The effect of the heat loads on the partial-vacuum thermosyphon performance

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Abstract

In the present research, the effect of the heat flux and the cooling water flow rate of the condenser on overall performance of partially vacuumed thermosyphon were studied. A rig was made from a 1 m copper tube with an inside and an outside diameter of 17.5 and 19 mm. The heights of the evaporator, the adiabatic section and the condenser are 40, 20 and 40 cm respectively. The temperatures at different places on the thermosyphon and on the inlet/outlet of the cooling water were measured. It was observed that with increasing of heat flux to the evaporator the thermosyphon performance increased. On the other hand, with decreasing of the cooling water flow rate, the performance of the thermosyphon was increased as the trapped air moved toward the end of the condenser. In order to illustrate the effect of existence of air to deactivating the thermosyphon, the pipe was cool down by disconnecting of power input to the evaporator. It was seen that the thermosyphon loss its performance as the trapped gas occupies the whole condenser. The whole study shows due to existence of air, the heat loads can have significant effects on the performance of the thermosyphon.

Keywords: Energy recovery, Thermosyphon, Heat transfer, Performance, Partial vacuum

Introduction

Due to human need to energy a more efficient way of using energy is a major challenge in the scientific activity. The performance of heat transfer is one the most important port of these types of investigation. The heat pipe is one of industrial equipments for transferring of heat with reasonable efficiency. The advantage of using the heat pipes is its need to small area and temperature difference. In addition, the simplicity of design, high rate of heat transfer, one way heat transfer (thermal diode), low cost, low weight, low cost of maintenance, etc. which makes this equipment more demanding [1, 2].

The first idea of using heat pipe was present by Perkins family in nineteen century. In heat pipes the key issue for heat transfer is change of fluid phase inside the heat pipe. Nowadays, a group of heat pipes that fluid circulation happens inside them due to gravity called Two phase closed thermosyphon [2]. The first heat pipe which used the capillary of the fluid for its movement was fabricated by Gaugler (1994) [3]. Consequently, Grover et al. (1966) [4] showed that the performance of the heat pipe for transferring heat can be more than metals with high conductivity. They called this equipment " Heat Pipe" for first time.

A heat pipe consists of an insulated pipe, a wick and working fluid as shown in Fig.1. The two phase thermosyphon is a type of heat pipe which haven't any wick for transfer the fluid and fluid moves inside the pipe due to difference in gravity of the working fluid. Any heat pipe has three sections including: the evaporator, the adiabatic and the condenser. In thermosyphon, the condenser always placed above the evaporator while in heat pipe with a wick in can be placed below the evaporator [1].

Fig. 2 shows a two phase closed thrmosyphon with its components. As figure shows the heat is input through the evaporator section where a liquid pool exists, turning the working fluid into vapor. The vapor rises and passes through the adiabatic section to the condenser section. In the condenser section, the vapor condenses and gives up

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its latent heat. Gravity then returns the condensate back to the evaporator section. Due to their high efficiency, reliability, and cost effectiveness, thermosyphons have been used in many different applications. These applications include preservation of permafrost, de-icing of roadways, turbine blade cooling , and applications in heat exchangers [1], humidity control [5], food industry [6], solar systems [7] and reactors [8].

