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An experimental investigation on the gravity assisted solar heat pipe under the climatic conditions of Tunisia

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ABSTRACT

This paper deals with an experimental investigation of the effect of the working fluid inventory on the performance of the gravity assisted solar heat pipe. Measurements of solar flux and the temperature in different positions over the heat pipe have permitted us to evaluate the performance of the system for different working conditions. Results prove that the optimum performance is observed when the 2/3 of evaporator volume is filled with methanol.

1. Introduction

The heat transfer is an integral part of many industrial processes. For this reason, many systems have become very efficient. However, large quantities of energy are being lost by thermal systems and only heat exchangers can be used to recover and put in use this energy for heating or cooling process. Among these devices, we note the heat pipe which can transport relatively a large quantity of energy over a small temperature gradient between its ends. The heat pipe technology is widely used for various heat transfer equipments and variety of industrial applications. This device presents many advantages in electronics cooling [1], chemical engineering [2], air conditioning systems [3] and in light water nuclear reactors [3]. For this reason, many researchers have drawn attention to this kind of heat exchanger. Negishi and Sawada [4] investigated the interactive influence of the inclination angle (10–90° from the horizontal) and fill ratio (5–100%) of an inclined two-phase closed thermosyphon without an adiabatic section. Heating and cooling were performed by water jackets surrounding the evaporator (up to 85 °C) and condenser (25 °C) sections. They showed that highest heat transfer rates are obtained when the fill ratio is between 25% and 60% for water and 40% and 75% for ethanol and the inclination angle is between 20° and 40° for water and more than 5° for ethanol. They determined that the overall heat transfer coefficient of the water thermosyphon was between 2.4×10^3 W/m^2 K to 3×10^3 W/m^2 K and for the ethanol thermosyphon between 0.9×10^3 W/m^2 K to 1.1×10^3 W/m^2 K. They found that the thermal diode characteristics of an inclined thermosyphon depend upon the fill ratio of working fluid. In order to stop the heat flow at a larger inclination angle, it is necessary to use a smaller fill ratio. Shalaby et al. [5] investigated the performance of a thermosyphon. They adopted the R22 as a working fluid. A smooth copper tube of total length 1500 mm and 21 mm inside diameter was used as a container of the thermosyphon. Each of the evaporator section and the condenser section had a length of 600 mm, while the remaining part of the tube was the adiabatic section. They found that at low heat transfer rate between 100 and 300 W, fill ratio between 30% and 100% and inclination angles between 22.5° and 90°, the optimum fill ratio was 50% and best inclination was 30°.

An experimental investigation was conducted by Noie et al. [6] on the geyser boiling in a two-phase closed. A series of experiments were carried out to investigate the influence of the filling ratio, aspect ratio, heat input and coolant mass flow rate on the period and intensity of geyser boiling under normal conditions. Two copper pipes of 1000 mm length with 15 and 25 mm inside diameter and methanol as working fluid were employed. The results showed that by increasing the filling ratio, the period of geyser boiling and the intensity of temperature oscillation increased, but when the filling ratio becomes less than 30%, the geyser boiling disappears. The effect of heat input on the period and intensity of temperature oscillation is so important that by increasing the heat input, the period and intensity of temperature oscillation decreases until it becomes very low and then completely disappears.

An experimental investigation was conducted by Zhu et al. [7] on the behaviors of a semi-open two-phase thermosyphon (SOTPT) during startup, shutdown and lack of water were studied to get complete understanding of its thermal characteristics. They found that the variation of wall temperature, heat-exchange condition and pressure fluctuations of semi-open two-phase thermosyphons

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Nomenclature

A_v	vapor flow area, m^2
Cp_w	specific heat of water, J kg^{-1} K^{-1}
g	gravitational acceleration, m s^{-2}
G	incident solar irradiance, W m^{-2}
h_{lv}	latent heat of evaporation, J kg^{-1}
M_w	mass of water in the tank, kg
Q_w	useful power transferred to the cooling water, W
Q_{ent}	entrainment limit, W
T_e	average evaporator temperature, °C
T_c	average condenser temperature, °C
T_{op}	operating temperature, °C
T_w	average cooling water temperature, °C
V	evaporator volume filled with liquid, ml
U	overall heat transfer coefficient, W/m^2 K
σ	surface intensity, Nm^{-1}
ρ_l	density of liquid phase, kg m^{-3}
ρ_v	density of vapor, kg m^{-3}

showed that the startup of SOTPT needs about 60–70 min in order to discharge excess water and to stabilize the vapor–liquid interface at the top. They showed that in the process of startup, the pressure variation of SOTPT is different from that of a closed two-phase thermosyphon (CTPT). The average pressure in the heat pipe is equal to the environmental pressure in general. The shutdown of SOTPT needs about 30–50 min, which is much shorter than that for startup. A semi-open two-phase thermosyphon shows a rather good response to a lack of water accident.

