Performance Evaluation of Heat Pipe using Nano fluid

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Abstract :

This paper summarises the research work done on heat pipes using Nanofluids. Heat pipes are one specific type of heat exchangers, having very wide application in electronics and other fields, because of its compactness, high efficiency, less number of components and no need for external circulation of working fluid. Addition of nano size solid particles having high thermal conductivity to the working fluid of low conductivity, will enhance the overall heat transfer coefficient of the system and inturn the efficiency. Nano particles of Al_2O_3, CuO, TiO_2 with base fluids like water, ethylene glycol, lubricating oil, etc. have been considered. Relevant nanofluid properties have been calculated using empirical correlations and Heat Pipe performance has been evaluated theoretically using merit number.

It is observed that using Merit Number there is significant enhancement in the overall performance of the heat pipes using nanofluids.

Keywords: *Heat Exchanger, Heat Pipe, Nanofluids, Heat Transfer, Merit Number.*

I. INTRODUCTION

Conventional heat exchangers are in existence for more than a century and are in use for various industrial applications. Their types, working principle, and performance are well established. Heat pipe is one such device widely used in electronics, computers, medical and many other applications.

In these devices normally heat exchange takes place between two fluids separated by a solid wall through conduction and convection modes of heat transfer which are directly linked with the thermal properties of the two fluids and the solid wall. It is well known that liquids have very poor heat transfer properties compared to solids thereby leading to low overall efficiencies. Researchers have found that addition of highly conductive solid particles into the fluids enhance their thermal properties and in turn improve the efficiency of heat exchanger devices including heat pipes.[1]

The primary factors influencing the enhancement of heat transfer properties are [1]

1. Material, size, shape, concentration, stability, dispersion, settling velocity of the particles.
2. Thermal properties like ρ, C_p, μ, k, h etc. of the resultant fluid.

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In most of the heat transfer equipment water is the main fluid being used, because of its abundant availability, easy handling, safety etc. although other liquids like oil, Ethylene glycol have been tried for specific applications. Addition of solid particles of metal or metal oxides should result in a homogeneous, uniformly distributed, stable mixture to get maximum benefit. It has been observed by previous investigators that the optimum size of nano particles shall be in the nano range (10 to 100nm) and hence the name nanofluid. The normal solid particles that can be added are Al, Cu, Ag, Al_2O_3, CuO, TiO_2 etc.which have very good thermal properties and upto a maximum of 3% by volume is sufficient to attain the required results depending upon the application.

The main purpose of using nano fluids is to attain highest possible thermal properties at the smallest possible concentration(< 1% by volume) by uniform dispersion and stable suspension of nano particles (10 to 80 nm) in base fluids.

NANOFLUID PROPERTIES:

When solid nano particles of high thermal conductivity are added to the base fluid of poor conductivity the resultant properties of the nanofluid have to be established either theoretically or experimentally, so that overall performance of the heat exchanger can be evaluated.

Many researchers have suggested several empirical correlations for calculating nanofluid properties and tried to validate the same with available experimental results. [2, 3, 11]

A few important relations are shown below:

1. $\rho_n = (1-\varphi)\rho_b + \varphi\rho_p$ -------------(1)
2. $C_{p_n} = \frac{(1-\varphi)\rho_b C_{p_b} + \varphi\rho_p C_{p_p}}{(1-\varphi)\rho_b + \varphi\rho_p}$------------(2)
3. $\mu_n = \frac{\mu_b}{(1-\varphi)^{2.5}}$

   $\mu_n = \mu_b(1 + 39.11\varphi + 533.9\varphi^2) - (3)$
4. $k_n = \frac{(k_p+2k_b)+2\varphi(k_p-k_b)}{(k_p+2k_b)-\varphi(k_p-k_b)} k_b$----------- (4) (Eq^n.4 is for

Spherical Particles------Maxwell Model.)

The resultant properties of nanofluid particularly k which increases to the extent of 50% will definitely help in enhancing the heat pipe efficiency and effectiveness.

From the available literature, there seems to be very little agreement between the above correlation and corresponding experimental results. Very little work has been done in estimating these properties at higher temperatures. Also the measuring instruments required for experimental work are not commonly available.[1,2,3,4]

MECHANISM OF HEAT TRANSFER:

The mechanism of heat transfer enhancement in the presence of nano particles in the base fluid has been very little understood and is mainly attributed to [5]

a. Brownian Motion of Nano particles(Small size of the particles and their speed of Brownian motion which makes the micro convection heat movement guide).
b. Liquid layering at the liquid/particle interface
c. Ballistic nature of heat transport in nanoparticles.
d. Large surface to volume ratio of the particles.

A large number of theoretical and experimental work has been done by many researchers in evaluating the performance of heat exchangers and understanding the heat transfer mechanism using nanofluids. Considerable amount of work also has been done on Heat Pipe.[5] but many results are inconclusive.