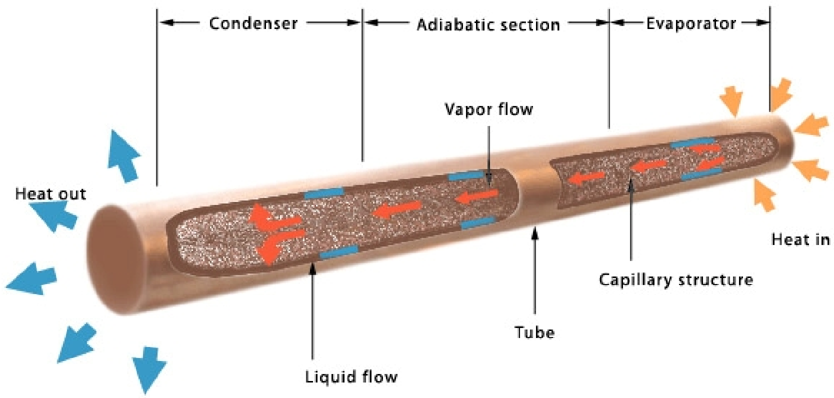


Fig. 1. Principle of heat pipe operation

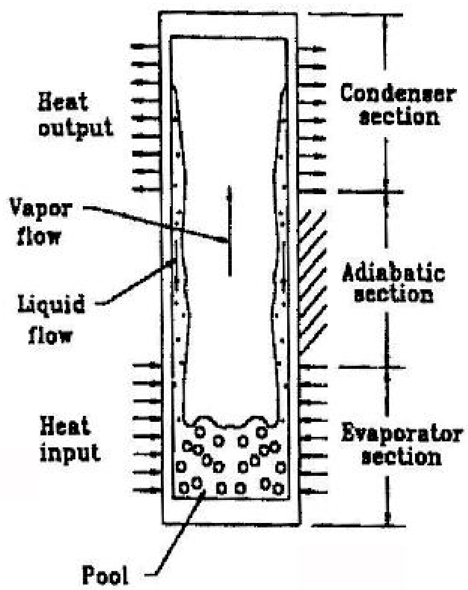


Fig. 2. Two phase closed thermosyphon

There is a type of heat pipe which is called Gas-Loaded Heat Pipe. This type of heat pipe contains non condensable gas (NCG), such as air. They employed for systems need to the evaporator section works in isothermal condition. However, this condition in other systems may be established due to non complete drain of air from the system. The NCG fills a part of condenser and deactivates that part. Therefore, system works at partially vacuum condition. Fig.3 illustrates the role of existence of the non-condensable gas on the performance of the heat pipe [1].

Numerous research work were carried out in order to study the heat pipe and the ways that can use it in more efficient ways.

A two-phase gravity assisted thermosyphon was designed, fabricated and tested with three nanofluids based on water (with 1% by weight of Al_2O_3, CuO, and laponite clay) by Khandekar et al. [9]. They obtained thermal performance with pure water as the working. They observed that thermal performance deteriorates when nanofluids are used as working fluids. Maximum deterioration was observed with laponite while minimum deterioration was for aluminum oxide particles based nanofluids. In addition, they observed that the wettability of all nanofluids on copper substrate, having the same average roughness as that of the thermosyphon container pipe, is better than that of pure water. A scaling analysis was presented which shows that the increase in wettability and entrapment of nanoparticles in the grooves of the surface roughness cause decrease in evaporator side Peclet number that finally leads to poor thermal performance.

