Proceedings of the
International Conference on Mechanical Engineering and Renewable Energy 2019
(ICMERE2019) 11 – 13 December, 2019, Chittagong, Bangladesh

ICMERE2019-PI-215

THERMAL PERFORMANCE ENHANCEMENT OF CYLINDRICAL HEAT PIPE USING TiO_2/WATER NANOFLUID

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Abstract- *The study aims at observing the behavior of nanofluid serving the improvement of the performance of cylindrical heat pipe. The working of heat exchanging devices shows better result using nanofluids rather than conventional base fluids. In this research work, two-step technique was followed to formulate nanofluid-TiO_2/water with various mass concentration of 0.1% to 0.5% for heat transfer study. For the completion of the observation an experimental arrangement was established with fill ratio 0.42, heat supplied 50.6 watt under constant operating condition. Thermal resistance and heat transfer co-efficient were two concomitant properties that had effect on nanofluid mass concentration. Temperature reading at condenser and evaporator section was noted at every 2 minutes interval by using K-type thermocouple. The heat transfer co-efficient was increased up to 42.06% and thermal resistance was reduced 27.21% in free convection for 0.5% mass concentration of TiO_2 as compared to base fluid water.*

Keywords: Thermal performance, Heat pipe, Nanofluid, Thermal Resistance, Heat transfer co-efficient.

1. INTRODUCTION

In the process of conquering invincible technical limitations many fascinating inventions were made. Heat pipe is one this kind which serves a great deal in energy conservation by its increased degree of transporting heat energy. The two phased heat transfer device was capable of deeming the muddle regarding heat conduction in space. Heat pipe is managed to transfer heat between two solid surface conjoining together. It's a copper tube which uses both the principle of thermal conductivity and evaporation-condensation cycle to carry away heat from source through capillary action. The design itself differs from that of thermos syphon which enables it to transfer heat against gravity utilizing the phase transition of the working fluid inside it.

Nano fluid being engineered suspensions of colloids of nanoparticles in a base fluid when used as working fluid, projects high heat transfer co-efficient and thermal conductivity increasing the thermal performance of heat pipe. The application of Nano fluid in heat pipe is sure to be an awe-inspiring idea because it has elevated the thermal conductivity of heat transfer fluids (HTFs) and minimized the problems associated with abrasion, clogging, eroding of pipe line due to large HTF particles. The study has enlarged scope of innovation as the structure modelling of heat pipe, rectification of air velocity during force convection and the vast variety of nanofluid composition can be put under numerous variety of experiments. Because of high component temperatures more than half of the breakdowns occur in electronic appliances. Furthermore, the current electronic field based research focuses on minimizing the size of components due to it the heat flux significantly increases. Heat pipe being two phase flow passive and a dependable heat exchanging device which can convey huge amount of heat energy effectively. Besides, the efficient working of heat pipes depend upon the working fluids properties. Thermal conductivity enhancement by using nanofluids instead of conventional fluid is the effective and most prominent process used to boost heat pipes capacity to transport heat.

It is evident from some of the most cited articles that with the inclusion of nanoparticles thermal conductivity of fluid enhanced that increased with the addition of more particle. Kumaresan et al. [1] studied analytically a cylindrical heat pipe of powdered wick filled with CuO nanofluids. They observed an optimal value of tilt angle 45° with 1.0% mass concentration that could be able to transfer 42.46 kW/m2 heat flux approximately. Naphon et al. [2] found the improvement in heat pipe thermal efficiency filled with TiO_2-refrigerant based nanofluid at an optimal value of tilt angle 60° with 50% charged volumetric ratio and the heat pipe filled with 0.1 vol.% of TiO_2 nanofluid achieved the highest efficiency that was 1.40 times higher than the conventional base fluid.

