HEAT TRANSFER PERFORMANCE OF A SELF-OSCILLATING HEAT PIPE USING PURE WATER AND EFFECT OF INCLINATION TO THIS PERFORMANCE

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Abstract

This experimental study is performed to investigate heat transfer performance and effect of inclinations to a self-oscillating heat pipe developed. In this experiment, pure water is employed as the working fluid. The heat pipe is composed of a heating section, a cooling section and an adiabatic section. The heating and cooling sections have the same size and are connected by four circular parallel pipes. The corresponding external dimensions are 45mm in length, 45mm in width and 8mm in thickness, and the internal dimensions are 42mm, 42mm and 5mm, respectively. The adiabatic section is consisted of four parallel circular pipes whose dimension is $\phi6$ (external diameter) x $\phi5$ (internal diameter) x 45 (length) mm. According to the experimental results, the effective thermal conductivity of the heat pipe in the case of fill charge ratio at 100% is higher than that of 30% and this effective thermal conductivity is decreased when the angle between the axis of the heat pipes and vertical direction is increased.

Keywords: Fill charge ratio, Heat transfer performance, Inclination, Self-oscillating heat pipe, Working fluid

Introduction

Nowadays, there are a lot of equipment or parts inside machines called heating elements need to be cooled during working process, especially with electrical or electronic devices. About their size, manufacturers are minifying with every passing day in order to satisfy requirements of users but the power must be maintained. This makes elements stand a high amount of heat, that is, high heat flux would be generated during working process. Therefore, there is a need of professional component to cool heating elements so that maintain their appropriate temperature and that is the maintenance of their longevity. However, with many actual cases, one saw that it is difficult to arrange a cooling device near the heating elements so that can rapidly decrease the heat amount that is generating.

Now there are a number of different cooling devices that are being used to cool heating elements. With normal cases as low heat flux, one can use conventional cooling systems as: heat sinks; or direct cooling systems with the use of water. However, as presented above, there are many cases having high heat flux but it is difficult to properly arrange cooling systems, for example with electrical or electronic devices. This requires manufacturers must suggest a new method to cool heating elements. The most common device is heat pipe. It works base on boiling heat transfer and condensation heat transfer principle.

Working fluid inside the heat pipe absorbs heat and boils at a certain pressure value in the heating area, after boiling, working fluid becomes vapor and evaporates to the already cooled area and the vapor would release latent heat to this section and is condensed to working fluid again. After that, working fluid would travel back up to the heating area by capillary principle with a wick composed of a porous substance (Peterson [2], Faghri [3], Boo [4]).

Despite being widely developed and applied, this type of heat pipe still has some weaknesses. They need a complicated structure that is wick to take working fluid back of heating area. Therefore, its performance will be decreased due to blending between condensed working fluid and evaporating vapor. In addition, with this design, it is difficult to manufacture a fine product.

Akachi [5] suggested "The loop type capillary heat pipe" this is a self- oscillating heat pipe with three sections: a heating section; an adiabatic section and a cooling section. This type of heat pipe usually made by closed circuit copper with calculated internal diameter and thin thickness. Inside of this heat pipe is also charged with fixed amount of working fluid. This heat pipe has no wick at all. With the study of Akachi [6] and Koizumi [7], this heat pipe is desirable with high performance.

Tun-Ping Teng et al [8] investigated a straight copper tube heat pipe with the inner diameter and length of 8 and 600mm, respectively. Authors discussed about the effects of charge amount of working fluid, tilt angle of heat pipe with the use of pure water and nanofluid, respectively. The experiment results showed that the thermal efficiency of the heat pipe increased until tilt angle reached 60^o, and the optimal charge amount was 60%.

Seok Hun Yoon et al [1] also investigated the heat transfer characteristics of a self-oscillating heat pipe using pure water as a working fluid, the excellent results were obtained in this study but this heat pipe was just applied with low heat fluxes.

With the same purpose to develop heat pipe, this study developed a new heat pipe with a very simple structure. In this research, the heat transfer performance was investigated with the different fill charge ratios and inclinations of the heat pipe.

