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EFFECT OF EVAPORATOR-CONDENSER DIAMETER RATIO (d/D) ON THERMAL PERFORMANCE OF THE TAPERING HEAT PIPE WITH VARIOUS HEAT SOURCES

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Дана робота є продовженням досліджень, що присвячені розробці теплових труб для підвищення їх теплової продуктивності. У цьому дослідженні розроблена суцільна теплова труба. Метод, який використовується для перевірки розподілу температури в теплових трубах, є експериментальним. Геометричні параметри конструкції встановлюються як співвідношення діаметрів випарника (d) та конденсатора (D), які знаходяться в межах d/D=1/1, 1/2, 1/3 та 1/4. Джерело тепла (Q) змінюється за допомогою джерела постійного струму 25, 30, 35, 40, 45 та 50 Вт. Температуру вимірювали за допомогою термопари k-типу з модулем NI-9211 та c-DAQ 9271. Теплова труба Wick встановлена як сітка із діаметром проводу 56,5 мкм з одним шаром. Використовуваний матеріал сітки з нержавіючої сталі має теплопровідність на шару, що дорівнює 40 Вт/(м·К). Характеристиками продуктивності є зменшення термічного опору, високого часу випаровування та стабільного розподілу температури. Найкраща теплова продуктивність визначалася саме за цими показниками.

Виходячи з результатів, можна зазначити, що d/D та Q впливають на різницю теплової продуктивності. Встановлено, що при збільшенні значень обох цих параметрів термічна продуктивність збільшується. Зокрема встановлено, що кращу теплову продуктивність у досліджуваному діапазоні забезпечує теплова труба з конічними трубами d/D=1/4 і Q=50 Вт

Ключові слова: конічна теплова труба, теплова продуктивність, співвідношення діаметрів випарника та конденсатора, джерело тепла

1. Introduction

The development of electronic technology was as the rapid and the increased heat flux, there request to be an appropriate solution. The heat transfer device is divided into two groups namely active and passive heat transfer devices. The heat pipe is a passive device of heat transfer suitable for solving high heat flux. This is the device of heat transfer from the heat source as the evaporator to the heat sink as the dissipation of heat in a relatively long time span through evaporation of latent heat of the working fluid.

The development of heat pipe technology has been widely perceived, one of which is used as a cooling system in electronic components as heat dissipation, especially on the microprocessor that produces greater heat flux due to increased performance and smaller dimension. The high capacity of the microprocessor is result in increased heat and is not capable of being absorbed by the conventional heat sinks.

The heat pipe has three sections namely the evaporator, adiabatic section and condenser as the heat dissipation. The working fluid in limited space and capillary pressure by a porous layer is utilized to driven of heat transfer occurs from the evaporator to the condenser by two-phase flow liquid to vapor or vapor to liquid. The feature heat pipe geometry is one of the factors that affect thermal performance. In this study, feature a novel geometry of the tapering heat pipe in the operation system, which does not require additional components is developed. Tapering heat pipe has two different ends namely evaporator and condenser. The small end is functionalized as an evaporator and the big end as a condenser resulting in the balance of evaporation and condensation circulation. The design of the tapering heat pipe is well to be developed and suitable for cooling today's electronic devices.

2. Literature review and problem statement

The recession in the liquid film process is as well as the possibility of evaporation or boiling transition with the increased heat flux [1–3]. Availability of the capillary wick, which is in the heat pipe causes intensive transitional evaporation or boiling resulting in significant heat flux increase.

The heat pipe is a device to transfer heat by boiling and condensation of working fluid in the vacuum pipe, having an effective conductivity several times or even nearly 10000 times better than that of good heat-conducting material such copper and silver [4]. The finned u-shape heat pipe has been used [5] to cool the high-frequency microprocessors such as Intel Core 2 Duo, Intel Core 2 Quad, AMD Phenomena series and AMD Athlon 64. Usually, the working fluid is water, ammonia, acetone, propane and toluene. The temperature difference between the evaporator and the heat sink increases with heat flow rate, Q, whereas the total thermal resistance decreases with Q [6]. The large values of diameter and inclination angle as well as at low values of length and wall thickness are high thermal performance of a heat pipe by high values of Q [7]. Nano-fluid of alternative fluid is as a working fluid to improve thermal performance of the operation heat pipe investigated [8].