The study of H. Jouhara et al. [3] has covered heat transfer applications of heat pipe at different scales of temperature from low temperature cryogenic application to higher temperature range. The study fails from mechanical point of view as sonic vibration develops inside heat pipe but it's all way beneficial as it includes manifold observations of isothermal, temperature control, heat flux etc. A 200 mesh screen heat pipe was used by Tsai et al. [4] where gold-DI water nanofluid and observed that thermal resistance is sensitized to changes in particle size. To improve heat pipe's heat transfer criteria inside of a solar collector, the research of Sung Seek Park, Nam Jin Kim [5] tried to enhanced nanoparticle's stability of dispersion according to a chemical reforming approach in which nanofluid putted together with hydroxyl radicals incorporate with oxidized multi walled carbon nanotubes. Experiments were performed to find out the most convincing nanoparticle mixture ratio. As the volumetric fraction of the oxidized multi walled carbon nano tubes and temperature increases the thermal conductivity increases. The viscosity increased gradually upto the concentration of 0.01% then abruptly increased.

Yang et al. [6] tested forced convective heat transfer of graphite in a laminar flow where nano scale graphite fragments bestrewed into two liquids flowing through a horizontal pipe interior. Their trials showed that, with increase particle volume concentration and Reynolds number heat transfer co-efficient increases. The rating of critical and boiling heat transfer coefficient of the portion of evaporator has been marked with significant increment in the study of Liu z h et al. [7] as they used average speck diameters of 30 mm of CuO-water flowing through thermosyphon. Nguyen et al.[8] performed trials using Al2O3-water in a conventional liquid cooling system with assorted values of volume concentrations and particle size of 36mm and 47mm. Significant finding of this study is that the 36 mm particle size has greater numerical value of heat transfer co-efficient than 47 mm particle. In general with the increment of particle volume concentration, the co-efficient of heat transfer increases. Esfe et al. [9] investigated thermal conductivity and viscosity of nano fluid as physical properties trialing with volume fraction up to 10% of MgO along with water. Xie et al.[10] shown in their study that MgO has the supremacy in thermal conductivity compared to TiO2,Al2O3,SiO2,ZnO.
Chandrasekhar et al. [11] studied heat transfer mechanisms of nanofluids elaborately and enlisted numerous feasible mechanisms which promote to magnify properties of nanofluid heat transfer. Some influential factors those have effect on thermal conductivity of nanofluid are-**Brownian motion:** It is the continuous irregular movement of small sized particulates suspended within fluid which arise from collisions with the fluid molecules. Brownian motion is an influential point that elevate heat transfer of nanofluid. **Nanolayer:** Nanolayers are characterized as liquid molecules which are adjacent to nano sized particles create an organized overlay of solid structure. **Nanoclusters:** Nanofluids thermal conductivity exaggerate because of clustering of nano sized particles in fluid. **Thermophoresis**: It is the effect of temperature gradient on various component mixtures of molecules. **Specific Surface Area of Nanoparticles:** Nano particles can contribute to a huge interfacial area. **pH value of nanofluid:** Nano fluid particles will coagulate together when pH rating of nanofluid is near to the isoelectric point and repulsive forces within particle is zero.

Ullah [12] performed his experiment in small scale setup where regular water or air cooling system will not suffice. His arrangement includes replete heat pipe of 10mm diameter and 300 mm long with 60% water. As the heat input was amplified the overall heat transfer co-efficient increased.

In recent years developing of energy efficient heat pipe is very important because the rapid development of technical industries. Heat pipe is considered to be a convenient solution to heat transfer not only because of its high heat transfer capabilities but also for its manifold advantages like sustainable geometry, environmental friendliness, low operating cost, facility of using reversible heat exchanger etc. this study therefore is conducted. The objective of the study is to observe the improvement in thermal performance of heat pipe, to improve the efficiency of heat pipe using nanofluids at different mass concentration and to find at which concentration percentage of improvement is better.

