International Journal of
Science and Engineering Investigations vol. 2, issue 23, December 2013
ISSN: 2251-8843

An Experimental Investigation on Axial Heat Flux for Heat Pipe

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Abstract- Purpose of this study was the design and construction of a heat pipe with heating source and cooling flow added by devices to measure the flow rate and temperature in order to determine the transferring heat flux in condensation zone at various saturation pressures. The experiments showed that enhancing the inlet heat flux which causes increasing the saturation pressure and temperature in the heat pipe, the axial heat flux is being enhanced with specific rate. This increase was differing in different temperature districts. The important fact was the decrease of the axial heat flux growing rate in some districts caused by saturation pressure enhancement and its retrieval.

Keywords- *Heat pipe, saturation pressure, axial heat flux, equilibrium zone*

I. INTRODUCTION

This template, Heat pipes are known as heat transfer superior devices and play an important role in thermal applications. The applications of heat pipes are in many industrial zones including energy and electronics cooling [1]. During all these years that heat pipes have been applied, many works have been done to improve them in order to achieve higher heat flux. Heat pipe vast industrial applications are based on properties which added by special processes, solve the industry practical problems in an efficient and economic way. Among these properties is high efficiency of heat transfer, no need to stop the facilities in the case of heat pipe damage, homogenous temperature, etc. [2]. Although many works have been done for heat pipes, there are few articles paying attention to the effects of temperature and pressure on axial heat flux. Osakabe et al. [3] applied heat pipe in voice amplifiers. Bilegan and Fetcu [4] experimentally investigated heat transfer characteristics of gravity-assisted aluminum extruded heat pipes, with heat pipes containing simple and inexpensive wick and Freon-12 (R-12) as working fluid. Operating temperature was used as one of the parameters. Merrigan et al [5] developed heat pipe for high temperature application. The heat pipes comprised a metallic liner and wick structure with a protective outer shell of an oxidation resistant material. The working fluids used in the heat pipes were alkali metals. Ho and Tien [6] studied condensation heat transfer inside a two-phase thermosyphon including reviewing of published experimental and theoretical investigations. Many thermal and geometrical parameters including saturation temperature and pressure were investigated. The significant point in all the mentioned articles is that axial heat flux was studied in small districts of temperature and pressure. Recently, there have been many efforts to develop lightweight and high performance heat pipes. Yang et al [7] reviewed various methods and approaches to achieve the requirements of lightweight and high performance. They also studied the use of lightweight materials in heat pipes and its limitations.

In this paper the relation between inlet heat flux and axial heat flux was investigated in a vast thermal interval.

II. THEORETICAL FRAMEWORKS

In basic form, the heat pipe is a sealed tube-type container with porous structure on its internal walls and filled with a working fluid. Vapor occupies the center of the tube (vapor core) while liquid fills the porous structure (wick). During the operation, liquid at the evaporator side evaporates, and vapor moves through the center of the tube to the condenser, where it condenses. Simultaneously, liquid flows through the wick from the condenser to the evaporator because of the action of capillary forces. This heat-mass transfer can transport great amounts of heat, from the evaporator to the condenser with little temperature drop. In Fig. 1 a schematics drawing of the heat pipe concept is shown.

The materials of the container’s wall and wick, as well as the working fluid are selected according to the application and compatibility of heat pipe. There exists also a variety of wick types available for usage [8].

