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# Experiment on Novel Design of Tapered Shape Heat Pipe

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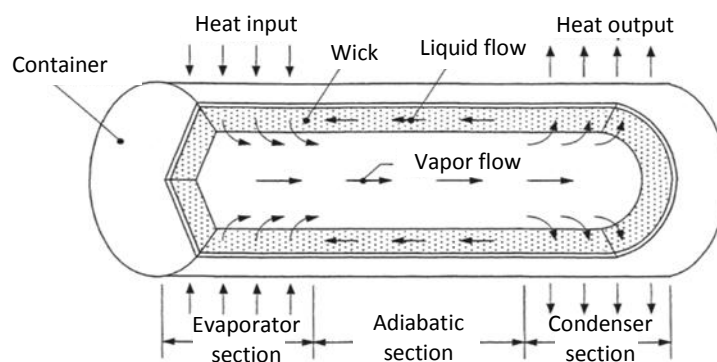
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**Abstract.** Most design of heat pipes did not consider the sudden volume increase of vapor when water evaporates. This experiment investigates the performances improvement of new design of tapered shape heat pipe, where the diameter of condenser section (D) is larger than evaporator section (d) to facilitate the increase of vapor volume. In this experiment the variation of D/d are 1, 2, 3, and 4. Heat inputs were also varied to 20 Watt, and 50 Watt. The experiment results show that the higher the heat input, the higher the boiling temperature and the higher D/d the boiling temperatures remain constant for the same heat input. The dominant driving force of vapor flow is resistance for D/d=1, while for D/d higher the dominant driving force are evaporation and condensation. The driving force is also influenced by heat input, where for low heat input the effect of D/d on the driving force is insignificant. The results of heat transfer coefficient with D/d and heat input is similar to the results of the driving force with D/d and heat input. Heat transfer coefficient of heat pipe which utilizes latent heat is higher than conventional heat exchanger which utilizes sensible heat.

## 1. Introduction

Some heat exchangers utilizing sensible heat as the transport mechanism of heat. Heat pipe is more efficient and powerful heat exchanger, since utilizes latent heat as transport mechanism instead of sensible heat. There are many advantages of heat pipes compared to the conventional heat exchangers, which are, it can transfer higher amount of heat through small distance to relatively long distance, small temperature difference, equipment's less size and more compact structure, and higher heat transfer coefficient. Figure 1 shows the schematic diagram of heat pipe.



**Figure 1.** Schematic diagram of heat pipe



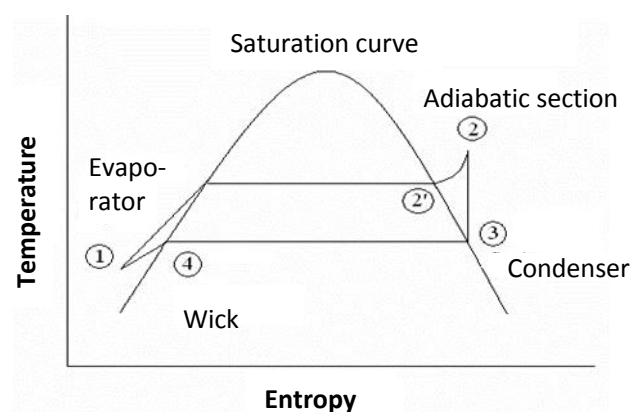
Heat pipe is long cylindrical pipe consisting of evaporator section, adiabatic section and condenser section. Evaporator section evaporates working fluid to absorb latent heat, adiabatic section transfer the mass of vapor to the condenser section which releases the latent heat by condensing the vapor. The condensate is then transferred back to evaporator section by gravitational or capillary mechanism. Gravitational mechanism drives the liquid by gravitational force, while capillary mechanism drives the flow by capillary force created by wick structure within the heat pipe. The processes work continuously in a cycle, where latent heat moves from the evaporator to the condenser and the condensate return back to the evaporator.

Depending to the required operating temperature, heat pipes may use different working fluids, such as water, alcohol, ammonia or sodium. Heat pipe may be designed as micro heat pipe (30  $\mu\text{m}$  width  $\times$  80  $\mu\text{m}$  depth for rectangular area) and 19.75 mm length to large heat pipes with 100 m length. For simplicity and easy manufacturing, heat pipe may be cylindrical and circular cross section. There are many other geometries of cross sectional areas of heat pipe, such as rectangular, conical rotating heat pipe, nose cap. Wide ranges applications of heat pipe are used, from smaller applications for cooling electronic devices to large application for internal combustion engines [1].

