International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 – 5161

Available at http://inpressco.com/category/ijcet

Research Article

A Review on Thermal Performance of Different Working Fluids in A Dual Diameter Circular Heat Pipe

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Accepted 02 March 2016, Available online 15 March 2016, **Special Issue-4 (March 2016)**

Abstract

In this paper, a review on heat transfer performance of a 40 cm-length circular heat pipe with screen mesh wick, experimentally investigated is carried out. This heat pipe is made of copper with two diameters; larger in the evaporator and smaller in the adiabatic and condenser. Three different liquids including water, methanol, and ethanol are separately filled within the heat pipe. Low heat fluxes are applied (up to 2500 W/m²) in the evaporator and constant temperature water bath is used at three levels including 15, 25, and 35 °C in the condenser. Results demonstrate that higher heat transfer coefficients are obtained for water and ethanol in comparison with methanol. Furthermore, increasing heat flux increases the evaporator heat transfer coefficient. For the case of methanol, some degradation in heat transfer coefficient is occurred at high heat fluxes which can be due to the surface dry out effect. Increasing the inclination angle decreases the heat pipe thermal resistance.

Keywords: *Heat pipe; Thermal resistance, Heat transfer coefficient, Methanol, Ethanol, Water*

1. Introduction

As alternatives to the conventional heat sinks, two-phase cooling devices such as heat pipe have been emerged as promising heat transfer devices with effective thermal conductivity over200 times higher than that of copper. As a high thermal conductor, heat pipes have been used in different applications such as energy conversion, energy storage systems, and electronic cooling. Heat pipes are able to dissipate substantial amount of heat with a relatively small temperature drop while providing a self-pumping ability due to an embedded porous material in their structure. Regarding this importance, several researches have been conducted to evaluate the thermal performance of heat pipes with different geometries and different working fluids. Reay carried out experiments on a plate heat pipe with100 cm length and 10 cm width. The orientation was horizontal in this study. Freon 11 and 113 were separately used as working fluids. It was found that Freon 11 was superior to Freon 113 from the point of view of thermal transport. Kempers *et al*. characterized the individual condenser and evaporator thermal resistances of a copper–water screen mesh wicked heat pipe. They examined the existence of boiling heat transfer in the heat pipe and its importance for the modeling of the heat pipe performance. Their results showed that a composite heat transfer model should be used for wicked heat pipes to take into account that either conduction or boiling can occur in the evaporator, with conduction only at the condenser.

Tsai *et al*. presented a novel dynamic test method and compared it with the conventional steady-states test. Bending angles, fill ratios, and shapes of heat pipes were investigated in order to study their influences on the thermal performances of heat pipes for both steady-state and dynamic tests. Experimental results demonstrate that deformation of heat pipes would damage the thermal performances of heat pipes most significantly. Larger fill ratios would increase the operation limitations but also lead to less sensitive temperature responses of heat pipes. Wong and Lin investigated three different working fluids including water, methanol and acetone, which possess different figures of merit at the same volumetric liquid charge. Different degrees of wettability were obtained by varying the exposure times in air after the wicked plates were taken out of the sintering furnace. It was found the lowered copper surface wettability led to reduced critical heat loads for water rather than for methanol and acetone. From the view of thin-film evaporation mechanism, water has larger surface tension, polarity, viscosity, and latent heat than methanol and acetone. Attia and El-Assal conducted an experimental study to evaluate thermal performance of a heat pipe with water and methyl alcohol at different charge ratios. Also, a solution of water and propylene glycol at two concentrations were tested to study the effect of using surfactant as enhancement agent for working fluid.

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Although the research work on traditional cylindrical and annular heat pipes has been well documented, there is far less work conducted for dual diameter cylindrical heat pipes. Furthermore, since heat pipes utilize the phase change of the working fluid to transport the heat, the selection of working fluid is of essential importance to promote the thermal performance of heat pipes. The study is to compare the thermal performance of water, methanol, and ethanol as the working fluid in a dual diameter heat pipe. This comparison had not been reported before and can be useful for understanding the working fluid selection for heat pipes.

Table No.1: Nomenclature

Nomenclature/subscripts	Description
h(W/m^2)	heat transfer coefficient
Q(W)	heat transfer rate
R(°C/W)	thermal resistance
T(°C)	temperature
c	condenser
e	evaporator
v	vapor
w	wall

2. Experimental Investigation

The experiments were performed by S.M. Peyghambarzadeh using a heat pipe which was made of a smooth copper tube. Porous wicks are attached to the inner surfaces of the heat pipe wall, as shown in Fig. 1.There were three layers of aluminum meshes (mesh number 100) inside the tube. This type of mesh has a suitable flexibility to be deformed. A close contact between the meshes and the inner wall can be guaranteed due to the internal tension ofthe mesh. The dimensions of evaporator, adiabatic, and condenser sections of the heat pipe were presented in. It is observed that the evaporator section has larger diameter than the remaining sections of the heat pipe. This configuration causes the evaporated liquid to pass the nozzle shaped entrance of the adiabatic section with higher velocity. When the vapor reaches the condenser faster, the heat transfer performance of the heat pipe would be improved.