In addition, the heat pipe is in equilibrium with isothermal environment. Furthermore, the liquid and the vapor are at saturation. When heat is applied to the evaporator, the temperature increases, and the liquid in the wick evaporates. The vapor pressure of the hot liquid working fluid at the hot end of is higher than the equilibrium vapor pressure of condensing working fluid at the cooler end of the pipe, and this pressure difference causes a rapid mass transfer to the condensing end where the vapor condenses, releasing its latent

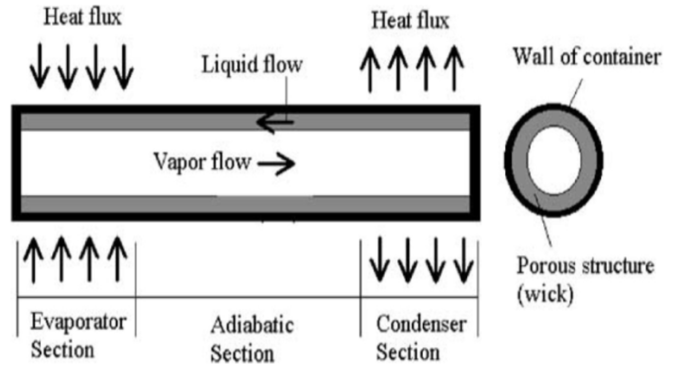

Figure 1. Conceptual drawing and operation of a conventional heat pipe [8].

heat, and warming the cool end of the pipe. In fact, the speed of the vapor is dependent on the rate of condensation at the cold side. The condensed working fluid then comes back to the hot end. Thus, heat pipe two phase heat transfer results in huge heat transfer capabilities. Nevertheless, if non-condensing gas subsists in the heat pipe, it obstructs the gas flow, and diminishes the effectiveness, especially at low temperatures, where vapor pressures are low [7].

III. DESIGNING THE SET UP

Design process included selecting the type of fluids, wick type and material, and pipe specifications that are not explained here for sake of abbreviation [9-12]. The system had distilled water as operating fluid. Heat pipe was made of two concentric pipes (one of copper and the other of stainless steel), and header was of copper. The properties of the pipes are shown in Table 1.

TABLE I. PROPERTIES OF THE PIPES

Item	O.D. (mm)	Thickness (mm)
Steel pipe	19	1.1
Copper pipe (at the junction to the steel pipe)	19	1.24
Copper pipe (in condensation zone)	25.4	1.65
Header	-	1.8

The wick properties are shown in Table 2.

TABLE II. PROPERTIES OF THE WICK

Material	Type	Mesh no.	Wire diameter (mm)	Thickness (mm)	No. of layers
Stainless steel	Wrapped screen	250	0.04	1	10

Fig. 2 shows the equipment including the heat pipe, electric heater, water conservation reservoir for entering fluid cooling, upper reservoir for balancing the temperature of fluid entering to cooling zone, entering water catharsis filters, digital thermometers, pressure gauge, control valves, safety valve, waterfront, flow meter, discharge reservoir, water pump, and junctions.

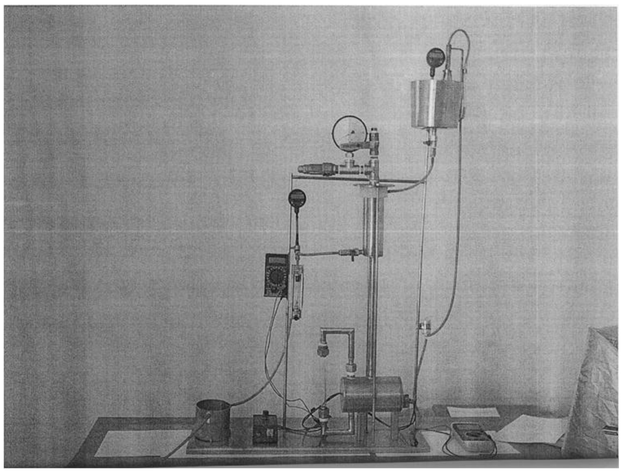

Figure 2. Photograph of the constructed experimental set up.