Experimental Method

Experimental Apparatus

A schematic diagram of experimental apparatus is described in figure 1. In this figure, the self-oscillating heat pipe is made in Laboratory of Kumamoto University – Japan, the heat pipe is heated on the heating section by the heater block made by copper containing 5 heaters (HAKKO) inside with the use of thermo-glue (AINEX) between two surfaces to improve heat transfer (5 heaters are not shown in this figure). 5 heaters are connected with the transformer (YAMABISHI) and its voltage and power are measured by the digital multi-meter (AC/DC POWER HITESTER 3334). While experiment was performed, the transformer was connected with power supply in the Laboratory. An adequate amount of pure water is filled inside of the self-oscillating heat pipe by the burette (NALJENE). Vacuum pressure inside the self-oscillating heat pipe is generated by the vacuum pump (GHD-030) with the measurement by the vacuum gauge (TRP – 10, DIAVAC) and the Power indicator transducer (TRP – 10, DIAVAC). The cooling section of the heat pipe is cooled by cooling water set at 15^oC by the thermostatic bath (NCC-1100) with the measurement of flow by the flow meter (RK400). The temperature of the heat pipe is measured by thermocouples type K with the aid of the data logger (KEYENCE NR-250) and a personal computer. The working fluid in this experimental study is pure water.

Figure 2 is detailed drawing of the self-oscillating heat pipe. During experiment, the adiabatic section and heating section are insulated with glass fiber to prevent heat loss, the cooling section is inserted to a water tank made by plastic to contain cooling water flowed circularly from the thermostatic bath. In order to fill in the working fluid and make vacuum pressure, each link part was manufactured.