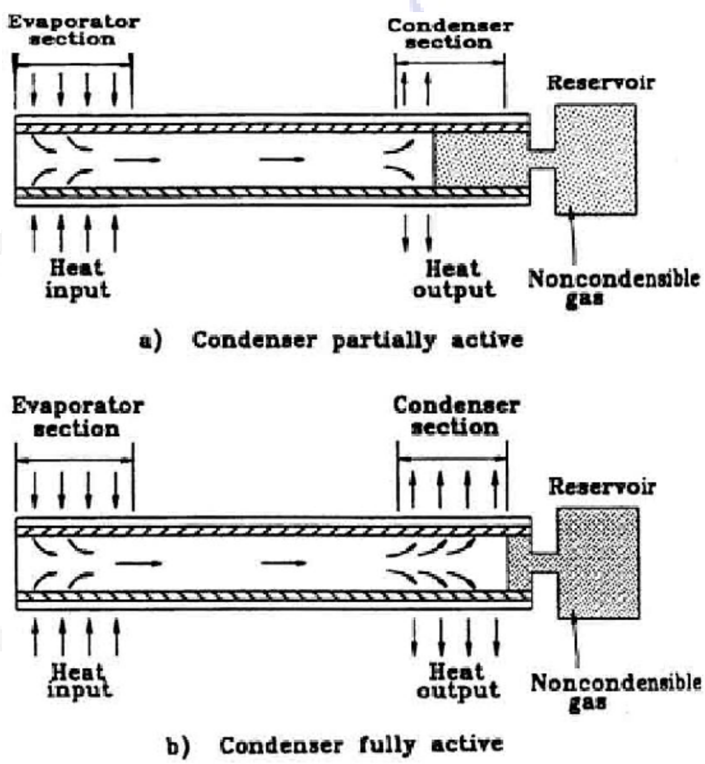
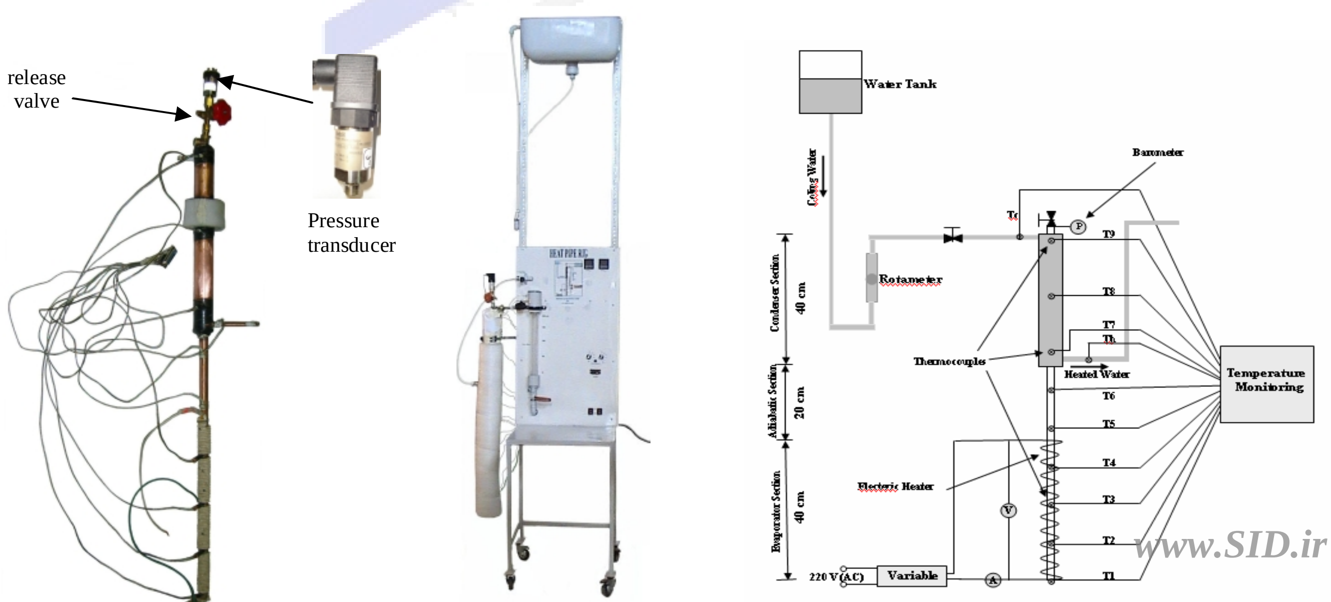


Fig. 3. Gas loaded heat pipe

Nuntaphan et al. [10] studied the critical heat flux (CHF) due to flooding limit of thermosyphon heat pipe using triethylene glycol (TEG)–water mixture. From the experiment they found that, 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 case of TEG–water mixture. For thermosyphon air preheater at high temperature applications, they found that with selected mixture content of TEG–water in each row of the thermosyphon the performance of the system could be increased approximately 30–80% compared with pure TEG for parallel flow and 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.