IV. EXPERIMENTAL PROCEDURES

First the operating fluid was inserted to the heat pipe reservoir, and the air was discharged. The electric energy was fed to the evaporator part having constant heat flux. During this stage, the axial heat flux was calculated using the data obtained from flow meter and difference between the entering and exiting temperatures of the fluid passing through condensation zone. The system pressure was obtained by a corresponding gauge. This was being continued till the system became steady getting constant pressure, temperature, and axial heat flux. This was the first equilibrium point. After this stage, by applying small changes to the inlet energy, the procedure was continued to find other equilibrium points. Within the condensation zone, the cooling fluid was maintained around 0 ºC using pieces of ice in the inner reservoir. It was pumped to the upper reservoir. After the temperature was measured, the cooling fluid was inserted to the condensation zone. At the mentioned zone, it absorbed the heat from the heat pipe framework, and immediately its temperature was measured at the exit. In this study, the temperature difference and the flow rate were the base of heat flux measurement. This is shown in (1):

$$Q = \dot{m}_c c\left(T_e - T_i\right) \tag{1}$$

Where, Q [J s^{-1}] is axial heat flux. [kg s^{-1}], c [J kg^{-1} K^{-1}], T_e [K] and Ti [K] are mass flow rate, specific heat, outlet temperature and inlet temperature of the coolant fluid, respectively.

V. RESULTS AND DISCUSSION

Heat flux was applied to the system, and the equilibrium state was achieved. The axial heat flux was enhanced that was due to the saturation temperature and pressure increase within the equilibrium system. After this stage, the enhancement rate was slowed down. It was because of pressure rise that reduces the heat transfer coefficient and causes a drop in circulative flow rate which in turn reduces the axial heat flux in the heat pipe. This is shown in Fig. 3.

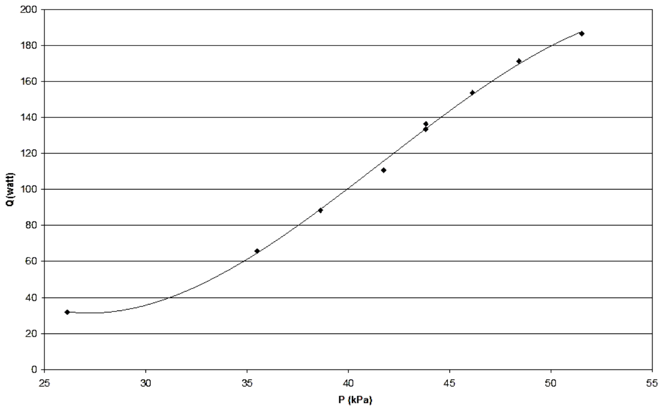

Figure 3. Variations of axial heat flux changes with saturation pressure for steady state in temperature interval 64-87°C.

By applying heat flux, evaporation was being started. As shown in Fig. 4, because the system was in unsteady state, the pressure was raised, and the axial heat flux had low amount. When the pressure was maintained constant, the axial heat flux was enhanced very rapidly. This situation continued till the steady state was achieved. Then, heat flux increasing rate was reduced and heat flux increased by constant rate. In this condition the system was at equilibrium at constant pressure and temperature (the so called saturation pressure and temperature). Since the Non-equilibrium diagrams presented similar behavior, their description is omitted.

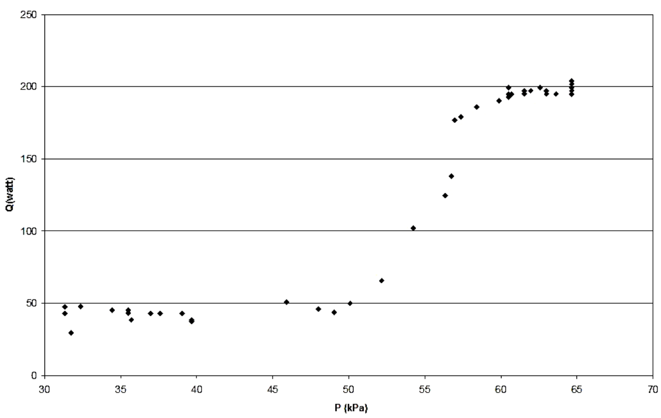

Figure 4. Variations of axial heat flux changes with saturation pressure for unsteady state in temperature interval 87.5-92.5°C

As seen in temperature interval 64-87°C, pressure increase had negative effect on the axial heat flux, and decreased condensation. So, the increasing rate was reduced till the increase rate of the axial heat flux approaches to zero which is observed in Fig. 5.