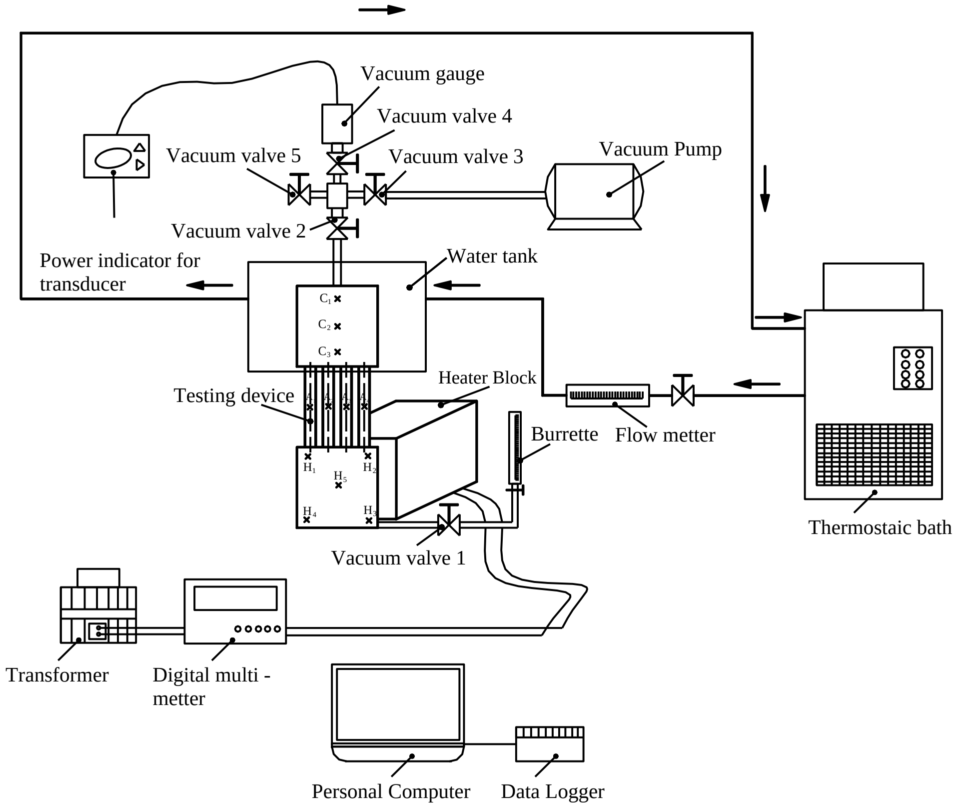

Figure 1. Schematic diagram of experimental

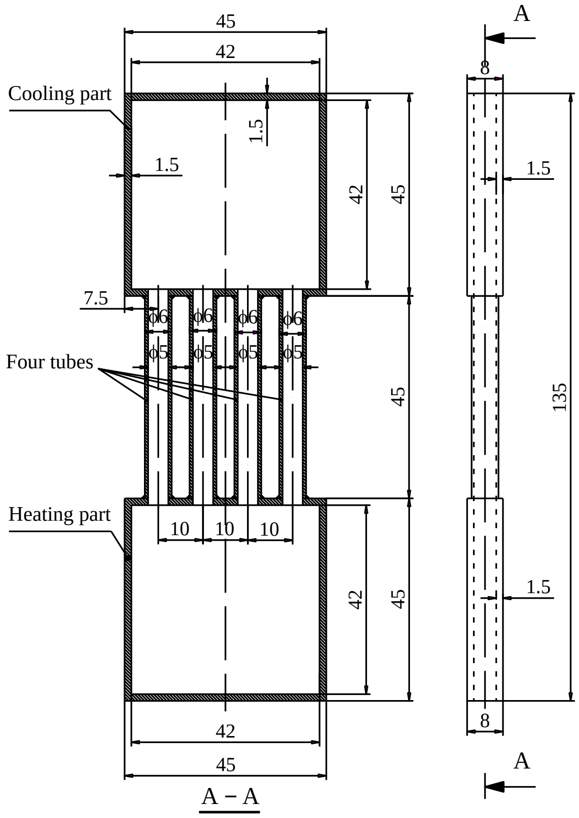

Figure 2. Structure of the self- oscillating heat pipe (length unit: mm)

Experimental Method

In this experiment, the volume ratio f_{cr} (fill charge ratio) between fill charge volume of pure water and internal heating section volume are 30% and 100%. The heat flux of the heating session is $15W/cm^2$ ($150kW/m^2$). After getting results and comparing heat transfer performance between two foregoing fill charge ratios, we perform to investigate the effect of inclination to this performance with the better fill charge ratio. The angle between heat pipe axis and vertical direction is 0^o; 45^o; 60^o; 75^o. As shown in figure 1, the temperature of each session of the heat pipe was measured with K thermocouples as follows: for the heating section: point H_1, H_2, H_3, H_4, H_5; for cooling section: point C_1, C_2, C_3. The entry temperature of the cooling water was set at 15^oC using the controlled thermostatic bath and cooling water was supplied to the water tank at a rate of 3.5l/min. After filling an adequate amount of pure water in heat pipe, the vacuum pressure will be established by vacuum pump and its value was maintained at 7400Pa for both cases. In order to get accurate vacuum pressure value, the vacuum pressure value was read on the power indicator transducer after 20 minutes and when changing from one fill charge ratio to another, the working fluid was filled in when the heating section of the heat pipe was 25^oC. Temperature was measured until the experiment reached steady state and the steady state time is at least 30 minutes.

Experimental Results and Discussion

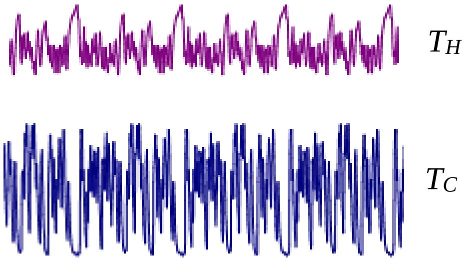

Figure 3. Temperature Form of the heating section T_H and the cooling section T_C

Figure 3 shows the temperature changes in the heating section and the cooling section at the fill charge ratio f_{cr} of both 30% and 100%. We can see the temperature changes around a certain value. This can be explained easily as follows: when the heat pipe is heated, the temperature of heating section is increased and the working fluid becomes vapor and it will be evaporated to the cooling section. The heating section reaches the highest temperature when the working fluid evaporates totally. When the vapor meets the cooling section, it would transfer latent heat to cooling section and then condense again to working fluid. Therefore, the temperature of the cooling section will be increased. When the condensed fluid travels back down the heating section, it will absorb heat from the heating section and make the temperature of the heating section decrease. At the same time, the cooling section is cooled by circulated cooling water contained in water tank.

Respectively, figures 4 and 5 show mean temperature of the heating section and the cooling section versus 30% and 100% of fill charge ratio. As shown in these figures, temperature of the heat pipe in the case of f_{cr} = 100% is smaller than that in the case of f_{cr} = 30%. Therefore, it is can be guessed that mean temperature of the heat pipe tend to decrease when the fill charge ratio is increased. However, in order to determine the optimal fill charge ratio of the heat pipe corresponding the lowest temperature of the heat pipe, the remaining fill charge ratios 40%; 50%; 60%; 70%; 80% should be experimented.