Nuntaphan et al. [8] studied the critical heat flux (CHF) due to the flooding limit of the thermosyphon heat pipe using triethylene glycol (TEG)–water mixture. From the experiments they found that the use of TEG–water mixture can extend the heat transport limitation compared with pure water and higher heat transfer can be obtained in comparison with pure TEG at high temperature applications. In addition, it was found that ESDU equation is appropriate to predict the CHF of the thermosyphon in the case of TEG–water mixture. For thermosyphon air pre-heater at high temperature applications, it was found that with a selected mixture content of TEG–water in each row of the thermosyphon, the performance of the system could be increased by approximately 30–80% compared with pure TEG for parallel flow and by 60–115% for counter flow configurations. They showed that the performances increase approximately 80–160% for parallel flow and 140–220% for counter flow compared with those of pure dowtherm, which is the common working fluid at high temperature applications.

Payakaruk et al. [9] considered the effect of dimensionless parameters as Bond number, Froude number, Weber number and Kutateladze number on the performance of an inclined thermosyphon with R22, R134a, ethanol and water as working fluids. Experiments were conducted with fill ratios between 50% and 100%, aspect ratios between 5 and 40, vapor temperatures between 0 and 30 °C and inclination angles from 5° to 80°. Their experiments results showed that the fill ratio has no effect on the ratio of heat transfer characteristics at any angle to that of the vertical position (Q/Q_{90}), but the properties of the working fluid affected Q/Q_{90}. They found that the optimum inclination angle for water is between 40° and 70°.

Two types of heat pipes (with and without wick) were studied experimentally by Said and Akash [10] using water as a working fluid. The wick was made of cotton, which is normally used in oil lamps. The heat pipe was positioned at different angles of 30°, 60°, and 90° with the horizontal. Results show that the performance of the heat pipe that contained a wick was more significant in terms of overall heat transfer coefficient, for the temperature range studied. It resulted in about 55%, 25%, and 70% increase for 30°, 60°, and 90° tilt angles, respectively.

The heat pipes are currently utilized in many solar energy systems according to their needs, in industrial applications including the solar system considered in the present analysis. For example, the heat pipes are suitable for domestic solar water heating [11], solar swimming pool heating [12] and solar space heating systems [13].

However, during the literature survey of our work, we have observed few papers illustrating the experimental optimization of these systems. In our work, an experimental investigation on gravity assisted solar heat pipe has been conducted. An experimental design based on heat pipe exchanger has been developed. A series of measurements conducted over the climatic conditions of Tunisia and for different methanol fill charges show that the efficiency of the system vary with the solar flux and the amount of the working fluid.

2. Heat pipe presentation

The heat exchanger with heat pipes occurs by phase change, in the evaporator and in the condenser. The evaporator is positioned lower than the condenser, in order to allow the condensed fluid return to the evaporator region through gravity. This type of heat pipe is known as a closed, gravity assisted, two-phase thermosyphon. The evaporator is partially filled with a working fluid, when this extremity of the heat pipe is heated; the working fluid is evaporated as it absorbs an amount of heat equivalent to the latent heat of vaporization; which increases the vapor pressure inside the cavity of the heat pipe. The difference between the vapor pressure at the evaporator end and the pressure at the condenser end causes a pressure gradient in the vapor core that causes the travel of vapor upward to the condenser section where it is converted into liquid, giving up its latent heat of condensation, which raises the temperature of the cooler extremity and causes the return of liquid condensate to the heat pipe evaporator as a thin film on the wall of the heat pipe under the effect of gravity. This process continues in a cyclic manner thereby facilitating the working of the heat pipe without any external driving force. A schematic diagram of a heat pipe is shown in Fig. 1.

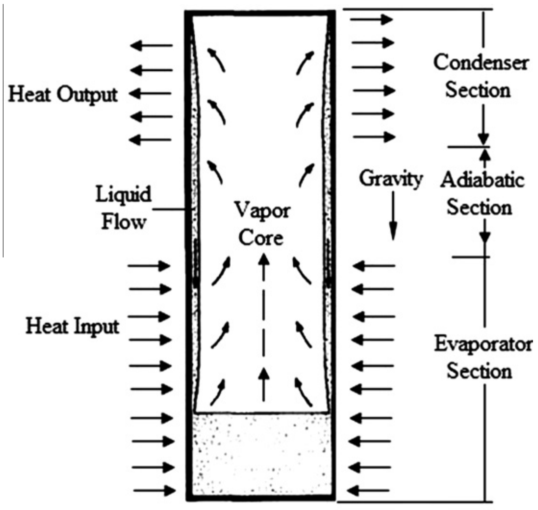

Fig. 1. A simple gravity-assisted two-phase closed thermosyphon.