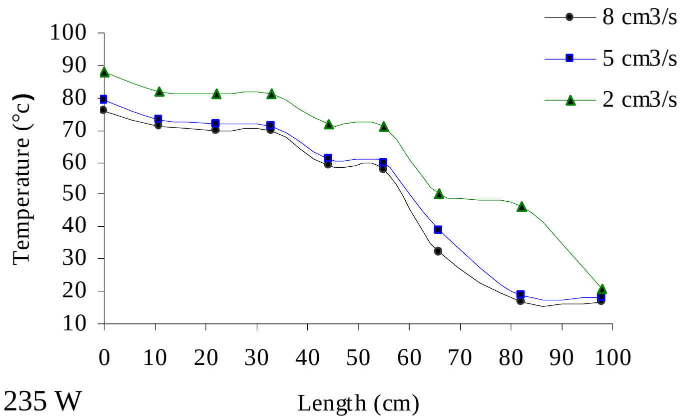
The thermal applicability of two-phase thermosyphons in ovens/furnaces was studied by Silva and Mantelli [6]. They evaluated the performance of thermosyphons as heat transfer devices responsible for connecting the combustion and cooking chambers. Two different approaches were used: first, an experimental setup, which simulates an internal cross section of a convectional bakery oven cooking chamber assisted by vertical thermosyphons, was built. The experimental measurements show that the thermosyphons were able to provide a uniform temperature distribution inside the cooking chamber without the appearance of any overheated spot. In addition to the experimental setup, a theoretical lumped model was used to predict the air temperature variation and the relative importance of the convective and radiative heat transfer modes inside the cooking chamber. The finite difference technique was applied for the computation of the non-linear differential system. They reported a good agreement between the model and the experimental data. In addition they found that the radiation was the major heat transfer mechanism inside the cooking chamber.
The experimental analysis of the thermal behavior of two-phase closed thermosyphons with an unusual geometry characterized by a semicircular condenser and a straight evaporator was investigated by Abrero and Colle [7]. All the tests were done in an experimental indoor setup that uses electrical skin heaters to simulate the solar radiation. Different evaporator length, fill ratio of working fluid, cooling temperature and slope of the evaporator were tested for different heat fluxes the analysis of the transient results and the steady state performance was used in order to provide information for the design of a compact solar domestic hot-water system.
In the present research, the effect of the heat flux and the cooling water flow rate of the condenser on overall performance of partially vacuumed thermosyphon were studied.

Experiments
Fig. 4 shows the real and a schematic views of the rig. It was made from a 1 m copper tube with inner and outer diameters of 17.5 and 19 mm respectively. A closed copper tube with a length of 40 cm and a diameter of 4 cm was used as condenser. The length of the evaporator, adiabatic and condenser sections are 40, 20 and 40 cm respectively. The rig equipped with temperature and pressure transducers as shown in the figure The temperature at nine places on the heat pipe as well as on inlet–outlet streams were measured. In addition, the pressure was measured at top of the thermosyphon as shown in the figure. The energy transferred to the evaporator section by an electrical heater with a predefined power input. The input energy was 1 KW which transfer via a electrical energy regulator. Water used as working fluid and the fill ratio of 30% was used in all experiments. The vacuum was established by simple heating the tube and purging the air by opening the release valve.