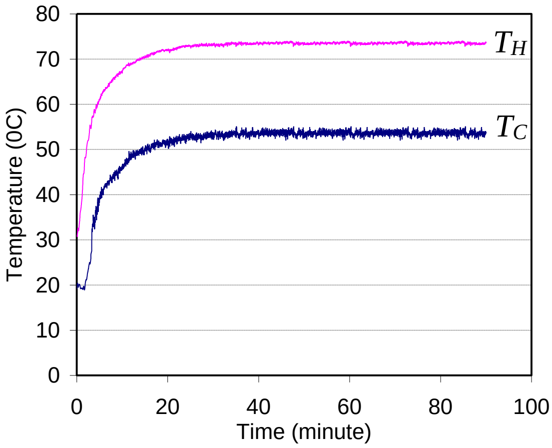

Figure 4. Variation of temperatures of the heating section T_H (**73,51°C**) and the cooling section T_C (**53,59°C)** for 30% of fill charge ratio and the angle between the axis of the heat pipe and vertical direction is 0^o

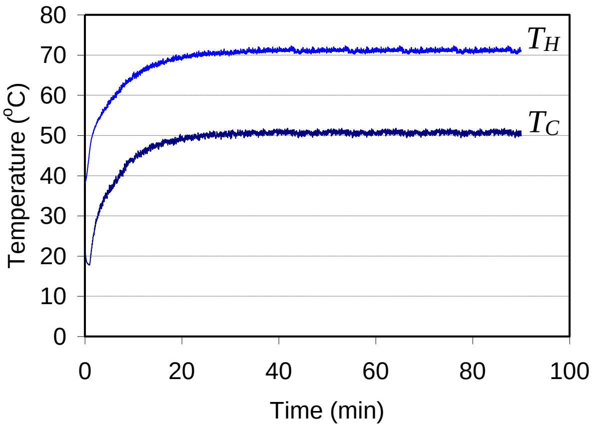

Figure 5. Variation of temperatures of the heating section T_H (**71,09°C**) and the cooling section T_C (**50,68°C)** for 100% of fill charge ratio and the angle between the axis of the heat pipe and vertical direction is 0^o

