HEAT TRANSFER CHARACTERISTICS OF HELICAL OSCILLATING HEAT PIPES

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ABSTRACT

This research aimed to study the heat transfer characteristics of the helical oscillating heat pipes with and without check valve, a coil diameter varied at 50, 70 and 90 mm and a pitch distance varied at 10, 15 and 20 mm. The heat pipes were made from a copper tube with a thickness of 0.5 mm, an inner diameter of 2.03 mm and using an adiabatic length of 100 mm. The evaporator and condenser section were equal length of 1000 mm before being rolled to helical. This study uses R-11 as working fluid with a filling ratio of 70% by total volume of heat pipes. In the condenser section, cooling air with a velocity of 1 m/s was used as heat sink and in the evaporator section, hot air with a temperature of 70 ºC was used as heat source. Inclination angle of heat pipes was 90 degree. It was found that, the heat transfer rate increased when installed check valve, reduced the coil diameter from 90 to 50 mm, and reduced the pitch distance from 20 mm to 10 mm. The maximum heat transfer rate and heat flux was 51.76 W and 4,992.32 W/m^2, respectively occurred at the 50 mm coil diameter, 10 mm pitch distance and installed check valve.

KEYWORDS: *Heat transfer, Heat pipe, Heat flux,*

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INTRODUCTION

Heat pipe is a thermal device that can transfer the heat from one place to other places. It does not need external power, and it has a lot of flexibility in working temperatures whether in hot or below the freezing point, very different or slightly temperatures. Heat pipes are rarely found problems in maintenance [7]. Normally, heat pipes structure consist of wall, wick and working fluids. Heat pipes are divided into 3 main sections: evaporator, adiabatic, and condenser section. The heat transfer characteristic of heat pipes is absorbed outside thermal by the wall at evaporator section to working fluids in heat pipe, boils working fluids and flows to condenser section via adiabatic section. At condenser section, heats are removed to external via the condenser section wall, and then working fluids condenses back to the liquid phase and flows to evaporator section through the heat pipes wick to be heated again. Oscillating or pulsating heat pipe (OHP) is a special type of heat pipes [1]. It's made from small diameter tube called capillary tube, several times back and forth bended and without the wick structure. Working fluids in oscillating heat pipe are splinted into 2 phases of liquid slug and vapor bubble. Oscillating heat pipe can work in both of vertical and horizontal plane. Generally, it can be divided into 3 types consist of closed-end oscillating heat pipe (CEOHP), closed-loop oscillating heat pipe (CLOHP), and closed-loop oscillating heat pipe with check valves (CLOHP/CV). Previously, researchers found that closed-loop oscillating heat pipe with checked valves has the best performance [2,6] and can be applied to the heat exchanger as well [3,5,9]. Helical oscillating heat pipe is a new type of heat pipes. In 2003, Yi et al investigated heat transfer characteristics and flow patterns in a looped heat pipe with the evaporator section using small helical coiled pipes and found that it gave a high heat transfer rate [10]. Lately in 2015, Sri-udom et al studied the effect of both of helical coiled evaporator and condenser section in an oscillating heat pipe to heat transfer characteristics and found that its gave high heat transfer rate and high heat flux as same as other types of oscillating heat pipe, but the good point application of helical oscillating heat pipes were using installed area of working less than the others [8]. However, literature necessitates the experimental investigation on heat transfer characteristics in helical oscillating heat pipe with check valve. Thus, this research aims to study the heat transfer characteristics of the helical oscillating heat pipes with and without check valve and including effect of physical properties such as diameter of coil (Dc) and pitch (p) distance for the information, predict and apply to heat exchanger in the future.

MATERIALS AND METHODS

Variables

In this research, it has 3 independent variables comprises of coil diameter: 50, 70 and 90 mm, pitch distance: 10, 15 and 20 mm, and installed and not installed check valve shown in Fig. 1 and Fig. 2.

