Analysis of Thermal Performance of a Characteristics Heat Pipe as an Efficient Heat Transfer Device with Colloidal Nanofluid

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Abstract:-**In different processes ranging from conversion, utilization & recovery of thermal energy in various industrial, commercial & domestic applications heat exchangers are used. Economical design of heat exchangers, which can help to utilize energy, use economical material and help in reducing cost should be achieved by increase in the performance of Heat exchanger. Use of Heat transfer enhancement techniques lead to increase in heat transfer coefficient but at the cost of increase in pressure drop. Therefore, while designing a heat exchanger, using any of these techniques, analysis of heat transfer rate & pressure drop needs to be done.**

To achieve high heat transfer rate in an existing or new heat exchanger several techniques have been proposed in recent years. This work presents the study of heat transfer enhancement of a circular heat pipe using nano particles produced as a result of wire electric discharge machining, collectively called as the colloidal solution of nanoparticles.

A heat pipe is a simple heat transfer device that can transport large quantities of heat with a very small difference in temperature between the hot ends to the other end. In this case study, the concept of the evaporation of the working fluid inside the heat pipe is used to compare the heat carrying capacity of two heat pipes. The objective of this study is to compare the efficiency between the primary heat pipe with distilled water as the working fluid and the secondary heat pipe with colloidal Nano Fluid, produced as a result from wire electric discharge machining as the working medium.

The heat pipe is divided into 2-sample specimen. First specimen of heat pipe using distilled water while the other one used colloidal Nano Fluid. These two heat pipes are built without the mesh wick and are dealing with inclination of angle to see the performance of the heat pipe. Both the heat pipes were built with the total length of 600 mm length and 16 mm diameter using copper as the pipe material. Gravity pumping was used with the inclination angle to pump back the working fluid to the evaporator section. The heat pipe was positioned at different angles of 0º, 45° and 90° with the horizontal.

To achieve the objective of this study, both pipes were studied experimental to find the most efficiency between the primary heat pipe and the secondary heat pipe. The important parameter involves in the case study are the variation of Thermal Resistance and the Overall Heat Transfer Coefficient with the varying heat inputs to the heat pipes. After performing the experiments, the objective of this case study is achieved.

Keywords: **Nanofluid, nano particles, heat exchanger**

I. INTRODUCTION

A heat pipe is a heat transfer mechanism that can transport large quantities of heat with a very small difference in temperature between the hot end and the other end. In other words, it is a simple device, which can quickly transfer heat from one point to another. They are often referred to as the "superconductors" of heat as they possess an extra ordinary heat transfer capacity and rate with almost no heat loss.

It consists of a sealed aluminum or copper container whose inner surfaces have a capillary wicking material. A heat pipe is similar to a thermosyphon. It differs from a thermosyphon by virtue of its ability to transport heat against gravity by an evaporation-condensation cycle with the help of porous capillaries that form the wick. The wick provides the capillary driving force to return the condensate to the evaporator. The quality and type of wick usually determines the performance of the heat pipe, for this is the heart of the product. Wickless heat pipes are another option, which perform their action by gravity pumping of the working fluid. Different types of wicks are used depending on the application for which the heat pipe is being used.

The saturated vapor, carrying the latent heat of vaporization, flows towards the colder condenser section. In the condenser, the vapor condenses and gives up its latent heat. The condensed liquid returns to the evaporator through the wick structure by capillary action or by gravity effect in case of wickless heat pipes. The phase change processes and two-phase flow circulation continue as long as the temperature gradient between the evaporator and condenser are maintained.

1.1. Electronic and Electrical Equipment Cooling

Miniaturization of electronic components is accompanied by increased demands on heat dissipation systems due to the increased density of the components. The overheating problems associated with the dense packing of heat-generating integrated circuit chips used in the computer (CPU and GPU Cooling) have escalated dramatically. Since the reliability of these and other types of electronic components is sensitive to their operating temperature, steps have been taken to improve heat dissipation by using heat pipes. Other applications to electronic cooling have included rectifiers, thyristors, and transistors, traveling wave collectors, audio and RF amplifiers.

1.2. Aerospace and Avionics

Heat pipes are very attractive components in the area of spacecraft cooling and temperature stabilization due to their low weight penalty, zero maintenance, and reliability.