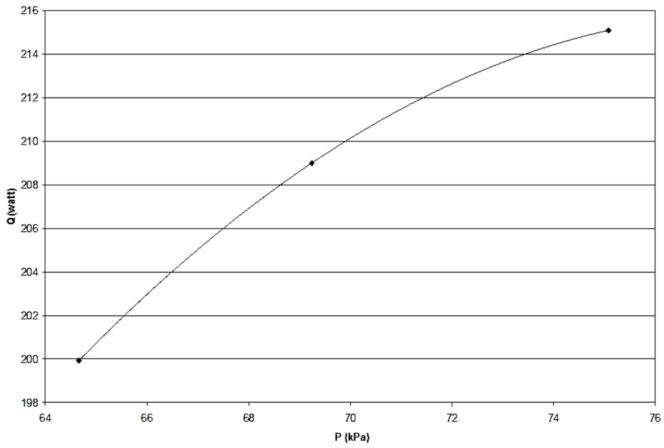

Figure 5. Variations of axial heat flux changes with saturation pressure for steady state in temperature interval 87.5-92.5°C

The decrease in the axial heat flux was seen in the first interval diagram. In the second interval, this rate reduction was continued until the heat flux became constant. In the third interval as shown in Fig. 6, the system began to retrieve itself. It means that as the pressure and temperature in the system increased, the axial heat flux was enhanced. However, due to circulative flow drop, heat flux increasing rate diminished.

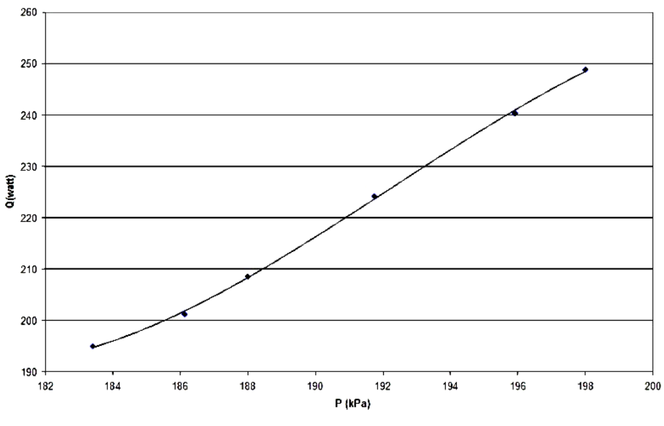

Figure 6. Variations of axial heat flux changes with saturation pressure for steady state in temperature interval 117.5- 121°C

As shown in Fig. 6, after a rather uniform stage for the axial heat flux increase, the system began to retrieve itself. Increasing the heat flux in evaporator zone, which enhances saturation pressure and temperature inside the system, the axial heat flux ascended. This is shown in Fig. 7. Since the diagram is similar to quadratic function, and the axial heat flux increasing rate is higher than that of the last interval, the axial heat flux increase can be predicted to be continued in the next thermal interval.

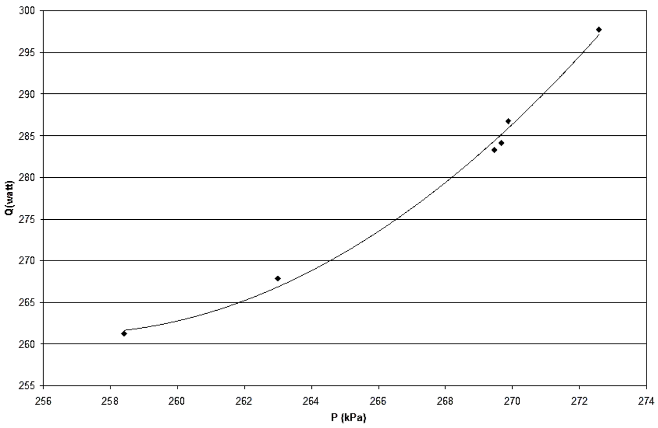

Figure 7. Variations of axial heat flux changes with saturation pressure for steady state in temperature interval 127.5- 129°C

As predicted earlier, the axial heat flux increasing rate is seen being increased in Fig. 8, and the diagram remains similar to quadratic function diagram.