2. EXPERIMENTAL FACILITIES

The basic structure of heat pipe includes three main modules- evaporation, adiabatic and condensation modules. One end of evaporation section of the pipe is in contact with the source fluid from where the working fluid consumes heat to evaporate and moves to the condensation region consequently of pressure difference. A cycle is established when the condensate returns to the evaporation region again after heat is rejected in the sink fluid. In this project Nano fluid is selected as working fluid and thermal transit can be explored in conduction, convection and pool boiling. A heat pipe made of copper is used as main equipment which is filled with nanofluid. The evaporator section was inside cork sheet box acts as insulating material. Temperature reading was taken by means of a thermocouple, attached at the condenser section of the heat pipe. Forced convection air cooling and free convection cooling system has been chosen in this project.

2.1 Fabrication of Heat Pipe

Considering all the facts and factors the experimental setups were made. Heat pipe was fabricated according to designed dimensions.

Table 1 shows all the technical specifications of the equipment's.

TABLE 1. Specification of heat pipe and other factors.

Parameter	Condition
Diameter of pipe	25.4 mm
Length of the heat pipe	450 mm
Length of condenser	170 mm
Length of evaporator	140 mm
Nanofluid	TiO_2 (0.1% to 0.5%)
Velocity of air	2.5 m/s
Corksheet box	42 cm x 35 cm

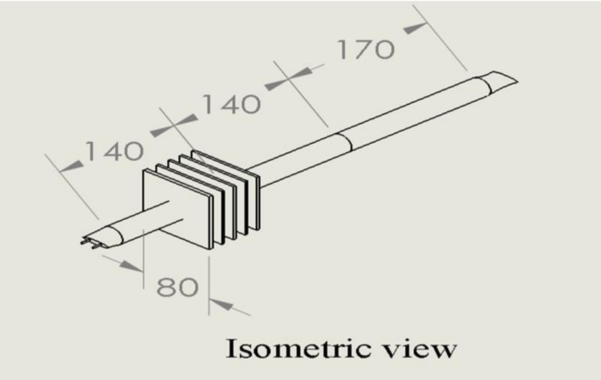

Fig. 1: Photograph of CAD model of Heat Pipe

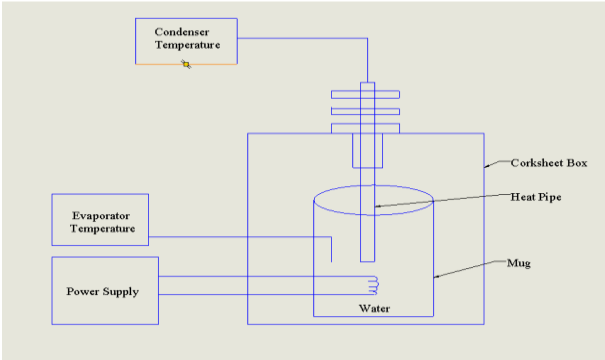

Fig.2: Block Diagram of the Setup.

2.2 Name and Use of Equipment's

The equipment that are estimated to make the heat pipe are- Copper tube, Thermocouple (K-type), Nano fluid (TiO_2 at vol. concentration of 0.1% to 0.5%), Cork sheet box, Water heater (500Watt).

Copper Tube: Copper being ductile, malleable and easily worked. It can smoothly be drawn into wire makes it convenient for electrical work in addition to its outstanding electrical properties. It constitutes the main body of the heat pipe having diameter 25.4 mm and length 450 mm. **Thermocouple:** A thermocouple is an electrical device that comprises of two dissimilar electrical conductors creating electrical junctions at distinct temperatures. A thermocouple forms a temperature-dependent voltage Due to the thermoelectric effect, it forms temperature dependent voltage which can be decode to measure temperature. **Nanofluid:** TiO_2/water nanofluid was conducted as working fluid inside the heat pipe. Nanofluid exhibited excellent thermal characteristics comparably than conventional base fluid. **Corksheet Box:** Cork sheet box is used in this experiment as a heat source. The cork sheet box is made of cork sheet of size 42 cm x 35 cm. Six cork sheet surface was used to make the box. Adhesive was used to attach the cork sheet surface.