Structural is othermalization is an important problem with respect to orbiting astronomy experiments due to the possible warpage from solar heating. During orbit, an observatory is fixed on a single point such as a star. Therefore, one side of the spacecraft will be subjected to intense solar radiation, while the other is exposed to deep space. Heat pipes have been used to transport the heat from the side irradiated by the sun to the cold side in order to equalize the temperature of the structure. Heat pipes are also used to dissipate heat generated by electronic components in satellites.

1.3. Heat Exchangers

Increases in the cost of energy have initiated the use of this technology in industrial applications. Due to their high heat transfer capabilities and with no external power requirements, heat pipes are being used in heat exchangers for various applications. In the power industry, heat pipe heat exchangers are used as primary air heaters. The major advantages of heat pipe heat exchangers compared to conventional heat exchangers are that they are nearly isothermal and can be built with better seals to reduce leakage.

1.4. Medicine and Human Body Temperature Control

One of the newest applications with great potential for growth is the use of heat pipes related to human physiology. A surgical probe incorporating a cryogenic heat pipe is used to destroy tumors in the human body. The cryoprobe is a hand-held device with a reservoir of liquid nitrogen and a 12-inch heat pipe extension, which is maintained at approximately 77K for nearly 90 minutes. Another application to human with significant growth potential concerns the control of body temperature for benefits such as prevention of frostbites.

A. Problem Statement

The research is carried out to study the effect of colloidal nano fluid produced as a result of electric discharge machining on the performance of the heat pipe. This can be considered as an alternative and comparatively economic method of forming the nanoparticles. The fluid then obtained is used as the working fluid for the heat pipe and compared with another heat pipe having distilled water as the working fluid.

B. Objective of the Study

The objective of this study is to compare the thermal performance of the heat pipes under different power inputs (heat input) and three different orientation i.e. 0º, 45º and 90º angles of inclination. Total thermal performance of heat pipe for distilled water and water-based colloidal Nanofluid is predicted. This study presents a discussion on the effects of different orientations of the heat pipes. The heat carrying capacity of the heat pipe with distilled water and water based colloidal Nano fluid is compared through this study. The conclusion of the effects is done after performing the experiments.

C. Scope of Study

The scope of the study is to find whether there is an effect, i.e. whether the thermal performance of the heat pipe with water based colloidal Nanofluid increases, reduces or remains equivalent to that of a heat pipe with just distilled water as a working fluid. The effect thereof can be used in many applications such as to improve the dehumidification capacity of an air conditioner and to make it act as an efficient heat transfer device in many electrical and electronic devices.

II. METHODOLOGY

A. Research Design

The first stage of the study is divided into 2 sections, which are the literature review and the fabrication methods. The literature review section gone through in the previous chapter contains the field of work that comprises from various sources of study. It also includes with the information to suite the problem statement and purpose of study. Meanwhile, the fabrication methods are the steps to bring up the actual model and samples for the specimens in the parameter study. It can be used either in the experimental, or in the CFD analysis study for comparisons of the results.

The important parameter studied in the experimental methods are the temperature, T (°C) and time, t (min.). These values can be presented into a graphical depiction that can be plotted based from the orientation angles for heat pipe specimens.

B. Mathematical Equations

One of the methods of evaluating the performance of a miniature heat pipe as present in the current study is measuring the "Thermal Resistance (°C/W)".

The overall Thermal Resistance is comprised of series-parallel combination of different resistances which cause a temperature drop between the two ends of the heat pipe.

The overall thermal resistance of the heat pipe can be calculated from:

$$R = (Te - Tc)/Q$$

Where,

R=Total Thermal Resistance of Heat Pipe

T_e= Temperature of the Evaporator Wall

T_c= Temperature of the Condenser Wall

Q= Heat Input

In addition, the overall heat transfer coefficient is calculated by:

$h = Q/A_e\Delta T$

where,

h= Overall Heat Transfer Coefficient

A_e= Surface Area of the Evaporator Section

Q= Heat Input to the Evaporator Section

$\Delta T = T_e - T_c$

Since the axial heat flow through the heat pipe wall at the evaporator is very low [16], it can be assumed that all the heat input is transferred to the working fluid in the evaporator. Hence, the load, Q, is used as heat input to the evaporator.