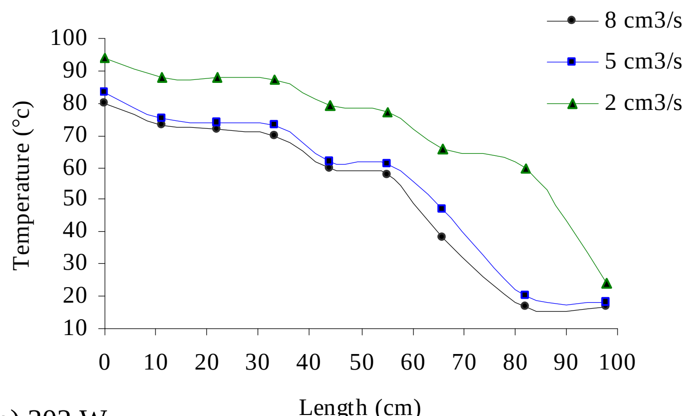


a) Thermosyphon a) Heat Pipe Rig c) schematic

The experiments was carried out using two heat rates of 235 and 302 W which transferred heat to the evaporation section. In addition, in experiments the cooling water rates of 2 and 5 and 8 cm^3/s were used in the condenser. In Fig. 5 the temperatures at various positions for the three cooling water flow rates and for two heat inputs are shown.
The results show that with increasing the heat flux, the temperatures at similar points for two setups increased. In addition, the highest difference was observed close to the bottom of the condenser. On the other hand, with decreasing the cooling water flow rate the temperature increased along the thermosyphon. The highest differences were observed in the whole condenser region.



a) 235 W



b) 302 W

Fig. 5. The temperature profile along the thermosyphon

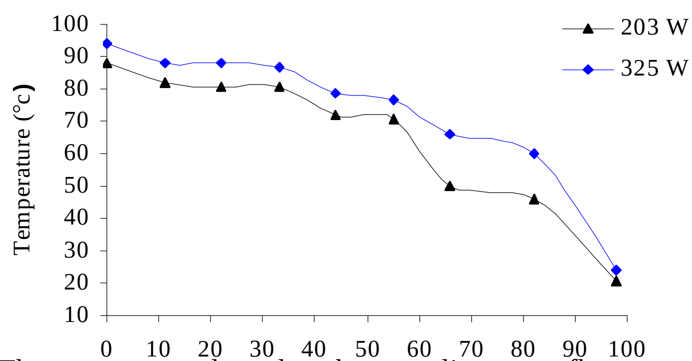


Fig. 6. The temperature along the tube at cooling water flow rate of 2 Cm^3/s

In Fig. 6 the temperature along the tube at cooling water flow rate of 2 cm^3/s for two different heat inputs of 235 and 302 W are compared. The results show the same temperature at the last measuring point which can be explained by existence of air for both setups at that section. In other word, at that place the condenser does not exchange heat with the water vapor properly. In addition, as can be seen in the figure a sharp decreasing of temperature occurs for the 203W setup after the sixth point of measurement. This happens because of existence of the air at that region. In other word due to lower vapor pressure in this setup air occupied more active volume of the condenser which is in agreement with previous explanation.
In order to illustrate the effect of the heat loads on thermosyphon, performance a relation has been proposed called thermosyphon performance as follow:

$$Q_{\mathrm{out}} = r\dot{V}c_{\mathrm{p}}(T_h - T_c) \tag{1}$$

$$h = \frac{Q_{\mathrm{in}}}{Q_{\mathrm{out}}} * 100 \tag{2}$$

Which Q_{in} is the input heat to the evaporator and Q_{out} is the heat absorbed by the condenser section. In addition, T_h and T_c are the input and out put temperature of cooling water passes through the condenser.
Fig. shows the thermosyphone performances for two heat input to the evaporator at various cooling water flow rate. The figure shows that performance of thermosyphon increase by increase of the evaporator heat load. In addition, the results shows that as cooling water flow rate increased the performance decreased. Both results conform existence of trap air has effect on the performance of the thermosyphon.