2.3 Nanofluid Preparation:

After concluding the decisions about the setup content the nanofluid was made first by stirring it for 4 hours at 500 rpm by using magnetic stirrer in the lab and put in the heat pipe. It was prepared using the double step technique. Dry powders of nanotubes, nanoparticles, and other non- materials used in this technique are first formed by some physical and chemical procedures then this nano sized gauged powder is spread into the base fluid.

2.4 Experimental setup:

The heat pipe was placed in perpendicular direction of the cork sheet box inside which evaporated section was set which was used as a heat source. The unremitting process of water heating was going on above the evaporation section where its wall temperature of the evaporation section was assumed to be 100℃ in a 26℃ room.

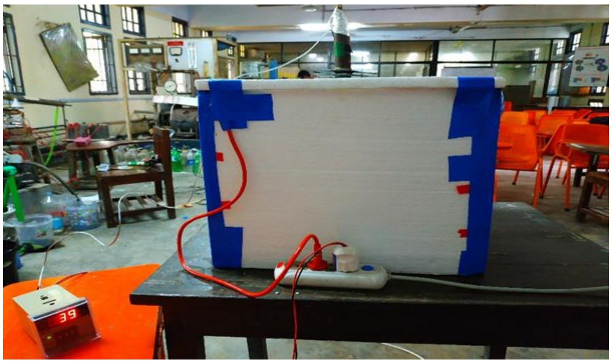

Fig.3: Photograph of Experimental Setup.

Condenser section temperature was taken at an interval of 2 minutes until the steady temperature was reached. The temperature reading at the condenser section was taken by using K-type thermocouple. The condenser section was assessed with two sets of cooling arrangements-natural and forced convection as mentioned.

3. RESULTS AND DISCUSSION

The temperature at evaporation section was assumed to be 100ºC throughout the process. Heat pipe was filled 42 percent of its total volume with TiO_2/water nanofluid. The amount of supplied heat was 50.6 watt under constant operating condition.

Table 1: Condenser section temperature of water and nanofluid of different mass concentration for free convection.

Time (min)	Water	Mass concentration (w/v)				
		0.1%	0.2%	0.3%	0.4%	0.5%
0	29	31	32	33	34	35
2	30	33	34	35	39	40
4	32	36	37	38	43	44
6	34	39	41	42	46	46
8	36	42	43	45	49	50
10	36	43	44	49	54	55

12	37	44	45	53	57	58
14	38	47	48	54	58	60
16	40	50	53	55	59	61
18	42	53	55	57	60	62
20	43	56	58	59	61	63
22	44	57	59	61	62	64
24	44	57	60	62	63	64
26	44	57	60	62	63	64

The temperature readings of water as well as nanofluid at table 1 was shown for free convection regarding to time. At every 2 minutes interval temperature was noted and found to be increased with temperature rise. As the mass concentration of nanofluid increases, temperature also increases regarding to the concentration. Temperature rise of water with time is lower than that of nanofluid.

Table 2: Condenser section temperature of water and nanofluid of different mass concentration for forced convection.

Time (min)	Water	Mass concentration (w/v)				
		0.1%	0.2%	0.3%	0.4%	0.5%
0	27	29	30	31	32	33
2	28	30	32	33	34	35
4	29	31	33	34	35	36
6	30	33	34	35	37	37
8	32	34	36	37	39	40
10	33	35	37	40	41	43
12	35	36	38	43	44	45
14	35	37	38	44	45	46
16	36	37	39	44	45	46
18	38	39	40	45	46	47
20	39	40	41	45	47	48
22	40	41	42	46	48	49
24	40	41	43	46	48	49
26	40	41	43	46	48	49

The temperature readings of water and nanofluid at table 2 was shown for forced convection with respect to time. At every 2 minutes interval temperature was noted and found to be increased with temperature rise. As the mass concentration of nanofluid increases, temperature also increases regarding to the concentration. Temperature rise of water with time is lower than that of nanofluid for forced convection also.