Most heat pipes have cylindrical cross sectional area with the same diameter along the pipe. This has disadvantage for not considering the large volume increase when liquid evaporate into gas. In case of water, 1 liter of liquid water changes into about 1,700 liters vapor when evaporate at the atmospheric pressure. If the sudden volume increase is not considered in the design of heat pipe, it will create some disadvantages in the operations. When it is not facilitated, the sudden volume increase creates larger friction on the vapor flow in the adiabatic section. Further it will cause less mass flow and heat transfer capacity of the system.

This experiment investigates a new design of tapered shape along the heat pipe length with small diameter of evaporator section and larger diameter of condenser section, to facilitate the large volume increase of liquid water when evaporates. Larger diameter of condenser section creates larger condensing heat transfer, due to larger heat transfer area. The experiment aims to investigate the performances improvement of tapered heat pipe, with the variation of diameter ratio of condenser and evaporator, and variation of heat input.

During the operation vapor pressure changes along heat pipes, due to flow restriction caused by friction, push force by inertia by evaporation, and pull force by sudden reduce of vapor volume by condensation [2]. The new design of tapered shape heat pipe improves the three driving mechanisms. It improves friction, due to the increase of the cross sectional area reduces vapor flow velocity. It improves the inertia forces, because the tapered shape increases the volume of vapor passages, reduces the pressure and the boiling temperature resulting in the increases the volumes and mass of vapor produced in the evaporator. The higher pull force by condensation is due to the higher heat transfer rate caused by greater heat transfer area of the condenser section. The operation of heat pipe is similar to steam power plant with Rankine cycle as shown in Figures 2.



**Figure 2.** Thermodynamics diagram of heat pipe

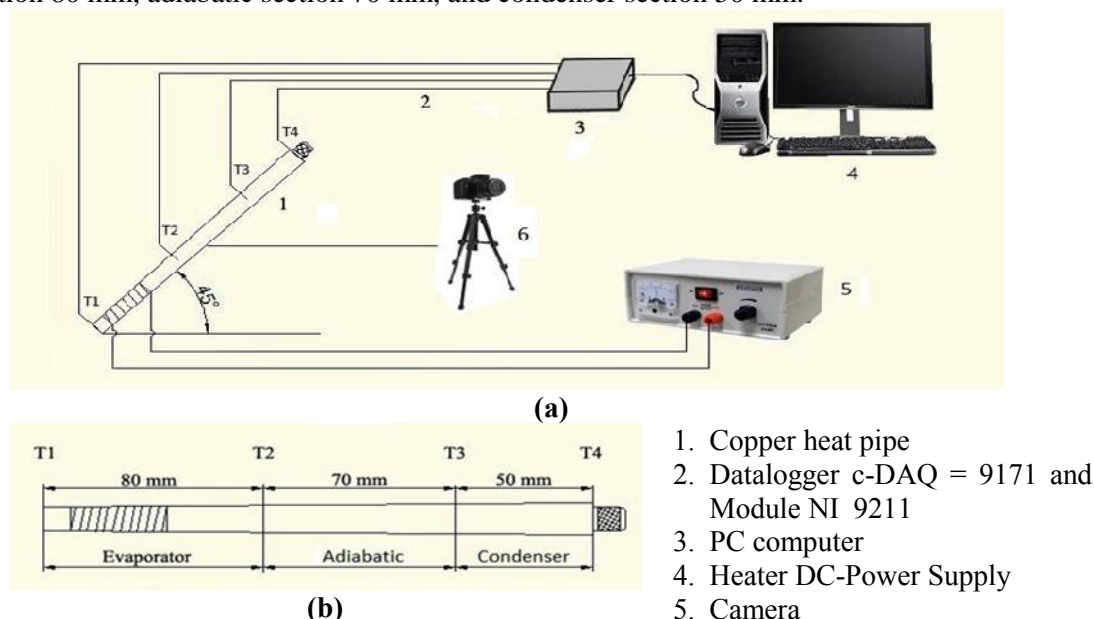
The difference between steam power plant and heat pipe are there are no steam turbine and pump in heat pipe and both are replaced by the resistance of vapor flow from point 2 to 3 and gravitational force/capillary force from point 3 to 4 in Figure 3b respectively. The other difference is that the output of heat pipe is not the work produced in process of 2–3, similar as turbines work in steam power plants, but the heat releases in the condenser from process of 3 -4. Vapor condition in the evaporator section is likely not superheated, since the fluids conditions mixed of liquid and vapor.