Fig.1: Screen mesh wick used in the heat pipe

The evaporator section was heated by an electrical heater(Watlow Company) surrounding at its circumference. The condenser section was cooled by the cooling water circulating in a constant-temperature thermal bath which was a cube with the dimensions of 0.2 m. The temperature and velocity of the cooling water were carefully controlled to keep the steam pressure in the tested heat pipe at a constant value for various heat fluxes. The evaporator and adiabatic sections were carefully insulated using glass wool.

Three E-type thermocouples were installed to measure the outside surface temperatures of the heat pipe and three others to measure the working fluid temperatures. Each group includes one thermocouple at the evaporator section, one at the condenser section and one at the adiabatic section. Very tiny grooves were machined in the heat pipe walls and a high conductivity cement was utilized to embed the thermocouples within the heat pipe wall. Distributions of the thermocouples along the axial direction are shown by S.M. Peyghambarzadeh. The wall temperature distributions along the circumference direction were quite uniform because the mesh structure could make the liquid film uniformly filled into the mesh layers of the inclined heat pipe. A pressure transducer placed at the central location of the adiabatic section which is used to measure the saturation pressure of the steam in the heat pipe, i.e., the operating pressure.

Table No. 2: Dimensions of different sections of the heat pipe

Specification	Evoparation Section	Adiabetic Section	Condensor Section
Length(mm)	100	200	100
Internal diameter(mm)	25.4	19	19
External diameter(mm)	26.4	20	20
Area(mm^2)	8920	12591	6295
Volume(mm^3)	50645	56976	28487

Different working fluids including water, methanol, and ethanol were filled into the heat pipe through a syringe. Some important physical properties of these working fluids are shown in Table 2. Since these working fluids have different physical properties, their implementation in the heat pipe may be useful in understanding the effect of each properties in heat transfer performance. The filling volume was fixed at 50% of the heat pipe volume. Before each test, the vacuum pumping and liquid preheating processes were performed to remove the dissolved gases in the heat pipe and the working fluid.

Almost all of the experiments were performed with the heat pipe in the horizontal orientation except for some runs which performed to analyze the effect of contact angle on the performance of the heat pipe. Tests were performed at different constant condenser temperatures of 15, 25 and 35 °C.

3. Data Reduction

The thermal resistance is one of the most important parameters that reflect the performances of the heat pipe during the heat transfer tests. The evaporator thermal resistance is defined as:

$Re = \frac{Te,w - Te,v}{Qe}$

whereTe,w is the evaporator wall temperature, Te,vis the vapor temperature at evaporator section and Qe is the input power. The condenser thermal resistance is defined as:

$Rc = \frac{Tc,v - Tc,w}{Qe}$

Where Tc,w is the condenser wall temperature, Tc,v is the vapor temperature at the condenser section and Qe is the input power. The total thermal resistance of the heat pipe can be defined as:

$R = \frac{Te,w - Tc,w}{Qe}$

The heat transfer coefficient at the evaporator section is calculated as follows:

$R = \frac{(\frac{Q}{A})}{Te,w - Te,v}$

An uncertainty analysis has been performed by S.M. Peyghambarzadeh according to the method proposed by Kline and McClintock . The estimated uncertainties of diameter, length and area are less than±0.4%. The uncertainty of temperature is ±0.2 K for the thermocouples. The maximum value of uncertainty of input power is 0.8% and the maximum value of uncertainties of the evaporator thermal resistance and the heat pipe thermal resistance are ±4.5% and ±5.1%, respectively.

4. Results and Discussion

4.1 Temperature Measurement

The vapor core temperatures at the evaporator, adiabatic, and condenser sections of the heat pipe are demonstrated. These temperature data were obtained at constant input power (20 W) and at different condenser temperatures. Results for different working fluids including methanol, ethanol, and water are shown. Therein the numbers 1, 2and 3 at the horizontal axis demonstrate the location of evaporator, adiabatic and condenser of the heat pipe,respectively. It is observed that higher vapor temperatures are obtained for water in comparison with methanol and ethanol at constant input power. The maximum temperature of the evaporator section of a heat pipe is related to the boiling point of the working fluid. Water has the largest boiling point among the other working fluids used in this study. Furthermore, difference in the condenser temperature has small influences on the vapor core temperature at the evaporator section for methanol and ethanol, while this effect is more pronounced for water.

S.M. Peyghambarzadeh demonstrates the variation of heat pipe wall temperature when filled with different working fluids. These results were also obtained at 20W input power and at different condenser temperatures. Once again, higher wall temperatures are obtained at the evaporator section and for the case of water.