For performance assessment two criteria- thermal contact resistance and heat transfer co-efficient was calculated and temperature was taken in brief using k-type thermometer in this regard.

$$Q = hA(Te - Tc) \quad (1)$$

$$h = \frac{Q}{A(Te-Tc)} \quad (2)$$

$$R = \frac{(Te-Tc)}{Q} \quad (3)$$

Q is heat supplied, h is heat transfer coefficient and R is thermal contact resistance, A is surface area of evaporator, T_e is temperature of evaporator section and T_c is temperature of the condensation section where all units are considered in SI units. For performance evaluation of heat pipe different mass concentration of nanofluid was placed inside it and consequent values of h and R was calculated. Heat transfer coefficient h is an evaluative parameter for estimating convective heat transfer s between the heat pipe and nanofluid. It depends on the physical characteristics of the fluid and situation.

3.1 Effect of nanoparticle addition on the physical properties of TiO_2/water nanofluid:

In this study, two parameters i.e., heat transfer coefficient and thermal contact resistance are used for evaluating the performance enhancement. For two cooling arrangement in condenser section the results are plotted against different mass concentration of TiO_2/water nanofluid.

Figure 1 shows the thermal contact resistance decreases when nanofluid is used instead of water in free convection mode. Thermal contact resistance also decreases with increasing concentration of nanoparticle mass.

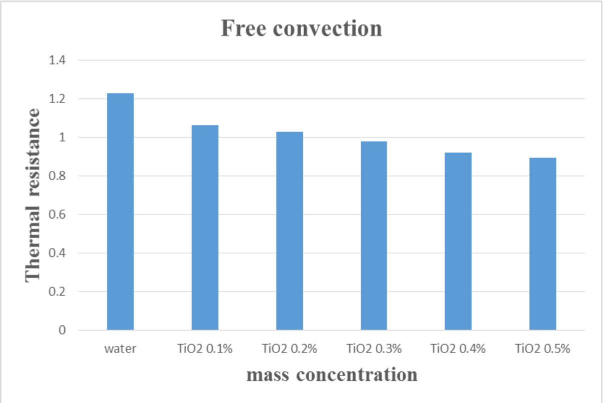

Fig.1: Variation of thermal contact resistance with different mass concentration of TiO_2 and water for free convection.

Figure 2 depicts the change in thermal contact resistance with mass concentration of TiO_2/water nanofluid for forced convection. It is found that with increasing mass concentration thermal resistance decreases. For forced convection the percentage of thermal resistance reduction is more as compared to free convection.

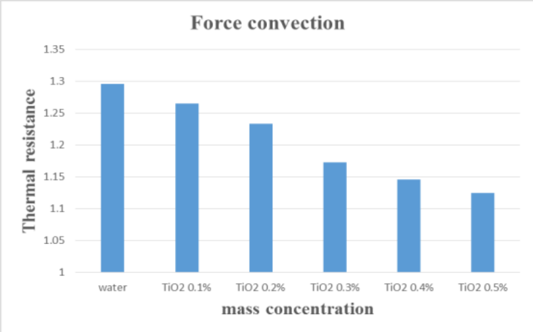

Fig.2: Variation of thermal contact resistance with different mass concentration of TiO_2 and water for forced convection.

In free and forced convection, thermal resistance decreases when nanofluid is used instead of water. The reason is, with nanoparticle being suspended in base fluid thermal conductivity of the fluid increases and heat transfer rate increases. Because of increase in heat transfer rate thermal resistance decreases radically with the increase in nanoparticle concentration.

Figure 3 shows the heat transfer coefficient increases when nanofluid is used instead of water in free convection mode. The heat transfer coefficient also increases with increasing concentration of nanoparticle mass.