Many efforts have been done to improve heat pipe performances, however none have been found that performances improvement was done by enlarging the cross sectional area along the heat pipe. Some experiments were done using different working fluid to meet the working temperatures. Ammonia was used for relatively low temperature of 25° C [3], water is the most widely used working fluid for temperature range of 50° C to 160° C [4-6]. For high temperatures from 300° C - 1200° C sodium, mercury, and lithium were used [7-9]. Many material were also used, which are copper and aluminum for relatively low temperatures, mild steel and stainless steel for temperature less than 600° C, and molybdenum for higher temperature up to 1200° C. Regarding the inclination of heat pipe relative to horizontal plane, Senthilkumar et al. [10] investigated the effect of inclination angle on the heat pipe performance. The experiment showed that the most optimum inclination is 45° C to the horizontal plane.

Extensive works have also been done to design the wick structure of heat pipe. Wick is a structure installed inside wall of evaporator and adiabatic sections. The function is to pump the condensate from the condenser back to evaporator by capillary force created by wick structure. The variety design of the wick such as, circumferential mesh wick [11], axial grooves [12] and axial rectangular grooves [13].

## 2. Experimental setup

The installation diagram of the experiment of tapered shape heat pipe is shown in Figure 3a, and placement of thermocouples in Figure 3b. The variation of tapered shape heat pipe was done by varying the diameter ratio between the condenser section (D) and the evaporator section (d). Four variations of D/d was chosen, D/d = 1, 2, 3, and 4. The heat input into the evaporator were also varied, 20 Watt, and 50 Watt. The total length of heat pipe was 200 mm, consisting of the length of evaporator section 80 mm, adiabatic section 70 mm, and condenser section 50 mm.



**Figure 3.** (a) Instalation diagram of the experiment; (b) placement of thermocouples.

Four thermocouples were installed to measure temperature of the fluid within the heat pipe, number one (T1) was placed at the end of evaporator section, T2 at the start of adiabatic section, T3 at the start of condenser section and T4 at the end of condenser as shown in Figure 3b. DC power supply was used as the source energy for heating the evaporator. The data collection was done using data logger and PC computer. The data was collected every 30 seconds, and measurements for data analysis were done after steady state condition.

The performances of the heat pipe evaluated in this experiment are driving the force of vapor flow, and the heat transfer coefficient. The driving force is the difference of the pressure in the evaporator and condenser, which could be predicted by the temperature difference of the evaporator of T1 and condenser of T4. Vaporization and condensation process occurred at saturated temperature and pressure, and the values remain constant along the process. The heat transfer coefficient was evaluated as follows.

$$he = \frac{qe}{\Delta T} \quad (1)$$

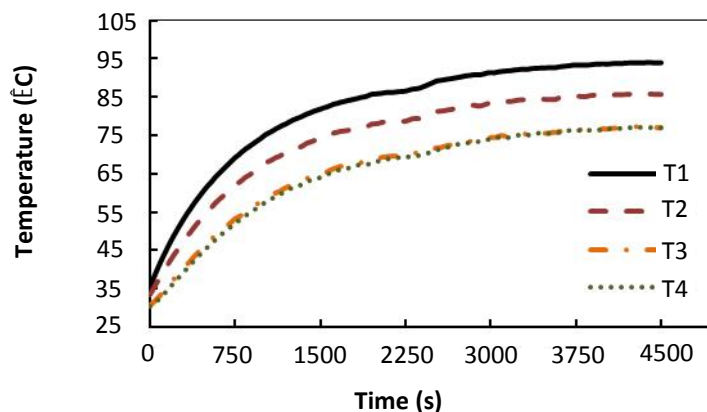
Where:  $he$  = heat transfer coefficient ( $\text{Watt.m}^{-2}.\text{°C}^{-1}$ )

$qe$  = heat flux ( $\text{Watt.m}^{-2}$ )

$\Delta T$  = temperature difference between inside and outside of the heat pipe section.

