or recycled through heat exchanger (HX) systems to be reused within the industrial processes, which would save energy and decrease the power consumption coming from fossil fuels, hence reducing GHG emissions.

In this paper, a heat exchanger system designed to recover waste heat using heat pipe (HP) technology has been investigated. The shell side heat transfer will be investigated theoretically, experimentally and numerically for multiple shell side fluid passages.

2. Heat pipes

To tackle the energy problem caused by the rapid decrease of oil and fossil fuel suppliers as mentioned by Olabi [7,8], more research and developments are required in the energy sector. One such recent development involves the use of heat pipe based heat exchanger systems in waste heat recovery. Heat pipes are devices that facilitate the transfer of thermal energy between two media (heat source and heat sink) within the heat exchanger. They are also described as superconductors because of the high heat transfer capability over large distances using a small temperature difference [9]. A heat pipe is a device that contains a small amount of liquid known as the working fluid, in an evacuated sealed tube. The common cross-sectional area of the tube is either cylindrical or rectangular. However, the shapes of the cross-section and design are not limited to these two options and can be altered, depending on the application [10].

A heat pipe may be divided in three different areas: evaporator, adiabatic section and condenser. The working fluid is located in the evaporator section where heat is applied on the external wall of the pipe. Heat is then absorbed by the working fluid through the evaporator wall, essentially in the form of latent heat. When the temperature of the liquid pool exceeds the saturation temperature, nucleation sites and small bubbles start to form on the inner wall of the evaporator. The absorption of more heat causes the bubbles to grow in size and the vapour generated travels towards the condenser under the effect of the vapour pressure difference between the evaporator and condenser section. Before reaching the condenser, the vapour travels through the adiabatic section where heat is conserved. Upon reaching the condenser, the vapour contacts the condenser inner wall which is at a temperature below saturation. The vapour will then condense back into liquid, forming a thin layer of liquid film, flowing back along the walls to the evaporator and hence completing the cycle. The conventional heat pipe returns the liquid condensate by capillary forces induced by

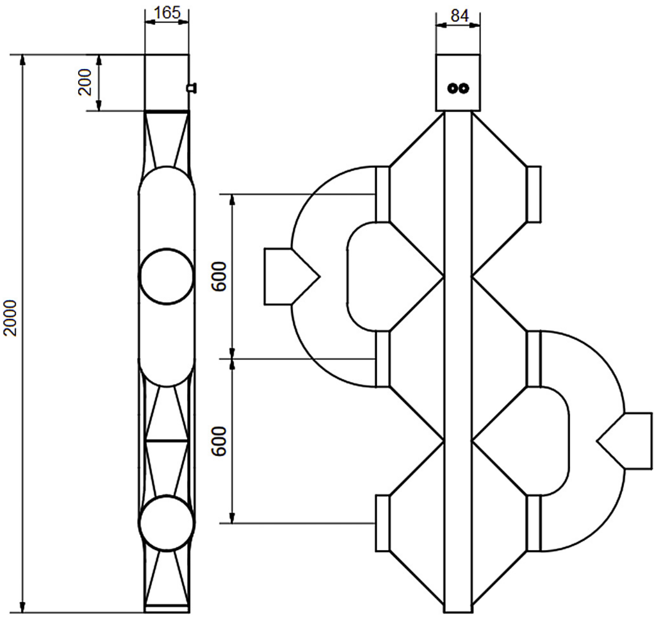

Fig. 2. Test unit dimensions.

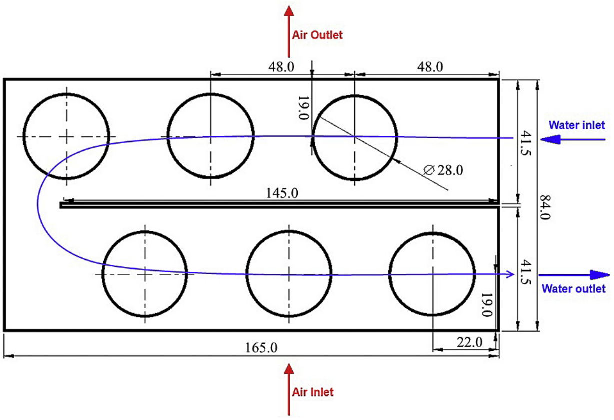

Fig. 3. Top view of the condenser (all dimensions are in mm).

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