Various parameters are the influence of thermal performance of the heat pipe, such as heat load, porosity and permeability of the wick, the type and amount of the working fluid and the geometry of the heat pipe. The geometry of heat pipes depends on the type of heat pipe applications, the five main types of the heat pipe, which are micro heat pipe, flat plate, and an array of micro heat pipe, loop heat pipe and direct contact system [9]. The study at three different heat inputs is conducted on the heat pipe operated with a coated wick. The thermal resistance and heat transfer coefficient are resulted in the evaporator lower and higher respectively than that of conventional one whereas the same are opposite in the condenser [10].

The studies are conducted on the effect of orientation on the thermal performance of the U-shaped heat pipe with different wick structures [11]. The position inclination angle of the heat pipe 45° may affect the efficiency of the thermal optimum heat pipe with the working fluid DI Water or Nano fluid copper [12]. Total thermal resistance is an important parameter to characterize the efficiency of this complex cooling system. It is defined as the temperature difference between the evaporator and the heat sink divided by the dissipated heat flow rate (Q) [13, 14]. The evaporator-condenser diameter ratio (d/D) had effected generation of bubbles size boiling and thermal performance of the tapering heat pipe [15]. Inclination position angle of the heat pipe is increasing whereas thermal resistance drops [16].

The large number of variables, such as heat pipe geometry and material, wick structure, working fluid properties, evaporator and condenser length are total thermal resistance a function [17, 18]. The general geometry of the heat pipe has an additional device such as the fan for thermal dissipation that has a high cost. The solution high cost was made by the evaporator-condenser diameter ratio to help thermal dissipation process. Diameter ratio is the small evaporator section and large condenser section, so the balance between heat input and output occurs. The balancing heat input and output are because evaporation and condensation processes occur continuously. The condenser section has a larger area because the thermal dissipation process is stable and no additional device is needed, which lowers the cost.

Based on the above background, it is important to develop a novel heat pipe design which is tapering heat pipe to enhance thermal performance.

3. The aim and objectives of the study

The aim of this study is to investigate the effect of the evaporator-condenser diameter ratio (d/D) on thermal performance with heat source variously. The tapering heat pipe positioned at an inclination angle of 45° was set to provide the purpose.

To achieve this aim, the following objectives were set:

1. To find boiling temperature and stable temperature distribution inside the tapering heat pipe.
2. To find a high heat transfer coefficient and low thermal resistance.

4. Materials and methods of research

Tapering heat pipes made of copper tubing with a ratio of diameter $d/D=1/1$, $1/2$, $1/3$ and $1/4$, where d is the evaporator outside diameter, in which d is constant = 10 mm, while D is the condenser outside diameter $2\times d$ (mm) and d/D varies of 1/1, 1/2, 1/3, 1/4. The length of the tapering heat pipe is 200 mm. Screen mesh wick serves as the axis of the capillary to the return liquid/back flow of fluid from the condenser to the evaporator.

A valve for injecting a working fluid into the tapering heat pipe is mounted at the condenser ends. Wick heat pipe is set as screen mesh with 56.5 μm wire diameter with a single layer with the number 67.416 per mm. Wick screen mesh is made of stainless steel with a thermal conductivity of 40 W/(mK), in the form of rolls following shape the tapering heat pipe so that the shape layer with a screen of 100 mesh. The design of the tapering pipe of heat copper pipes can be seen in Fig. 1.