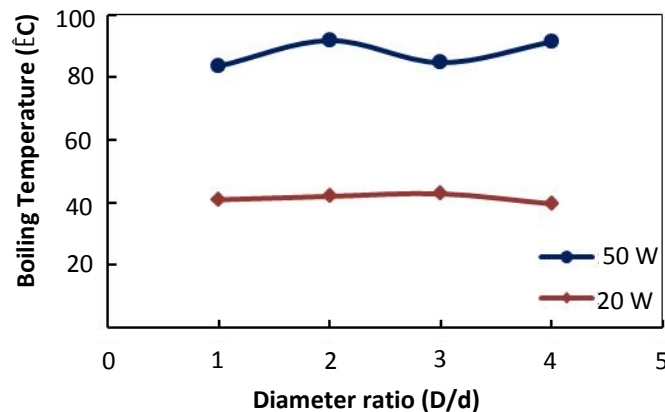
### 3. Results and Discussions

Figure 4 shows the temperature at each measurement point as function of time for  $D/d = 4$  and the heat input of 50 Watt. It can be seen that the end of transient condition and the beginning of steady condition occurred at about 3000 seconds (50 minutes). The vapor conditions were saturated, since the vapor temperature is relatively constant during boiling. For 50 Watt heat input and  $D/d = 4$  the boiling temperature of water is about  $90^\circ\text{C}$ , indicate that the pressure inside the evaporator section is less than atmosphere pressure. The saturated temperature in the evaporator is about  $20^\circ\text{C}$  higher than in the condenser. The temperature difference indicates pressure difference, which is the driving force of vapor flows. Pressure difference between evaporation and condensation section caused by pressure drop due to decreasing of specific volume of condensed liquid as well as pressure drop due to fluid friction. Furthermore, it could be predicted that the driving force varies with heat input and  $D/d$ .



**Figure 4.** Temperature at 4 measurement point for heat input 50 Watt,  $D/d = 4$ .

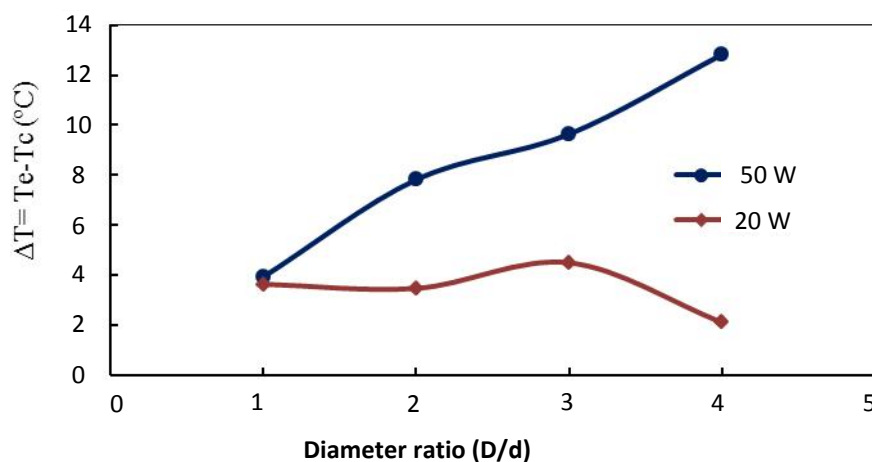
Figure 5 indicates the influence of  $D/d$  and heat input variations on boiling temperature. As could be predicted that the higher the heat input the higher the boiling temperature, which is about  $90^\circ\text{C}$  for heat input 50 Watt, and about  $40^\circ\text{C}$  for heat input 20 Watt. It can also be seen that for the same heat input the boiling temperature tend to constant with the variation of  $D/d$ .