INTRODUCTION AND WORKING PRINCIPLE OF HEAT PIPE:

The basic phenomena of evaporation, condensation surface tension, pumping through a capillary wick, permit the heat pipe to transfer latent heat continuously without the help of external work.

Heat Pipe is a compact heat exchanger without having any moving parts. Consists mainly of a narrow bore tube, both ends closed, with a wick lining on the inside surface of the tube which is soaked with the heat transfer fluid at saturated state. It is a different kind of heat exchanger which has an ability to transport heat over a large distance with relatively small temperature difference. The heat from hot source to cold sink is transported in the form of latent heat.

Heat Pipe is simple in construction, less expensive, silent in operation and has long life. In Heat pipe, energy transfer takes place by Conduction, convection and radiation.
One end of the heat pipe acts as an evaporator, the other end as a condenser and the middle portion acts as a convective passage for motion of the fluid vapours by capillary and gravitational forces. By virtue of high latent heat of vaporisation and condensation and the capillary action of the sink, a large quantity of heat can be transported from one end to the other end of the pipe continuously and does not require mechanical pump.

Circulation of working fluid in heat pipe is maintained by capillary forces which develop in the wick structure at the vapour interface. These forces balance the pressure losses due to the flow in the liquid and vapour phases and are manifest as many tiny menisci which allow the pressure in the vapour to be higher than the pressure in the adjacent liquid in all parts of the system.
In a heat pipe, convection in the liquid is not required because heat enters the pipe by conduction through a thin saturated wick.

The closed outer vessel is made up of Glass or Metal tube. The working fluid used in heat pipe is water, acetone, alcohol, glycerine, ammonia, Freon-11,Freon-113, molten salts, molten metals (Hg,Na,Li). The porous wick is used in heat pipe is made up of woven cloth, fibre glass, porous metal, wire screen, porous ceramic tube, narrow grooves cut length wise on the pipe wall, thin corrugated and perforated metal sheet. Pressure within the heat pipe is the saturation vapour pressure corresponding to the operating temperature condition.

Heat Pipe with conventional heat transfer fluids have been in use for many applications in the field of electronics, computers, medicine, aerospace, solar, Nuclear etc. and their performance have been evaluated. Because of its high thermal conductance in steady state operation it is also known as 'Super Thermal Conductor'. In order to achieve a higher heat transfer rate nanofluids like water with Al_2O_3, CuO, TiO_2 have been tried by many researchers. Trai et.al. first studied the effect of nanofluids on simple heat pipe and found that the resistance of heat pipe decrease tremendously.

PRESENT WORK:

In the present work a typical heat pipe configuration has been chosen as an example (Fig.1.)[7] and its performance evaluated theoretically, with and without using a nano fluid.

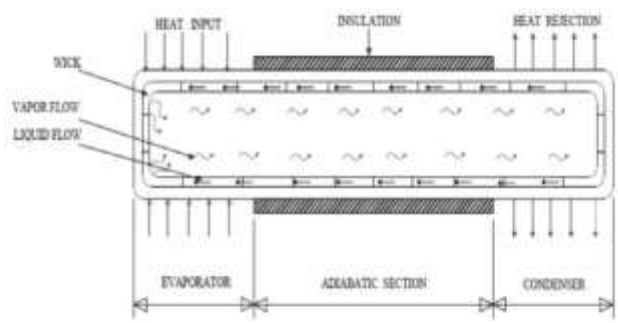

Fig.1: Heat Pipe.

Al_2O_3, CuO,TiO_2 nano particles with water as base fluid have been tried with volumetric fractions of 0.1 to 1.0%. Resultant physical and thermal properties have been calculated using the empirical relations. (Equation No.s 1,2,3,4).

Typical sizes of the heat pipe used by the researchers are:
a)Cu tube with Water + Al_2O_3 nanofluid.[7]

1. Outer dia. = 8 mm, Length = 190 mm, Wick = 1mm thick.
2. Outer dia. = 9.52 mm, Length = 0.3m, 0.45m, 0.6m.

Heat Input 40W- Performance (increased k with 40^0 tilt angle): (i) for 0.3m – 22.7%; (ii) for 0.45m –56.3%; and (iii) for 0.6m –35.1%
b) Cu tube with DI Water + 50 nm CuO nanofluid.[6]
Outer dia. = 8mm, Wall thickness of the heat pipe 0.6mm,
Evaporator, Adiabatic and Condenser Length is 100mm, 100mm, 150 mm respectively.