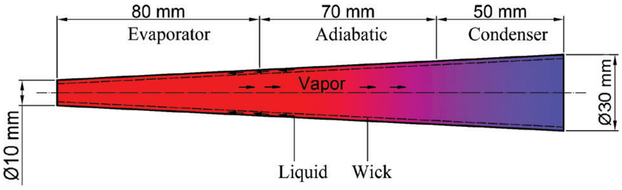

Fig. 1. Tapering heat pipe made of copper tube with the diameter ratio $d/D=1/3$

Fig. 2 is a testing scheme of boiling on tapering heat pipes made of copper pipe with an inclination position of 45° and Fig. 3 is the inclination position of the thermocouple on the tapering heat pipe.

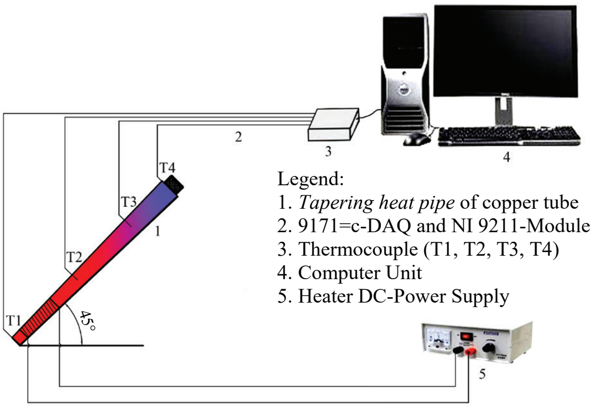

Fig. 2. Experimental set-up

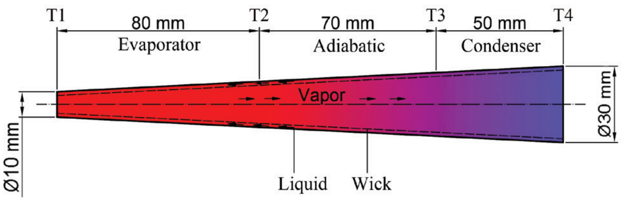

Fig. 3. Thermocouple positions

Tapering heat pipe testing was done by measuring the temperature at some point with the thermocouple positions of 10 mm, 80 mm, 150 mm and 200 mm, as in Fig. 3. One end of the tapering heat pipe is used as an evaporator, heater (flexible heater) wires are wound on the side of the evaporator serving as a heat source and the condenser serves as heat dissipation. To avoid heat loss in the evaporator, adiabatic sections are isolated and the condenser is left open freely to the outside air so that the heat dissipation can run freely. Heat source (Q) is varied by using a DC-power supply of 25, 30, 35, 40, 45, 50 Watt, to provide heat energy to the tapering heat pipe. K-type thermocouples are installed at some point to measure the boiling temperature distribution associated with data acquisition, 9171 c-DAQ and module NI-9211. The heat flux at the evaporator (q_e) was calculated by the equation:

$$q_e = \frac{Q}{(2\pi r_0 L_e)}, \tag{1}$$

$$T_i = T_0 \frac{q_e r_0}{\lambda_w} Ln \frac{r_i}{r_0}, \tag{2}$$

where Q is the heat source, r_0 and r_i are the radii of the outer and inner tapering heat pipes, L_e is the length of the evaporator, T_i and T_0 are the temperatures of the inside and outside walls of tapering heat pipes and λ_w is the thermal conductivity of copper. The coefficient of heat transfer from the evaporator can be calculated through a comparison between the heat flux at the evaporator compared with the temperature decrease ΔT:

$$h_e = \frac{q_e}{\Delta T}. \tag{3}$$

Thermal resistance can be calculated by the equation:

$$R = \frac{T_{hot} - T_{cool}}{Q}. \tag{4}$$

5. Experimental data and processing of the obtained results of experiment and discussion

5. 1. Effect of the heat source with variation of the evaporator-condenser diameter ratio on the thermal performance of the tapering heat pipe