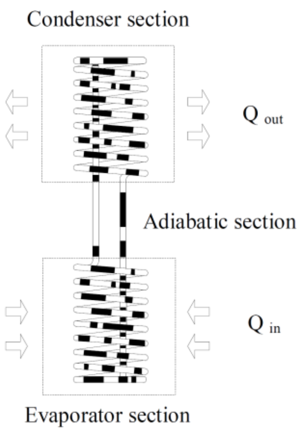

Fig. 1. Helical oscillating heat pipe

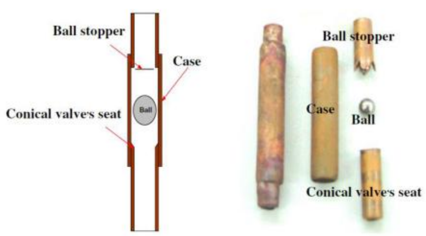

Fig. 2. Check valve [6]

Control variables with the heat pipes were made from copper capillary tube with inner diameter (Di) of 2.03 mm computed from Maezawa et al equation to make sure these heat pipes were oscillating heat pipes [4] shown that

$$Di \leq 2 \times (\sigma/g(\rho l-\rho v))^{1/2} \quad (1)$$

When σ is the working fluid surface tension (N/m), g is the gravitational acceleration (m/s^2), ρl is the working fluid in liquid phase density (kg/m^3) and ρv is the working fluid in vapor phase density (kg/m^3). R-11 was used as working fluid then the exactly result of this equation was 2.12 mm but in the reason of commercially available, a copper tube inner diameter nearest the result was 2.03 mm. Using capillary tube thickness of 0.5 mm. The evaporator and condenser section were equal length of 1000 mm before were rolled to helical. Using R-11 as working fluid with a filling ratio of 70% by total volume of heat pipes. In the condenser section, cooling air with a velocity of 1 m/s was used as heat sink and in the evaporator section, hot air with a temperature of 70 ºC was used as heat source. Inclination angle of heat pipes was 90 degree and when installed check valve, it was fitted with single.

Experimental setup

To design the experimental set shown in Fig. 3 and Fig. 4, square channels were made from galvanized iron sheet and divided by different temperature of air: hot air for heating evaporator section and cool air for cooling condenser section. Both hot and cool air channels were collaterally installed on square steel tube structure. Heating hot air circle by electrical heater while controlled by controller box. Managed velocity of hot and cool air is contributed by adjustable small electronic fan. Collected temperatures by type k thermocouple on all 3 sections of heat pipe and inlet and outlet air both hot and cool air circles. All thermocouples were connected to Yokogawa DX200 data logger with accuracy of ± 0.1 ºC.

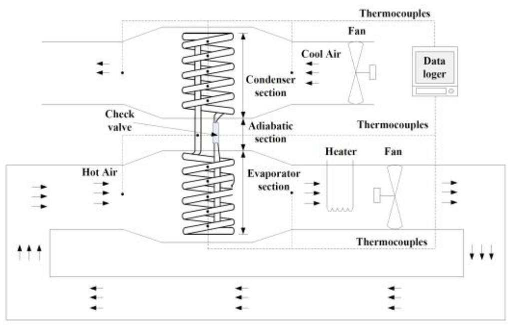

Fig. 3. Experimental set diagram

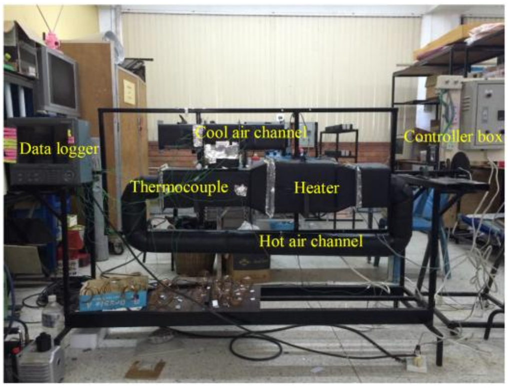

Fig. 4. Showed another instruments for detection

Experimental procedure

First, filling R-11 the working fluids into helical oscillating heat pipes by filling set and 2 stage vacuum pump with filling ratio of 70% by total volume of heat pipes. Second, installing helical oscillating heat pipe into experimental set while the evaporator section must setup at the hot air circle and the condenser section must setup at the cool air circle. Third, installing thermocouples and connecting data logger. Fourth, starting electrical heater and adjusting fan with velocity of 1 m/s. Fifth, waiting 30 minutes for steady state working of heat pipes. After that collecting the changed temperatures by data logger. Sixth, exporting values form data logger to computing the heat transfer rate (Q) by equation shown that:

$$Q = mCp(Tco\text{-}Tci) \qquad (2)$$

When m is the mass flow rate of air (kg/s), Cp is the specific heat capacity air (kJ/kg ºC), Tco is average temperature of air when passed the condenser section (ºC) and Tci is average temperature of air before visited the condenser section (ºC). From equation (2) it can be computed the heat flux (q) by equation shown that:

$$q = Q/\pi DoLcn \qquad (3)$$

When Do is the outer diameter of capillary tube (m), Lc is the condenser section tube length (m) and n is the number of turns of the oscillating heat pipes (for helical oscillating heat pipes, n = 1). At last, Experiment again while changing the variables.

