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Experimental study of Mesh wick heat pipe performance enhancement with varying CuO nanofluid concentration and tilt angle.

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Abstract

Heat pipe transfers heat from one location to other based on the change of phase principle. The heat pipes are quite superior conductors compared to even the metals since the latent heats are involved. Continuous efforts are going on to improve the thermal performance of heat pipe by using various nanofluid concentrations and wick structures. This paper reviews influence of percentage of nanoparticles and the tilt angle of heat pipe on the improvement of thermal efficiency of heat pipes. An experimental investigation is carried out with CuO nanofluid concentration varying from 0.5%, 1%1 1.5% and compared against DI water. The observations are taken at varying angles from 0^o to 90^o in steps of 15^o

Keywords: heat pipe, nanofluid, thermal resistance, tilt angle

1. Introduction

Heat pipe transports large quantities of heat with minimum temperature differential over length. The density difference that arises from heating the fluid at evaporator section and the capillary force of the wick together act as a driving force and hence no external power is necessary for pumping the heat from source to sink. The heat pipes are used in various applications such as electronic devices, heat exchangers, chemical applications, waste heat recovery, power generation, air conditioning systems, water heating utilities and solar energy collectors.

The heat pipe can be divided into three sections:

- Evaporator: This is the portion at heat source
- Condenser: This is the portion at heat sink;
- Adiabatic section: It connects the other two

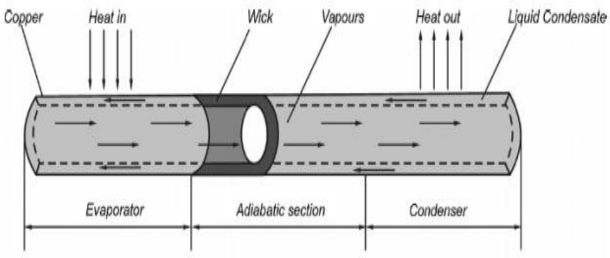

Fig. 1 Heat Pipe working principle

The working medium present in the wick structure is heated until it crosses saturation temperature and hence vaporizes. This vapor being lighter rises to the condenser section and gives away heat. Considerable quantity of heat is taken away with a very small end to end temperature difference since the latent heat of evaporation is quite large. This gives the structure a high effective thermal conductance.

2. Literature review

Heat pipe is seen to be in a various places where we come across the electronic components which have high speed operations or heavy heat generation rates. G. Kumaresan [1] has evaluated the two-phase flow as well as the heat transfer in a small tube using R141b as a medium. A highly efficient heat pipe for cooling of electronics with heavy heat fluxes was developed by them. L.G. Asirvatham [4] compared the performance of a heat pipe under variation of heat fluxes, tilt angles and quantity of the working fluid. Z.H. Liu [5] used heat pipe in a solar-based heat pump system which was used for water heater purpose. Lin et al used the computational fluid dynamics software simulation to model the heat pipe. N. Putra [6] studies the effect of mean vapor temperature on heat transfer characteristics of heat pipe. The paper considers the mathematical analysis of heat transfer limitations.

3. The heat pipe transfer limitations:

The working fluid transport properties decide heat transfer capability of the heat transfer. The limitations determine the maximum heat transfer rate for a heat pipe under the normal working conditions.

3.1. Capillary limit: This limit is relevant under normal working conditions of heat pipe. Capillary limit is dependent on surface tension. The dependency of surface tension of pure liquids is normally in inverse proportion with the temperature and hence surface tension decreases along the interface towards the evaporator zone. Since the driving capillary pressure becomes insufficient to provide the necessary liquid flow from the condenser to the evaporator, evaporator wick may dry out. The circulation of the fluid is caused by capillary pressure difference. Hence the maximum capillary pressure needs to be greater than the addition of all pressure drops inside the heat pipe. This pressure drop is composed of 3 components.

1. ΔP_l required for the liquid to travel from the condenser to the evaporator.

2. ΔP_v pressure drop to make the vapour to flow from the evaporator to the condenser.

3. ΔP_g , pressure drop due to gravity which can be zero, positive or negative, depending on the tilt angle of the heat pipe.

For correct operation,

$\Delta P_{c,max} \geq \Delta P_l + \Delta P_v + \Delta P_g$

Tilt angle plays a vital role since the gravitational pressure drop is a negative term in the equation which in effect reduces the need of having higher capillary pressure.