Heat source had effected boiling temperature and temperature distribution, which enhanced the thermal performance of the tapering heat pipe. The value of the heat source is increasing as the boiling temperature is enhanced and temperature distribution becomes more stable. The results of boiling temperature and temperature distribution on the tapering heat pipe were described as follows (Fig. 4, 5):

A. Heat source of 25 Watt.

Fig. 4, 5 show that there is a difference in temperature distribution and time of evaporation on the tapering heat pipe with different values of diameter ratio. Values of the diameter ratio increased causing a cross-condenser as the dissipation heat expanded so as to accelerate the process of heat dissipation causes the boiling time takes longer than the tapering heat pipe with a diameter ratio (d/D)=1/1. Temperature distribution of evaporation on each diameter ratio d/D is measured from the end of the evaporator, so there are differences in boiling temperatures due to lower pressure in the evaporator and condenser. Meanwhile, to achieve each time of evaporation on the diameter ratio also occurs a difference, if the diameter ratio (d/D)=1/1 requires a relative evaporation faster than the tapering heat pipe has a diameter ratio is greater than 1.

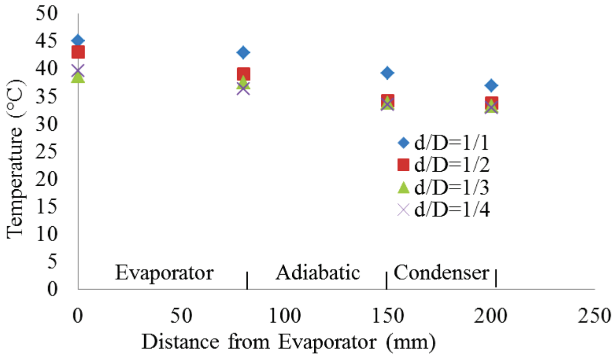

Fig. 4. Temperature distribution on the tapering heat pipe with variation of diameter ratio (d/D)

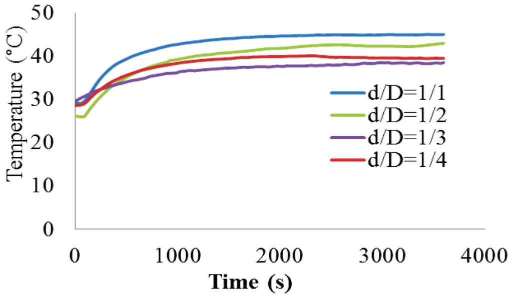

Fig. 5. Evaporation temperature on the tapering heat pipe with variation of diameter ratio (d/D)

B. Heat source of 30 Watt.

Fig. 6, 7 show that there is a difference in the temperature distribution and evaporation time, as well as on the tapering heat pipe with a heat source of 25 Watt, but there is little difference in the temperature distribution lines and evaporation time coincident with each other due to a difference of heat source are relatively small. Temperature distribution and evaporation time during boiling occur in a stable condition, the situation is a good indicator of thermal performance.

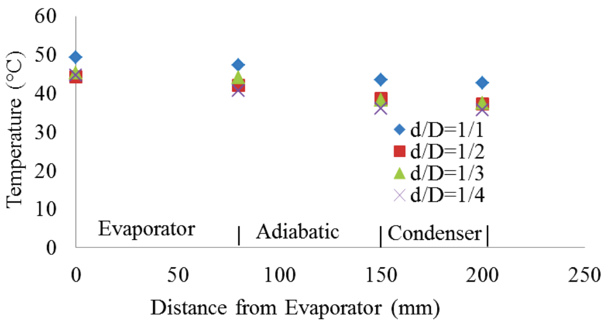

Fig. 6. Temperature distribution on the tapering heat pipe with variation of diameter ratio d/D