RESULTS AND DISCUSSION

Effect of installed check valve, changed coil diameter and pitch distance on heat transfer rate

Fig. 5 showed the heat transfer rate when installed and not installed with check valve, changed coil diameter and pitch distance. It was found that the heat transfer rate increased when installed check valve, reduced the coil diameter from 90 to 50 mm and reduced the pitch distance from 20 mm to 10 mm. The maximum heat transfer rate was 51.76 W occurred at the 50 mm coil diameter, 10 mm pitch distance and installed check valve.

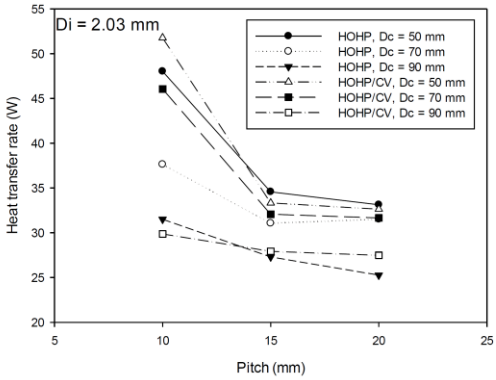

Fig. 5. Result of installation check valve, coil diameter and pitch distance affected heat transfer rate

Effect of installed check valve, changed coil diameter and pitch distance on heat flux

Fig. 6 showed the heat flux when installed and not installed check valve, changed coil diameter and pitch distance. It was found that the heat flux increased when installed check valve, reduced the coil diameter from 90 to 50 mm and reduced the pitch distance from 20 mm to 10 mm. The maximum heat flux was 4,992.32 W/m^2 occurred at the 50 mm coil diameter, 10 mm pitch distance, and installed check valve.

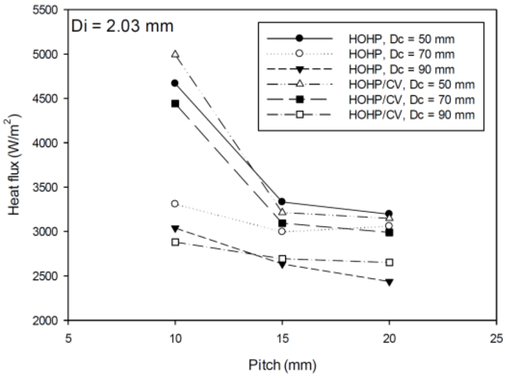

Fig. 6. Result of installation check valve, coil diameter and pitch distance affected heat flux

CONCLUSION

From the results, it can be concluded that the heat transfer rate and heat flux of helical oscillating heat pipes with check valve was higher than without check valve because the working fluids in helical oscillating heat pipes without check valve had uncertainly and not continuously flow pattern. Working fluids flow back and forth in short time. It made working fluids couldn't condensed back to receive the heat as well. Contradictory of the helical oscillating heat pipes with check valve, working fluids was certainly and continuously flooded by check valve. It made heat pipes working all the time. Large diameter of the coil made heat transfer rate and heat flux decreased because the centrifugal force was increased by the large coil diameter. Working fluids in the large coil diameter of the heat pipes needed more force than the small coil diameter to conquer the centrifugal force. In term of heat transfer rate and heat flux, the helical oscillating heat pipes with short pitch distance was better than the long pitch distance because the later made helical oscillating heat pipes steeped. It made working fluids in the short pitch distance helical oscillating heat pipes flooded to condenser section more quickly better than in the long pitch distance. The maximum heat transfer rate and heat flux was 51.76 W and 4,992.32 W/m^2, respectively and occurred at the 50 mm coil diameter, 10 mm pitch distance, and installed check valve.

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