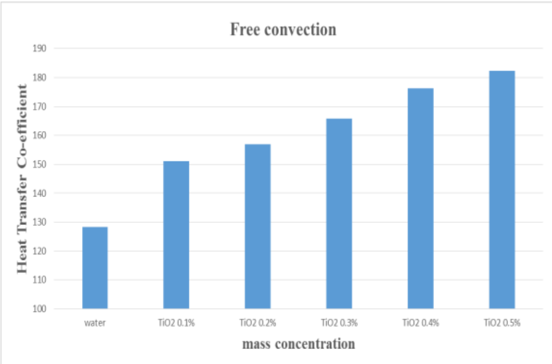

Fig.3: Variation of coefficient of heat transfer with different mass concentration of TiO_2 and water for free convection.

Figure 4 depicts the change of coefficient of heat transfer with different mass concentration of titanium oxide nanofluid forced convection. It is found that heat transfer co-efficient increases with increase in mass concentration forced convection. The percentage of increase in heat transfer co-efficient is higher in free convection than forced one.

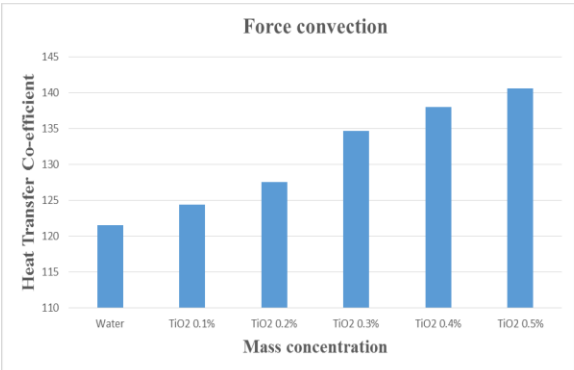

Fig.4: Variation of coefficient of heat transfer with different mass concentration of TiO_2 and water for force convection.

In two modes of convection- free and forced, heat transfer coefficient increases with high nanoparticle accumulation. The heat transfer coefficient raises as thermal conductivity of fluid increases due to suspended nanoparticle. As thermal conductivity increases, heat transfer rate also increases which amplifies the coefficient of heat transfer.

4. CONCLUSION

The study has been persued to improve the thermal performance of heat pipe, different fractional mass of nanofluid is used and percentage of enhancement is calculated. The smaller size (dia-25.4 mm, length- 450 mm) cylindrical heat pipe was used in this experiment. The TiO_2/water nanofluid has been prepared and used as a operating fluid inside the pipe. The heat pipe filled with the TiO_2/water nanofluid of different mass concentration has been assessed for thermal performance and found to be enhanced with the temperature rise. Two sets of cooling arrangements-forced and natural convection are used.

- From the experimental results, comparisons of thermal performance of heat pipe using water & different mass concentration of TiO_2 as nanofluid the heat transfer co-efficient and thermal contact resistance were estimated.
- Thermal contact resistance of TiO_2 for all performed mass concentration is lower than water. The maximum value of reduction in thermal resistance was achieved as compared to water for 0.5% mass concentration is 27.21% in free convection.
- The heat transfer co-efficient of TiO_2/water for all performed mass concentration is higher than water. The maximum enhancement of heat transfer co-efficient as compared to water for 0.5% mass concentration is 42.06% in free convection.

5. LIMITATIONS

Some limitations were experienced during this experimental analysis. An assumption of evaporator temperature was taken 100ºC. Due to limited heating capacity of heater the heat supplied was kept constant. The insulation was made by using cork sheet box because of higher cost of other insulating material and complexity to arrange the setup. The pressure of water vapor inside the box may affect the process. As thermocouple used was not attached at various points of condenser section so the temperature reading was not highly accurate.

6. REFERENCES

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7. NOMENCLATURE

Symbol	Meaning	Unit
T_e	Evaporator Temperature	ºC
T_c	Condenser temperature	ºC
Q	Heat Transfer Rate	Watt
h	Heat transfer coefficient	W/m^2K
A	Area of evaporator section	m^2
R	Thermal Resistance	K/W