**Figure 5.** Boiling temperature with the variation of D/d and heat input.

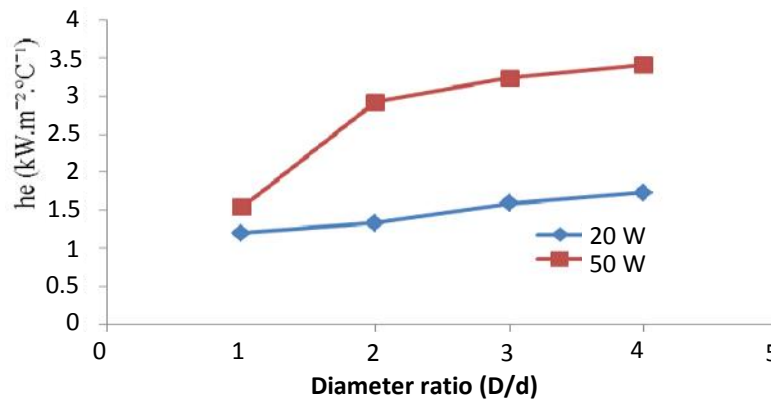
The variables governing the flow are resistance, evaporation and condensation, and all of three variables are influenced by the variation of D/d. Figure 6 shows the temperature difference of evaporator ( $T_e$ ) and condenser ( $T_c$ ), to indicate the pressure difference as driving force for vapor flow from evaporator to condenser. Pressure difference between evaporator and condenser section increases with the increasing of their temperature difference. While the heat input is low (20 W), the driving force for vapor flow is almost constant with the increasing ratio diameter D/d. Vice versa, the driving force is significantly increase with the increasing ratio diameter at high heat input (50 W). The rising of the driving force from D/d = 1 to D/d = 4 at 50 W heat input was about three fold, from about 4° C to 12° C and still rising for higher D/d.

Small heat input results a low evaporation and condensation rates, which generate small pressure at the evaporator section as well as at the condenser section. Therefore, the pressure difference at these two sections is low, although the pipe space increases due to the increasing of D/d. The effects of low heat inputs on the flow resistance may also not be significant, regarding the variation of D/d. For high heat input, the combination effects of resistance, evaporation and condensation rate with the increasing of D/d on the driving are significant as shown in Figure 6. At diameter ratio of unity (D/d = 1), the driving force is almost same disregard the heat inputs. This condition is caused by the large vapor volume increase is suppressed by the same pipe area, therefore the dominance factor of the flow is resistance. For higher D/d the influence of resistance diminishes, and gradually evaporation and condensation take over as the dominance factors.



**Figure 6.** Evaporator and condenser temperatures difference with D/d and heat input.

It could be seen that the increasing of driving force become higher with the increase of diameter ratio for high heat inputs, due to the rate of vapor volume increasing during evaporation is the highest. It could be predicted that the optimum  $D/d$  is about square root of 5,000 or about 71 for boiling temperature  $70^\circ\text{C}$ .



**Figure 7.** Heat transfer coefficient with  $D/d$  and heat input.

Figure 7 shows the heat transfer coefficient as function of  $D/d$  for heat input of 20 Watt and 50 Watt. It can be seen that heat transfer coefficient increase with the increasing of the heat input, due to higher heat transfer rates for the same heat input. Furthermore, the figure show that the higher  $D/d$  the higher the heat transfer coefficient for 50 Watt heat input. This tendency is similar to Figure 6, which is the higher  $D/d$  the higher driving force for high heat input. For low heat input, the value of heat transfer coefficient does not influenced by variation of  $D/d$ , and its value tend to constant, only increase slightly. This results is similar to variation of the driving force affected by  $D/d$  for low and high heat input in Figure 6. The magnitude of heat transfer coefficient for  $D/d = 1$  with different heat input is about the same, similar to the tendency of driving force for  $D/d = 1$  in Figure 6.

Heat transfer coefficients of heat pipe are generally higher than conventional heat exchangers which transfer sensible heat. It shown in Figure 7 that the heat transfer coefficient of tapered heat pipe between 1 to  $3.5\text{ kW.m}^{-2}.\text{°C}$  compared to around  $0.5\text{ kW.m}^{-2}.\text{°C}$  for conventional heat exchangers. Based on the results shown in Figure 7, the heat transfer coefficient of tapered shape heat pipe will be much higher for higher  $D/d$ .

#### 4. Conclusions.

Based on the discussion at the previous section, it can be concluded some important point as follows:

1. The boiling temperature of the working fluid tends to constant for all variation of diameter ratio  $D/d$ , however the boiling temperature is significantly affected by the heat input. The boiling temperature increase with the increasing of the heat input.
2. The driving force of vapor flow is affected significantly by diameter ratio  $D/d$  for high heat input, the driving force increase with  $D/d$ . However, for low heat input the effect of  $D/d$  is insignificant.
3. The driving force of vapor flow is almost same for  $D/d=1$ , disregards the heat input.
4. The effect of diameter ratio  $D/d$  and heat input variation on the heat transfer coefficient are similar to their effect on the driving force.
5. Heat transfer coefficient of heat pipe is higher than conventional heat exchangers, and tends more higher with higher  $D/d$  for tapered heat pipes.

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