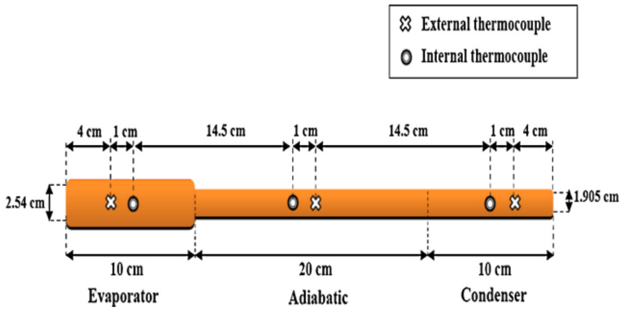

Fig.2: Locations of thermocouples in the heat pipe

Higher temperature of the condenser causes the returning liquid to the evaporator to be warmer and consequently, higher wall temperature of the evaporator obtained. For methanoland ethanol the effect of condenser temperature is not strong, since the returning liquid to the evaporator section would boil when 20 W of input power applies. When a liquid boils on the surface through which a constant heat flux is applied, the temperature of the surface will be constant. Conversely, it has been shown that when Tc =15 °C, the returning liquid does not boil. So, the surface temperature differs from other condenser temperatures.

Another important point which is observed that the curvature of the temperature curves is different for axial vapor core and wall temperatures. It means that for vapor core, larger temperature drop occurred at the distance between adiabatic and condenser while for wall temperature, larger temperature drop occurred between evaporator and adiabatic sections.

4.2 Heat Transfer Coefficient

The heat transfer coefficients for implementing different working fluids in the heat pipe are shown as a function of heat flux and condenser temperature. It is observed that the heat transfer coefficient increases with increasing the applied heat flux at the evaporator. For methanol and at higher heat flux, the heat transfer coefficient decreases with increasing heat flux. It is due to dry out occurred at the evaporator surface which causes heat transfer degradation. The dry out for methanol is not observed at lower condenser temperature (Tc=15 °C), since the returning liquid from the condenser is toocold to be completely evaporated. This phenomenon would probably be occurred for ethanol and water at higher heat fluxes than that investigated in this study.

4.3 Thermal Resistance

Thermal resistance of the evaporator is shown in form ethanol, ethanol and water respectively. Increasing heat fluxdecreases the thermal resistance of the evaporator. The effect of dry out for methanol is again shown in at high heat fluxes and high condenser temperature. Furthermore, higher condenser temperature causes the evaporator resistance to be decreased.

The variation of condenser thermal resistance as a function of heat flux and condenser temperature is presented in. At the lowest heat flux applied in this study, very large condenser thermal resistance observed specially for water and methanol when using the highest condenser temperature (Tc = 35 °C).It is not strange behavior; since the filled liquid temperature to the heat pipe is 25 °C and the applied heat flux is very low to change the liquid temperature at the evaporator significantly. Therefore, it was observed that the temperatures of all the working fluids at the evaporator would be less than that of condenser. It means that heat pipe works conversely in this condition. Liquid warms at the condenser and cooled at the evaporator. So, higher condenser thermal resistance wouldbe expected in this condition.

The trend of total resistance of the heat pipe fordifferent working fluids as a function of heat flux is demonstrated. Although similar investigations showed that increasing heat flux causesthe total resistance of the heat pipe to be decreased and at Tc= 35 °C different trends were observed for all the working fluids. As stated earlier high condenser temperature and low heat flux leads to the lower temperature difference between condenser and evaporator (Te,w–Tc,w) and this reduces the overall resistance close to zero. Increasing heat flux in this condition warms the evaporator wall and increases the overall resistance.

4.4 Effect of Inclination Angle

The effect of inclination angle of the heat pipe on its total resistance is demonstrated in. It is observed that increasing the contact angle (setting the evaporator in lower level than the condenser) causes the condensed vapor returns faster to the evaporator section by means of gravity and consequently, lower thermal resistances and higher heat transfer coefficients were obtained.

Conclusion

In this study, thermal performance of a dual diameter circular heat pipe investigated using three different working fluids including water, methanol, and ethanol by S.M. Peyghambarzadeh is shown and the following results were studied:

1) Water is the best working fluid among the other working fluids regarding the higher temperature and heat transfer coefficient in the evaporator section.
2) Thermal resistance of the evaporator section was an order of magnitude higher than that of the condenser section for all the working fluids tested.
3) At lower condenser temperatures, lower heat transfer coefficients and higher thermal resistances were obtained.
4) Although the experiments were performed at low heat fluxes, dryout was observed for methanol at the highest condenser temperature. This phenomenon causes the heat transfer coefficient decreases with increasing heatflux, contrary to the usual behavior.
5) The inclination angle has a great effect on the heat pipe thermal resistance using water as the working fluid.

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