For regular applications at moderate temperatures, water is a suitable working fluid because of its easy availability, low cost, safety in handling and high surface tension. At elevated temperatures, however, the surface tension of the water decreases rapidly with increase in temperature. Hence the water is being replaced by nanofluids which have improved transport properties. The increase in percentage of nanoparticles inside water leads to an improvement of thermal conductivity and hence better heat transfer rate.

3.2. Boiling limit: Boiling limit is the second most important limitation on heat pipe transfer efficiency. At heat fluxes exceeding the normal operation, nucleate boiling prevails in the wick structure. It allows vapor to get trapped in the wick and hence blocks the return path of liquid. This eventually results in evaporator dry out. This phenomenon is known as the boiling limit. It is different from the other limitations; in essence, it depends on the radial heat flux or circumferential heat flux applied to the evaporator whereas other limits deal with the axial heat flux.

3.3. Viscous limitation: This limit comes into picture for heat pipe operated at relatively lower temperatures. At such temperatures, the total pressure in the vapor region becomes inadequate to maintain the flow of vapor in the liquid. In such cases, the liquid is balanced by viscous forces only. The viscous limit is applicable in case of long heat pipes.

3.4. Sonic limitation: This limit is observed at heat pipe start up or at low temperature because of relatively very low vapour densities. The result is a chocked flow/ sonic flow. This limit usually does not come into picture except in case of very small vapor channel diameters.

This study is mainly concentrated on the thermal efficiency improvement of mesh wick heat pipes with CuO nanofluid at different concentrations and different tilt angles. The results are checked against DI water heat pipe.

4. Experimentation

The experimental set up is as shown in figure 2. The heat pipe is fixed in an adjustable stand. Tilt angle of heat pipe can be changed with the help of the stand. The tilt angle of heat pipe can be varied from horizontal axis to 30° to 90° in steps of 15°. One end of thermocouples is connected to the data logger whereas the other connected to the surface of heat pipe. The data logger is attached to a personal computer for monitoring and recording purpose. It takes the reading of temperature values. The input power supply is changed from 10 W to 140 W in steps of 10 W. Cooling water is circulated in the condenser section.

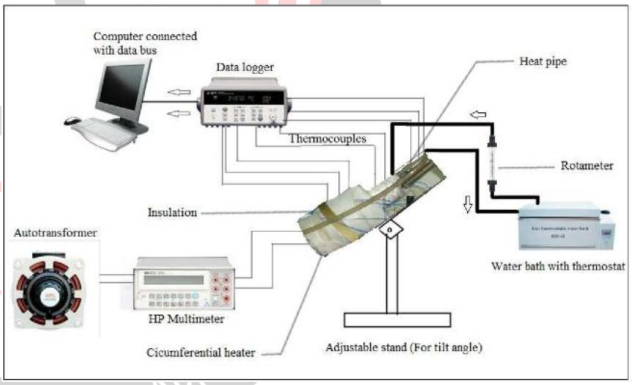

Fig. 2 Schematic of experimental setup to study efficiency improvement of heat pipe

5. Results and discussions

Thermal efficiency denoting the performance of the heat pipe is defined as a ratio of the heat carried out from the condenser section to the heat supplied to evaporator section. There is an increase in the efficiency of heat pipe performance due to increase in the concentration of CuO nano particles as well as increase in tilt angle upto 45° as shown in figures 2. (a to d).

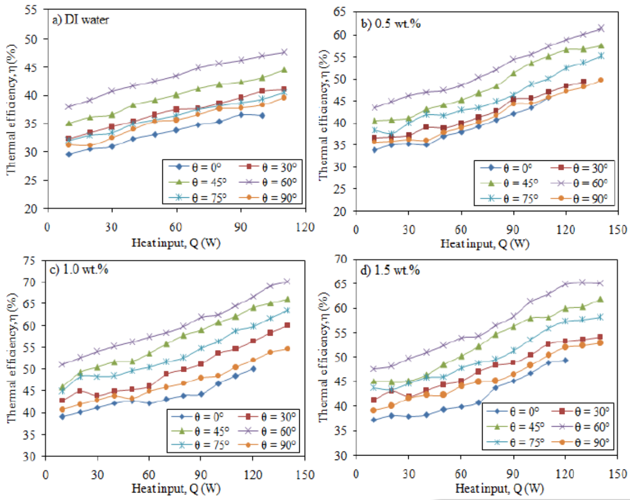

Fig. 3 Heat pipe performance with varying CuO particle concentration and tilt angle

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