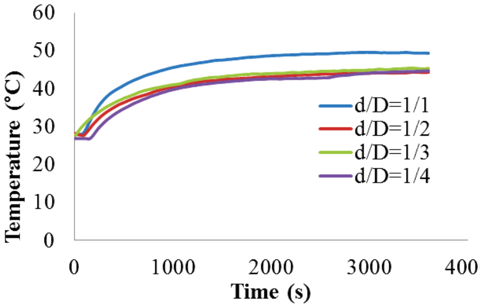

Fig. 7. Evaporation temperature on the tapering heat pipe with variation of diameter ratio *d/D*

C. Heat source of 35 Watt.

Fig. 8, 9 with the heat source of 35 Watt show that the temperature distribution and evaporation time occur differences are not sequential. Temperature distribution and evaporation time starting of $(d/D)=1/1$, 1/4, 1/3 and 1/2 indicate that these differences occur because the heat source is increasingly rising.

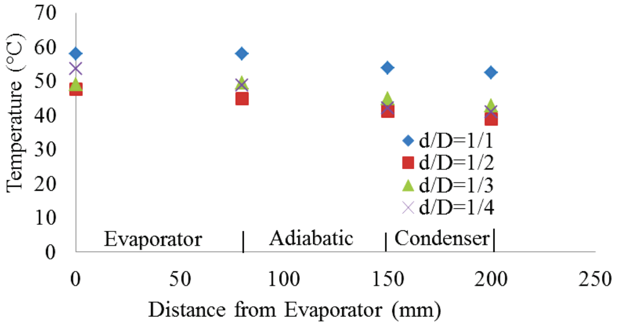

Fig. 8. Temperature distribution on the tapering heat pipe with variation of diameter ratio *d/D*

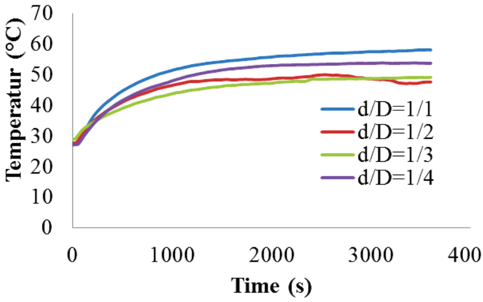

Fig. 9. Evaporation temperature on the tapering heat pipe with variation of diameter ratio *d/D*

D. Heat source of 40 Watt.

Fig. 10, 11 with the heat source of 40 Watt show that the temperature distribution and evaporation time also occurs differences in non-consecutive and decline is not uniform. Temperature distribution and evaporation time starting of $(d/D)=1/1$, 1/3, 1/4 and 1/2 show that these differences also occur because the heat source is increasingly rising.

E. Heat source of 45 Watt.

Fig. 12 and 13 with the heat source of 45 Watt show that the temperature distribution and evaporation time that uniform decreased though occur not sequentially. Temperature distribution and evaporation time starting of $(d/D)=1/1$, 1/4, 1/3 and 1/2 indicate that these differences occur because the heat source is increasingly rising. Evaporation time at each diameter ratio d/D started show differences appear with be marked lines began to separate.

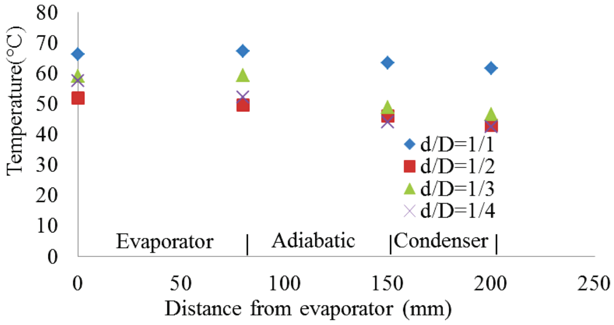

Fig. 10. Temperature distribution on the tapering heat pipe with variation of diameter ratio *d/D*