Peterson [16] motivated this simplification based on steady decrease in the vapor temperature through the evaporator region and on into the adiabatic section due to slight decrease in the vapor pressure and smaller temperature gradient in the vapor region than in the liquid region along the pipe as well as the fact that the vapor temperature is lower than the external wall temperature in the evaporator while it is higher than the external wall temperature in the condenser make it possible to employ this assumption with acceptable accuracy. Although, the inner wall surface temperature of the evaporator should be used in the calculation of the evaporator heat transfer coefficients since the radial thermal resistance of the heat pipe wall is very low, the measured outer surface temperature can be used with an acceptable accuracy.

Lastly, the heat pipe effective thermal conductivity is defined as:

$$K_{eff} = (L_{eff})/A_c R$$

Where,

Ac = Cross Section Area of the Heat Pipe

L_{eff} = Effective Transport Length, and is given by

$L_{eff} = 0.5L_{evaporator} + L_{adiabatic} + 0.5L_{condenser}$

2. Experimental Setup

2.1. Heat Pipe Preparation

In the current experimental setup, two heat pipes have been fabricated in house with the description given herewith. One heat pipe contains distilled water as the working fluid and the second contains deionized water from micro electrical discharge machining.

Total length of the Heat Pipe (L) : 600 mm

Evaporator Section Length (L_e) : 150 mm

Adiabatic Section Length (L_a) : 300 mm

Condenser Section Length (L_c) : 150 mm

Internal Diameter (d_i) : 14 mm

Outer Diameter (d_o) : 16 mm

Wall Thickness of Heat Pipe : 1 mm

Total Internal Volume of Heat Pipe : $\pi * r^2 * h = \pi * 49 * 600 =$ 92.36 ml

Effective Length of Heat Pipe : $0.5L_{evaporator} + L_{adiabatic} + 0.5L_{condenser}$

0.5 x 150 + 300 + 0.5 x 150 = 450 mm

Surface Area of Evaporator :

$\pi * d_o * L_e = \pi * 0.016 * 0.15 = 0.0075\ m^2$

In general, fill ratios of working fluid greater than 85% of volume of evaporator [18] show better results in terms of increased heat transfer coefficient, decreased thermal resistance and reduced temperature difference across the evaporator and condenser.

Internal Diameter of Evaporator Section: 14 mm

Evaporator Section Length : 150 mm

Volume of Evaporator Section (Approx.) : $\pi * r^2 * h = \pi * 49 * 150 = 23$ ml

Volume of Working Fluid (Approx.) : 0.85*23=20 ml

Both the heat pipes are fabricated using the same volume of working fluid.

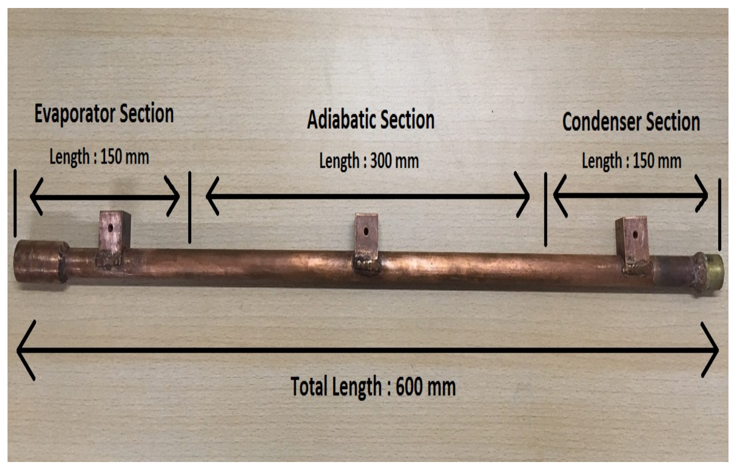

Figure 1. Fabricated Heat Pipe with Different Sections and Length

The copper tube is sealed at both the ends using copper end caps with the help of brazing.

2.2. Vacuum Conditions in Heat Pipe

After preparing the heat pipe as descried above, vacuum needs to be created in the heat pipe.

As stated above, fill volume of working fluid greater that 85% of the volume of evaporator show better result in terms of heat transfer coefficient, decreased thermal resistance and reduced temperature difference across the evaporator and condenser.

The end plugs of the heat pipes are having a small drill which have then been screwed. This was done to create the vacuum condition in the heat pipe. The heat pipes with working fluid were heated and vapour were allowed to move out from the small drill. Once continuous vapour was observed coming out, the ends were screwed securely and locked to prevent any leakage.