PERFORMANCE ESTIMATION:

In order to study the effect of various parameters influencing the enhancement of physical as well as thermal properties, a semi quantitative technique can be used. It offers an attractive way for design choices addressing the heat transfer demands of a given industrial application. This is an approximate ranking of engineering parameters that assume equal and independent weightage for each of the nanofluid properties contributing to thermal transport. Effect of increase in temperature of base fluid(water) on Merit Number is shown in fig.2.Using this technique overall performance has been evaluated by considering the Merit Number also called as Mouromtseff reference number (Mo) which is defined as[8]

$$M_o = \frac{\rho^{0.8} k^{0.67} C_p{}^{0.33}}{\mu^{0.47}}$$

Results are shown in fig.3.The ratio of nanofluid to the base fluid Merit Number should be greater than one ($\frac{M_{o_n}}{M_{o_b}} > 1$) for better performance of the heat pipe. Using Mo, heat transfer rate of the heat pipe is given by[8]

$$q = \frac{A_w P_w M_o}{L}\left[\frac{2}{r}(\cos\alpha_e - \cos\alpha_c) - \frac{g\rho L}{\sigma}\cos\beta\right] W/m^2$$

A liquid with large Merit Number(Mo) provides higher heat transfer rate. The choice of the right kind of liquid and wick material is important in heat pipe design. Liquids such as NH_3,N_2, H_2O,alcohol and liquid metals are used. Wick materials may range from Wire screen to woven cloth.
These results are plotted in and it is very clear that addition of nano particles enhances the overall performance of the Heat Pipe.

Recently available experimental results have been collected and imposed on the theoretical plots. The mismatch between theory and experiments very clearly indicate that lot of work needs to be done in this area to understand the mechanism of heat transfer enhancement in nanofluids.

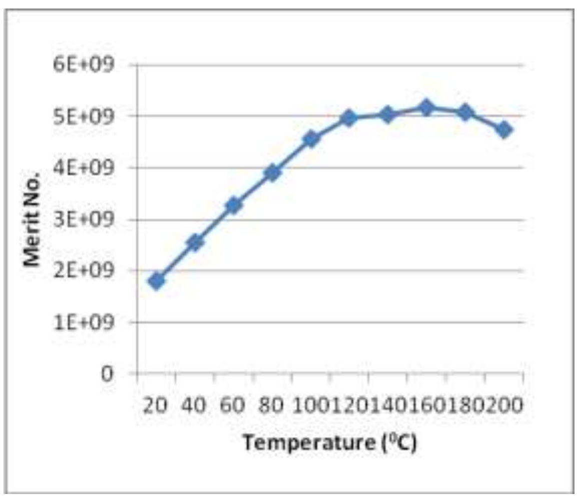

Fig.2: Temperature vs Merit No. of base fluid Water.

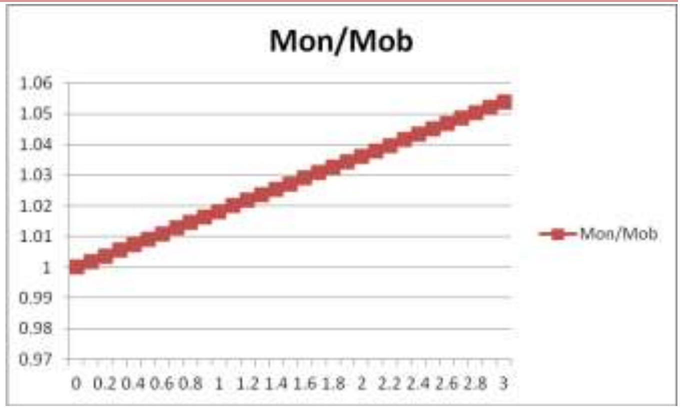

Fig.3: % volume of nanoparticle vs Merit No. of 94% Alumina

FUTURE WORK:

Further it is proposed to procure/ fabricate a Heat Pipe and do experimental investigation, using nano fluids, analyse the results and arrive at better correlation to estimate its performance.

Detailed theoretical and experimental investigations are needed to understand the heat transport properties of nanofluids in heat pipes and the optimise their concentration.

CONCLUSION :

From the theoretical estimation made so far it is observed that use of nanofluids like Al_2O_3, CuO in water will enhance the performance of heat pipes to the extent of 20 to 80% respectively. Mainly there are two benefits seen in the present work: (i) enhancement of heat transfer properties using nanofluids and (2) enhancement of the heat pipe performance. These results will be validated experimentally in the next phase of the project.

Nomenclature:

A_w= Wick Cross sectional area, m^2.
Cp = Specific Heat, kJ/kgK.
k = Thermal Conducitivity, W/mK.
L = Length of heat pipe, m.
Mo = Merit Number.
P_w = Permiability of the wick
r = Radius of pipe, m.
α_e = Capillary contacting angle- Evaporator
α_c = Capillary contacting angle- Condenser end
β = Pipe orientation angle relative to the gravity vector.
h_{fg} = Latent Heat of Evaporation or Condensation, J/kg.
σ = Surface ttension at the interface, N/m
ρ = Liquid density, kg/m^3.
μ = Liquid dynamic viscosity, Ns/m^2.
g = $9.81 m/s^2$.
Suffix
b for Base Fluid and p for Particle and N for Nanofluid

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