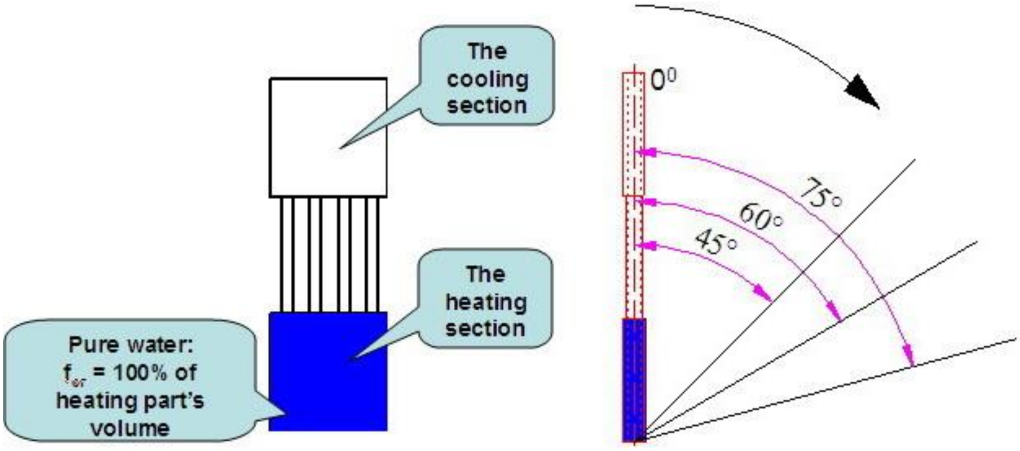

Figure 6. Inclinations of the heat pipe

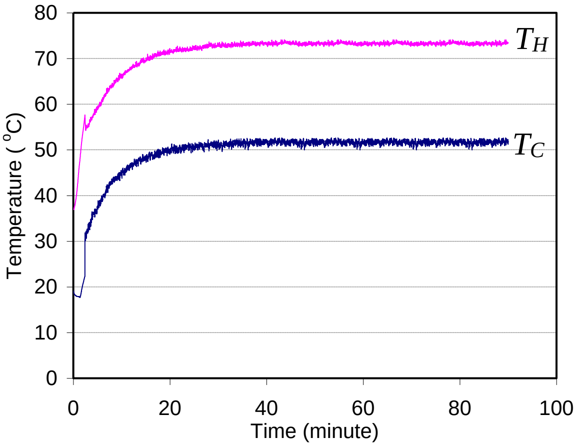

Figure 7. Variation of temperatures of the heating section T_H (**73,25°C**) and the cooling section T_C (**51,65°C)** for 100% of fill charge ratio and the angle between the axis of the heat pipe and vertical direction is 45°

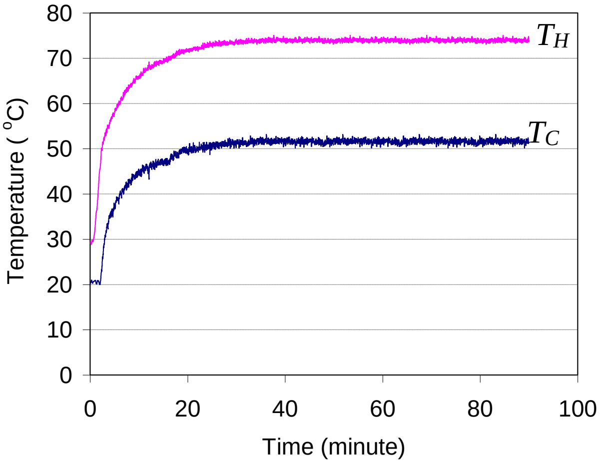

Figure 8. Variation of temperatures of the heating section T_H (**74°C**) and the cooling section T_C (**51,95°C)** for 100% of fill charge ratio and the angle between the axis of the heat pipe and vertical direction is 60°

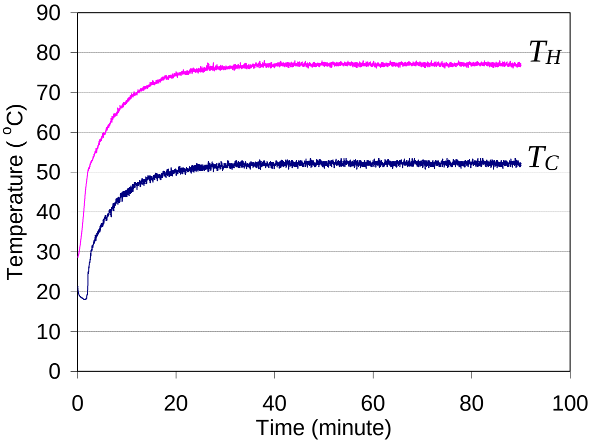

Figure 9. Variation of temperatures of the heating section T_H (**77°C**) and the cooling section T_C (**52,16°C)** for 100% of fill charge ratio and the angle between the axis of the heat pipe and vertical direction is 75°

Figure 6 illustrates four cases in order to investigate heat transfer performance of the heat pipe with different angles: 0°; 45°; 60°; 75°.

Figures 7, 8 and 9 show the effect of inclination of the heat pipe on mean temperature of the heating and the cooling section, from these results, it can be seen that the higher the angle, the higher the mean temperature of the sections of the heat pipe.

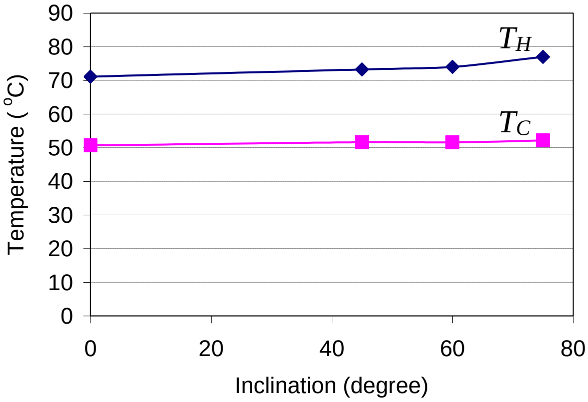

Figure 10. Mean temperatures of the heating section T_H and the cooling section T_C of the heat pipe versus the angle between the axis of the heat pipe and vertical direction

As shown in figure 10, it can be seen that when the angle of the heat pipe increases up to 60°, mean temperature of the heat pipe also increases but not so high. But when the angle increases until 75°, mean temperature of the heating and the cooling section of the heat pipe increases very rapidly, especially of the heating section. This explains that when the angle of the heat pipe exceeds a certain value, the heat transfer performance of the heat pipe approaches it working limit very rapidly.