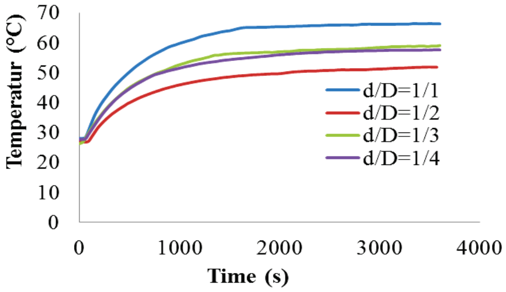

Fig. 11. Evaporation temperature on the tapering heat pipe with variation of diameter ratio *d/D*

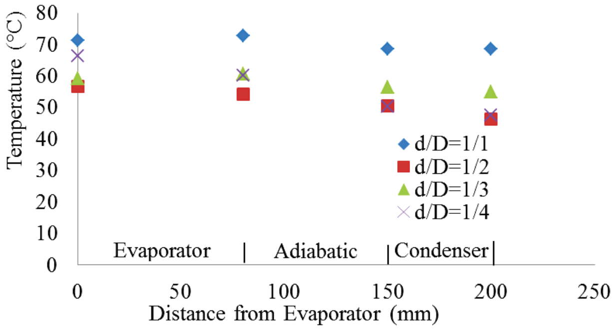

Fig. 12. Temperature distribution on the tapering heat pipe with variation of diameter ratio *d/D*

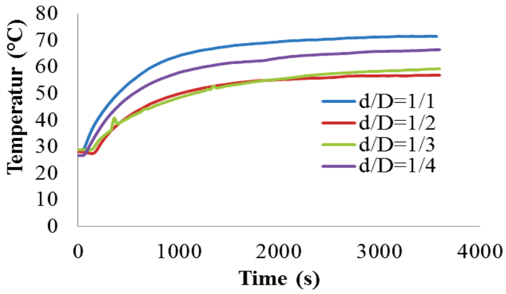

Fig. 13. Evaporation temperature on the tapering heat pipe with variation of diameter ratio *d/D*

F. Heat source of 50 Watt.

Fig. 14, 15 with the heat source of 50 Watt show that the temperature distribution and evaporation time also decreased uniform though occur not sequentially. Temperature distribution and evaporation time starting of (*d*/*D*)=1/4, 1/1, 1/3 and 1/2 indicate that these differences occur because the heat source is increasingly rising. Evaporation time at each diameter ratio *d*/*D* shows a clear difference marked by the widened distance between the lines. Experimental results indicate that various heat sources with variation of the evaporator-condenser diameter ratio had a significant effect on temperature distribution and boiling temperature, identical to the results obtained by the previous study with the experiment in the straight heat pipe.

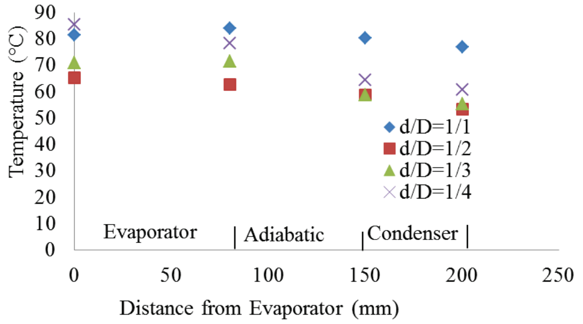

Fig. 14. Temperature distribution on the tapering heat pipe with variation of diameter ratio *d*/*D*

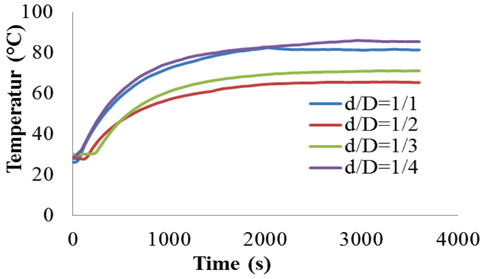

Fig. 15. Evaporation temperature on the tapering heat pipe with variation of diameter ratio *d*/*D*

5. 2. Heat flux and heat transfer coefficient

Fig. 16 shows that the heat transfer coefficient with the diameter ratio *d*/*D*=1/4 result the highest value indicates that the value of diameter ratio (*d*/*D*) could affect the heat transfer coefficient value. Heat transfer coefficient has an important role in the process of boiling and heat transfer due to the higher value of heat transfer coefficient, meaning that thermal performance of the tapering heat pipe is getting better.