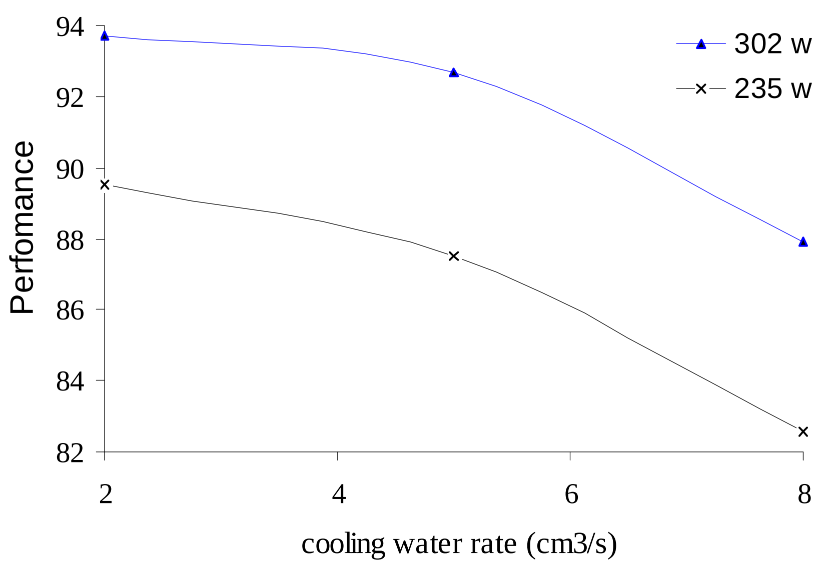


Fig. 8. Performance of the thermosyphon

In order to show how expansion of air can decrease the condenser performance, an experiment was carried out with cutting the power input to the evaporator. Fig. 8 shows the recorded temperatures along the tube as well as the pressure. The positions of the measuring points has been shown in Fig. 4. the figure shows that during the first 10 seconds there is a sharp decreasing in temperature which corresponds to the high performance of the thermosyphon in transferring of heat. However, after this period the thermosyphon does not work property due to expansion of the air and deactivation of the condenser. At this stage the thermosyphon just work as simple tube.

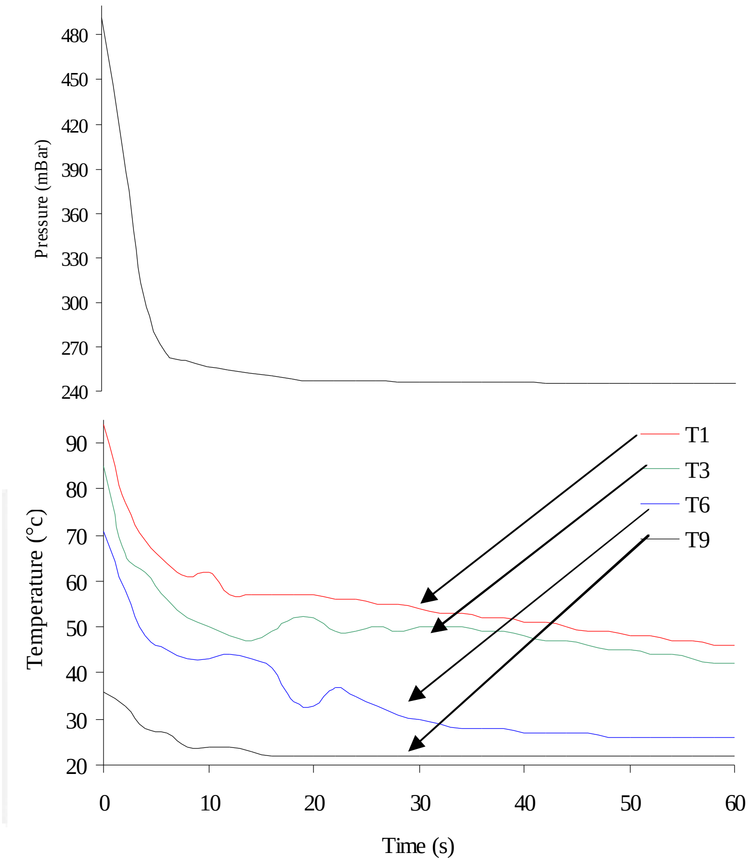


Fig. 8. The temperature and pressure of the thermosyphon

Conclusion

- The trapped non condensable gas in partially vacuumed thermosyphon has significant effect on its performance.
- Due to existence of the trapped gas, increasing of the heat load to evaporator can improves the performance of the thermosyphon.
- In partially vacuumed thermosyphon increase of cooling water flow rate decrease the performance of thermosyphon.
- In order to access to the maximum performance of a thermosyphon when employing it for transferring of heat at lower temperature conditions more vacuum should be established inside it.

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