Now the heat pipe is filled with both the liquid and the vapor phase of the working fluid.

The figure1. shows the heat pipe sealed at both ends and with working fluid inside it. Also, the heat pipe is covered with glass wool in the adiabatic section to minimize the effect of heat loss during the experiment.

III. OBSERVATION DATA

3.1. Introduction

The experiment with the two heat pipes were conducted for three orientation i.e. at 0^o, 45^o and 90^o angle of inclinations. Heat input was given using a band type heater with different power inputs and the temperature at the three sections of the heat pipe was tabulated and is shown below.

3.2. Data Collection

3.2.1. Heat Pipe with Distilled Water

3.2.1.1. Data Collection at 0^o Inclination

S. No	Current (A)	Voltage (V)	Power (W)	Temperature Reading (ºC)		
				T1	T3	T5
1	0.4	20	8	35.3	32.3	28.5
2	0.4	30	12	36.9	32.9	29
3	0.4	40	16	42.2	36.1	32
4	0.4	50	20	47.1	39	34.5
5	0.4	60	24	53.2	43	39

Table 3.1. Heat Pipe with Distilled Water at 0º Inclination

3.2.1.2. Data Collection at 45^o Inclination

S. No	Current (A)	Voltage (V)	Power (W)	Temperature Reading (ºC)		
				T1	T3	T5
1	0.4	20	8	36	33.3	30.3
2	0.4	30	12	38.5	33.9	31.2
3	0.4	40	16	42.8	37.8	33.3
4	0.4	50	20	46.6	40.7	35.3
5	0.4	60	24	50.9	43.5	38

Table 3.2. Heat Pipe with Distilled Water at 45º Inclination

3.2.1.3. Data Collection at 90^o Inclination

S. No	Current (A)	Voltage (V)	Power (W)	Temperature Reading (ºC)		
				T1	T3	T5
1	0.4	20	8	36	33	29.9
2	0.4	30	12	39	34	31.5
3	0.4	40	16	42.6	37.6	32.9
4	0.4	50	20	47.3	40	35.5
5	0.4	60	24	52	42	38.6

Table 3.3. Heat Pipe with Distilled Water at 90º Inclination

3.2.2. Heat Pipe with Deionized Water from EDM

3.2.2.1. Data Collection at 0^o Inclination

S. No	Current (A)	Voltage (V)	Power (W)	Temperature Reading (ºC)		
				T1	T3	T5
1	0.4	20	8	34.7	32	29.6
2	0.4	30	12	36.5	33	29.4
3	0.4	40	16	41.6	37.3	32.8
4	0.4	50	20	46.6	39.6	35.5
5	0.4	60	24	51.2	46.2	39.2

Table 3.4. Heat Pipe with EDM-DI Water at 0º Inclination

3.2.2.2. Data Collection at 45^o Inclination

S. No	Current (A)	Voltage (V)	Power (W)	Temperature Reading (ºC)		
				T1	T3	T5
1	0.4	20	8	34.2	32.5	30
2	0.4	30	12	37	33.5	31.2
3	0.4	40	16	40.5	36.7	33.2
4	0.4	50	20	42.5	39.1	33.2
5	0.4	60	24	47	43	37.2

Table 3.5. Heat Pipe with EDM-DI Water at 45º Inclination

3.2.2.3. Data Collection at 90^o Inclination

S. No	Current (A)	Voltage (V)	Power (W)	Temperature Reading (ºC)		
				T1	T3	T5
1	0.4	20	8	34.6	32.5	30
2	0.4	30	12	37.9	33.5	31.5
3	0.4	40	16	40.4	36	32.3
4	0.4	50	20	44.4	38.4	34.3
5	0.4	60	24	49	41.3	37.4

Table 3.6. Heat Pipe with EDM-DI Water at 90º Inclination

IV. RESULTS

4.1. Axial Temperature Profiles

Axial temperature profiles are drawn from the data of temperatures that is obtained at different axial distances on the heat pipe body.

The axial temperature distribution along the heat pipe for distilled water as the working fluid is shown below in figures 4.1 to 4.3, at different angles of inclination.