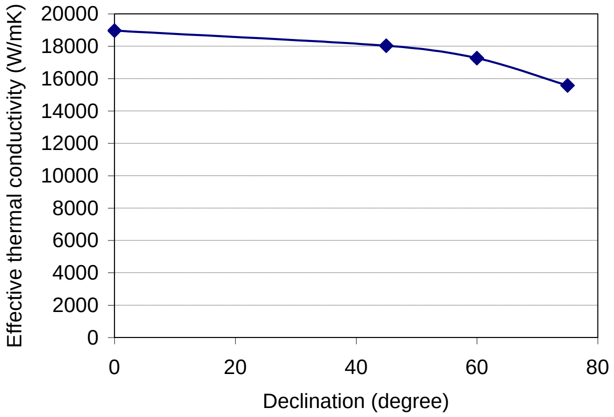

Figure 11. Effective thermal conductivity of the heat pipe versus different inclinations

Figure 11 shows the variation of effective thermal conductivity k_{eff} as a function of inclination. Effective thermal conductivity was calculated as follows:

$$Q = \mathrm{NA}q' = \mathrm{NA}k_{eff}\frac{T_H - T_C}{\mathrm{L}} \qquad (1)$$

$$k_{eff} = \frac{Q\mathrm{L}}{\mathrm{NA}(T_H - T_C)} \qquad (2)$$

Where, Q is total heat load, q' is the heat flux from the heating section to the cooling section, L is the length from the center of the heating section to the center of the cooling section, that is, the approximate distance between T_H measuring point and T_C measuring point. N is the number of tubes of the adiabatic section (N = 4). A is the flux area of the inner part of a tube in the adiabatic section. To get mean temperature T_H of the heating section and T_C of the cooling section, temperatures were measured and averaged. For this, with the measurement by K thermocouples, points H_1, H_2, H_3, H_4 and H_5 are for the heating section and C_1; C_2; C_3 are for the cooling section. These points were depicted in figure 1. In figure 11, effective thermal conductivity k_{eff} decreases when the angle (compared to vertical direction) of the heat pipe increases, but this k_{eff} does not so much change when the angle increases up to 60^o, effective thermal conductivity k_{eff} decreases rapidly when the angle approaches 75^o. This can be explained that when the angle is so high, working fluid inside of the heat pipe is difficult to travel back the heating section to cool it.

From the result shown in figure 11, the effective thermal conductivity of the heat pipe 18958W/mK is 47 times greater than that of copper 401W/mK, Even in the case of the inclination is 75^o, the effective thermal conductivity of the heat pipe is still 38 times greater than that of copper, Thus this type of heat pipe has excellent transport characteristics even structure is very simple.

In the future, the remaining fill charge ratios 40%; 50%; 60%; 70%; 80% should be experimented and other values of heat flux also should be experimented in order to determine the optimal fill charge ratio and limited heat flux of the heat pipe. In addition, other working fluid also should be employed to compare with the effect of the use of pure water.

Conclusions

From the observation of the results in this study, the following conclusions are drawn:

- With this type of heat pipe in the conditions of the experiment as $150\mathrm{kW/m^2}$ of heat flux, 3,5l/min and 15^oC of cooling water applied for the cooling part, the heat transfer performance of the heat pipe in the case of 100% of fill charge ratio is higher than that of 30% of fill charge ratio.
- The effective thermal conductivity of this heat pipe with the conditions of experiment and in the case of 100% of fill charge ratio is 18958 W/mK, which is much higher than that of copper 401W/mK 47 times.
- The higher the inclination is (angle between the axis of the heat pipe and vertical direction), the lower the heat transfer performance is. And the heat transfer performance of the heat pipe decreases rapidly when the inclination exceeds a certain value - beyond 60^o.
- When the inclination of the heat pipe approaches 75^o, the effective thermal conductivity of the heat pipe is still 38 times greater than that of copper.

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