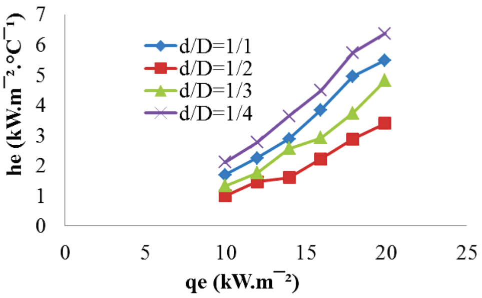

Fig. 16. Heat transfer coefficient with variation of diameter ratio *d*/*D*

5. 3. Thermal Resistance

Fig. 17 shows that thermal resistance to the diameter ratio *d*/*D*=1/4 result the lowest value indicates that the value of taper can affect the value of thermal resistance. Thermal resistance has an important role in the process of boiling and heat transfer due to the lower thermal resistance values indicating more tapering heat pipe thermal performance is getting better. The heat transfer coefficient and thermal resistance in the study had the same trend as obtained by the previous study.

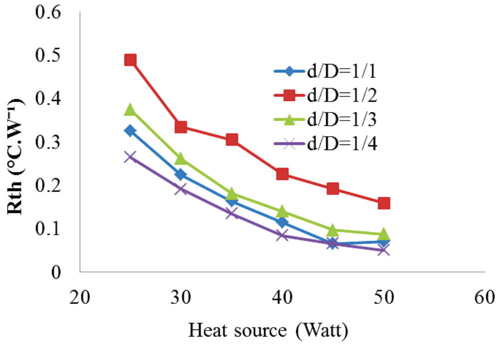

Fig. 17. Thermal resistance with various evaporator-condenser diameter ratios with different heat sources

6. Discussion of the results of research of the effect of evaporator-condenser diameter ratio on the thermal performance of the tapering heat pipe with various heat sources

The results of the research with various heat sources were been loading on the tapering heat pipe generated different boiling temperatures and temperature distributions at various diameter ratios. The boiling temperature and temperature distribution are increased and stable with increasing the value of heat source. The high heat source was generated enhanced the heat transfer coefficient and decreased thermal resistance that occur circulation continuous two phase flow. Advantages and disadvantages of this study are:

Advantages:

1. Boiling temperature and temperature distribution are increased and stable.
2. The temperature difference of the evaporator section and condenser are increased at a diameter ratio of 1/2, 1/3, and 1/4 compared to 1/1.
3. Enhanced heat transfer coefficient and decreased thermal performance at high heat source.
4. Operation system does not need additional components on the condenser section.
5. The inclined position angle of flexible.

Disadvantages:

1. The working pressure is not measurable.
2. The only value of a certain diameter ratio has a high heat transfer coefficient value and low thermal resistance.

The studies are useful if done further research and application on the electronic cooling device such cooling system laptop, microprocessor, etc. This study is a continuation of the previous research.

7. Conclusions

The results of the research of the effect of the evaporator-condenser diameter ratio on the thermal performance of the tapering heat pipe with various heat sources can be summarized as follows:

1. Boiling temperature and temperature distribution are increased and stable along with the increased heat source value at various diameter ratios analogous with conducted by Thuchayapong et al. [17] that capillary pressure gradient inside the wick at the end of the evaporator section was very large and of fast liquid motion at the end of the evaporator section, thus, providing efficient heat transfer through convection.

2. The enhanced heat transfer coefficient and decreased thermal resistance along with the increased heat source value at various diameter ratios, that the study results identical of obtained by Putra et al. [8] that the best performance heat pipe on the screen mesh wick by using the one with the Al_2O_3-water nanofluid with 5 % volume concentration as working fluid.

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