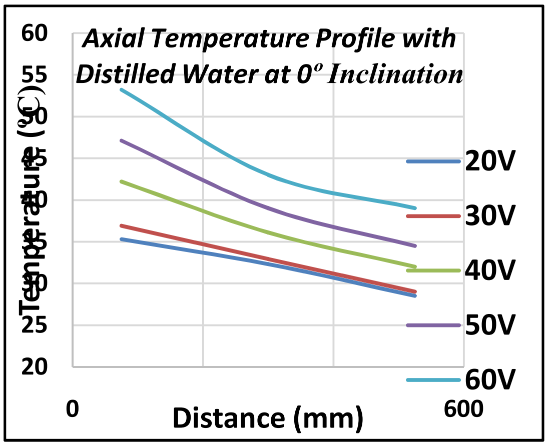

Figure 4.1.

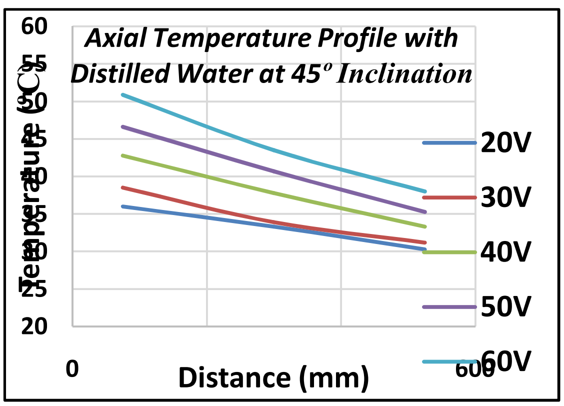

Figure 4.2.

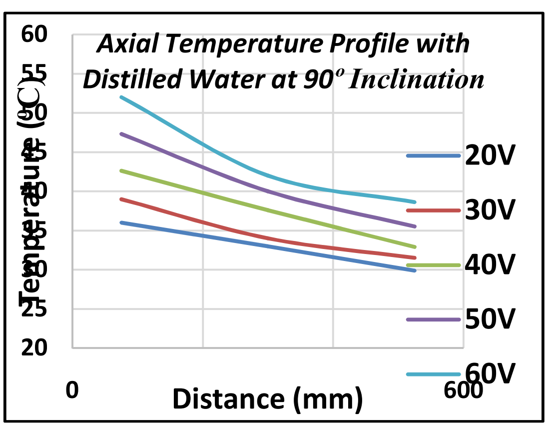

Figure 4.3.

The above figures shows that the slope of axial temperature distribution increases with heat input and larger temperature difference is observed across the condenser and the evaporator section. The trend is obvious since greater slope is required for greater heat transfer.

From the above graphs, it can also be figured out that heat pipe with 45º angle of inclination shows lower slopes at the different power inputs when compared with slopes of 0º and 90º angles of inclination. This clearly indicates the effective augmentation of heat transfer at even reduced temperature slopes. The rate of heat transfer at 45º angle of inclination is more when compared with the other angles of inclination at same power inputs.

The axial temperature distribution along the heat pipe for EDM-Deionized Water as the working fluid is shown below in figures 4.4 to 4.6, at different angles of inclination.

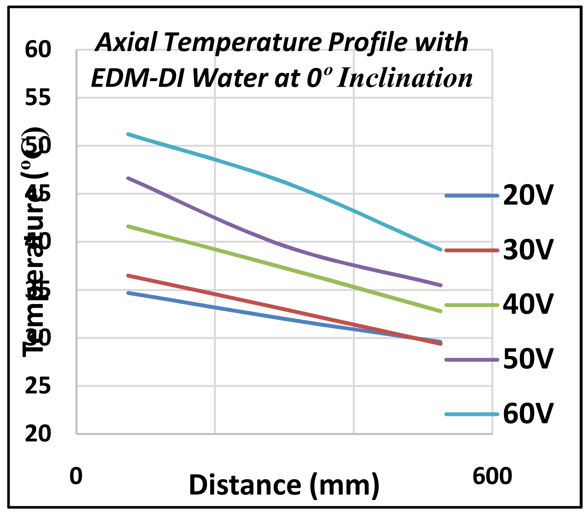

Figure 4.4.