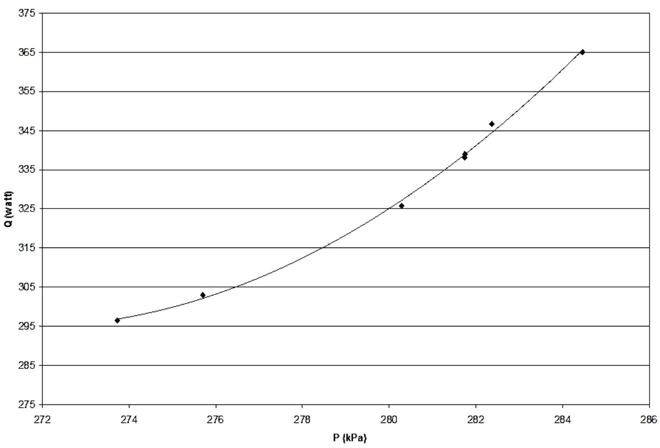

Figure 8. Variations of axial heat flux changes with saturation pressure for steady state in temperature interval 129.5- 131°C

As shown in Fig. 9, the diagram of this interval behaves as a quadratic function. However, the curvature radius is a little smaller than that of the last interval. This means that although the axial heat flux increases with the increase of saturation pressure and temperature inside the system, but this increasing rate will be diminished. So, it can be predictable that the axial heat flux increasing rate will be reduced in following thermal intervals because of severe increase in saturation pressure inside the system and heat transfer coefficient decrease.

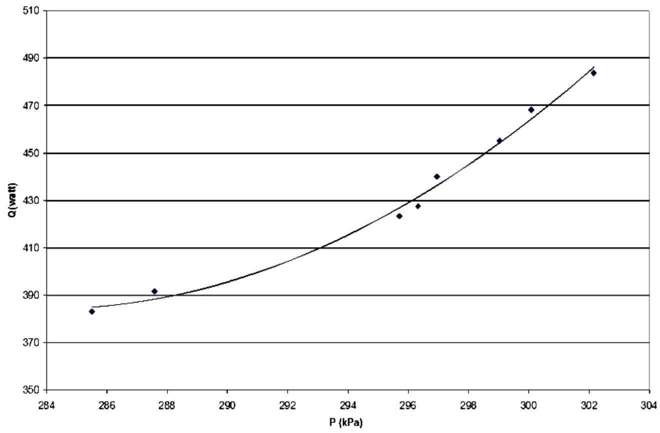

Figure 9. Variations of axial heat flux changes with saturation pressure for steady state in temperature interval 131-133.5°C

VI. CONCLUSIONS

It is figured out that in a certain saturation temperature and pressure inside the heat pipe, enhancing the inlet heat flux causing a rise in the saturation temperature and pressure of the system in equilibrium state, which results in axial heat flux rate enhancement. This will be continued in different temperature intervals till the saturation pressure comes to a specific limit, after which this increasing rate will be reduced. This is because the pressure enhancement decreases the condensation, and because the heat transfer and mass transfer coefficients are lowered, and axial heat flux increasing rate decreases. By enhancing the inlet heat flux to the evaporator, axial heat flux is being increased again. Finally it can be concluded that the optimized pressure and axial heat flux inside a heat pipe must lie within equilibrium zone (the zone in which heat flux growing rate is being uprising), which is located away from the unsteady zone.

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