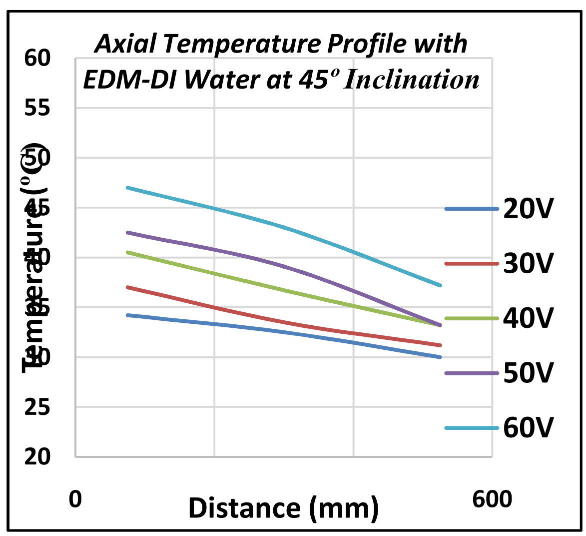

Figure 4.5

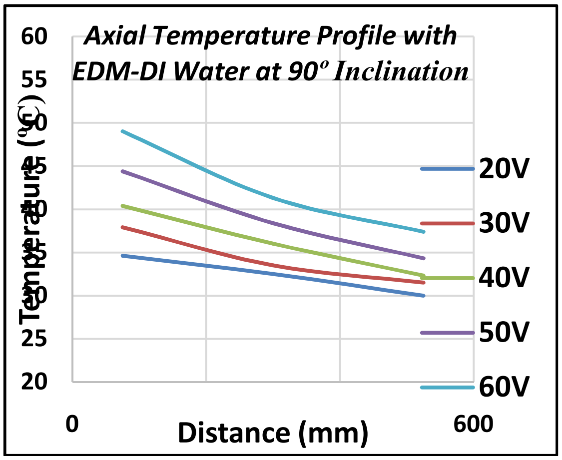

Figure 4.6

From the above figures, it can be concluded that the axial temperature profile for EDM Deionized water as the working fluid for the heat pipe follows a similar trend to that when Distilled Water is used as the working fluid. The axial temperature distribution increases with heat input and larger temperature difference is observed across the condenser and the evaporator section and the trend is obvious since greater slope is required for greater heat transfer.

The heat pipe with EDM Deionized water as the working fluid at 45º angle of inclination also shows lower slope when compared with the 0º and 90º angles of inclination. This shows the effective heat transfer is taking place even at reduced slopes (at 45º angle of inclination) when compared with the other two.

On comparing the graphs for Distilled Water (Figure 4.1 to 4.3) with the graphs for EDM Deionized Water (Figure 4.4 to 4.6), it can been seen that lower slopes is observed in all the angles of inclination with EDM Deionized Water as the working fluid at the same power inputs to the heat pipes at the evaporator sections. This also shows heat carrying capacity of the former heat pipe is better when compared with the latter at tested angles of inclination and given power inputs. For both the heat pipes, the slopes increase when power is increased at the evaporator section.

V. CONCLUSION

The following are the main conclusions of the experiment that has been carried out to assess the performance of the heat pipes:

1. The experimental results show that the Thermal Resistance of the heat pipes decrease as the power input to the heat pipe at the evaporator section is increased. This occurs in both the heat pipes which have been fabricated for the experiment. In addition to this, it is observed, the heat pipe with EDM Deionized Water as the working fluid performs better than the heat pipe with Distilled Water as the working fluid. The reason behind this is the formation of nanoparticles during the electric discharge machining process. The nanoparticles absorb the heat through the walls of the heat pipe and in turn reduce the wall temperature and then gets carried away towards the condenser section where they reject heat. Thus they effectively transport more heat compared to when distilled water is used as the working medium of the heat pipe.
2. The heat pipes perform better when they are operated at 45º inclination with the horizontal. Both the heat pipes fabricated here follow a similar trend. Least thermal resistance was observed at 45º inclination, followed by vertical installation (90º) and the highest in the horizontal installation (0º).
3. It was observed, since the thermal resistance of the heat pipe decreases with the increase in input power, the overall heat transfer coefficient increases. An average increase of 15% overall heat transfer coefficient was observed in heat pipe with EDM Deionized Water as the working medium over Distilled water at horizontal installation (0º), 22% when operated at an angle of 45º with the horizontal and 17%, when operated vertically (90º).
4. From the above discussion, it can also be stated that the thermo-physical property of EDM Deionized Water is better when compared with Distilled Water.

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