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The Effect Of Different Inclination Angles On Heat Transfer Enhancement Of Ferrofluid In A Closed Helical Loop Oscillating Heat Pipe Under Magnetic Field

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1. **ABSTRACT**

The effect of the copper closed-loophelical oscillating heat pipe (HOHP) under the magnetic field for inclination angles varying from 0^0 to 90^0 under different heat inputs from 10w to 90w are discussed in this paper. The working fluid was Fe_2O_3/Kerosene nano - fluid with a filling ratio of 60% by total volume. The helical oscillation heat pipe's thermal efficiency increase was measured. The heat transfer coefficient of the heat pipe was tested both with and without the magnetic field. By exposing the ferro-nano particles to a magnetic field, the vapour temperature was measured directly at the centre of the oscillating heat pipe. Fe_2O_3 nanoparticles were shown to improve thermal resistance and, as a result, thermal performance as well as the heat transfer coefficient of the pipe. Especially in the presence of a magnetic field. The heat transfer coefficient of the heat pipe rose as the input heat flux increased. The results also showed that the inclination angle of the heat pipe had a considerable impact on its performance.

Key Words: Helical Oscillation heatPipes, Magnetic field, Thermal Resistance, Inclination Angle.

2. INTRODUCTION

The passive two-phase heat transfer devices that can transmit heat without requiring external power. They're typically employed in electronic systems as a heat management method. As current electronic systems get more compact, more heat is generated in a tiny place, such as a computer processor. To move this heat out of the system, certain reliable thermal management techniques are necessary. Heat pipes can be an effective and dependable option in such situations. Angier March Perkins, a single-phase heat transfer expert, invented the first heat pipe in 1839. Angier March Perkins was a single-phase heat transfer expert. Many scholars worked on heat pipes and single-phase heat transfer principles, but the Perkins tube was created in 1936 by Jacob Perkins, a descendent of Angier March Perkins. Water was employed as the working fluid in Perkins tubes, and it travelled via twisted metal tubes to and from the evaporator and condenser portions. For the creation of conventional heat pipes, it was the basic two-phase heat transfer model. CHP (conventional heat pipe) development began in the 1960s. Heat pipes were the starting point for numerous aerospace businesses. Heat pipes were invented and used to manage heat in spacecraft. Lots of work has been done over the last two decades to overcome the limitations of traditional heat pipes [1], which include liquid and vapour flow separation, wick structure design, tube orientation, heat pipe size and weight, and so on. As a result, new and more efficient types of heat pipes, such as loop heat pipes, capillary pumped loop heat pipes, and micro heat pipes, have been developed. Aka chi and his colleagues. In 1990, a new type of heat pipe called an oscillating or pulsing heat pipe was invented (HOHP or PHP). Because of its capacity to dissipate a large amount of heat, HOHP has a wide range of applications in modern electronics systems. The construction and operation of helical oscillating heat pipes will be described in this review paper, which will also outline the work done by various researchers on oscillating heat pipes to improve their efficiency. Previous research suggests that ferrofluids are effective coolants [2,3].

2.1. HEAT PIPE

Heat pipe is a two-phase passive heat transmission device that does not require any external electricity to operate. It features a lot of flexibility, a straightforward design, and is simple to use. As shown in fig.1traditional heat pipe comprises of a sealed container, wick structure, and working fluid [5]. Heat pipes often use containers with a cylindrical form, but they can be any shape or size. Condenser, Evaporator, and Adiabatic portions are the three primary sections of a heat pipe. The wick structure, which is a porous structure that allows working fluid to flow from the condenser to the evaporator and vice - versa, is located on the container's inner periphery.

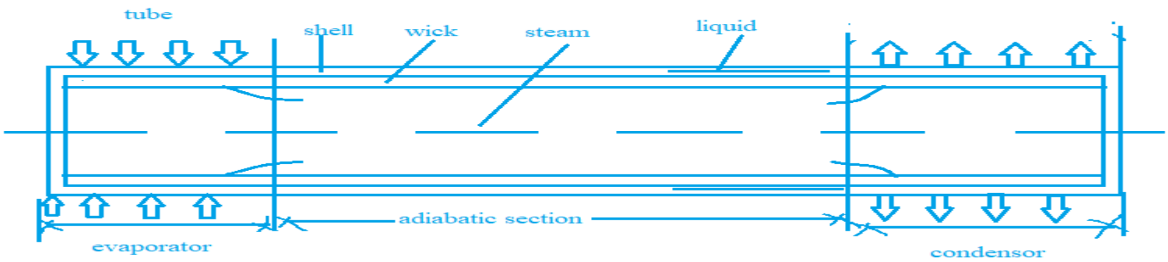


Fig no 1) heat pipe

The working fluids come in a variety of forms. [5] which can be used as a heat transfer medium in heat pipes. The temperature range for which the working fluid will be used is the most important factor to consider. Single or several heat sources and heat sinks can be used in heat pipes. The adiabatic section primarily serves as a conduit for the working fluid. The evaporator section's working fluid absorbs heat from the cylinder wall and wick structure, causing the working fluid to evaporate and the vapour pressure to rise. The working fluid is driven from the evaporator to the condenser section by the vapour pressure created in the container, where it loses its heat to the condensate and is converted back to liquid. The pressure that builds up in the wick structure pumps this liquid back into the evaporator region, completing the cycle and allowing heat to be transferred from the evaporator to the condenser section to be transferred again and again. In the heat pipe, vapour pressure varies mostly owing to friction, inertia, vapour generation in the evaporator section, and vapour transformation to liquid in the condenser section, whereas liquid pressure varies primarily due to friction. However, as previously stated, conventional heat pipe (CHP) has a number of advantages, including ease of construction, flexibility, and control. It also has several disadvantages, such as difficulty in wick structure design, mixing of vapour and liquid streams of working fluid, and efficiency. Many researchers worked on heat pipes to overcome their limitations and improve their efficiency, resulting in the development of novel heat pipe kinds [6]. Capillary-Driven Heat Pipe, Annular Heat Pipe, Vapor Chamber, Rotating Heat Pipe, Gas-Loaded Heat Pipe, Loop Heat Pipe, Capillary Pumped Loop (CPL) Heat Pipe, Pulsating Heat Pipe, Micro and Miniature Heat Pipes, Micro and Miniature Heat Pipes, Micro and Miniature Heat Pipes, Micro and Miniature Heat Pipes, Micro and Miniature Heat Pipes, Micro and Miniature Heat Pipes, Micro and Mini. Nonconventional Heat Pipes, Inverted Meniscus Heat Pipes, and so on. Various types of heat pipes have been developed by various researchers, depending on the use and operational limitations.

2.2. OSCILLATING OR PULSING HEAT PIPE (OHP/PHP)

A modern type of two-phase heat transmission equipment is the oscillating or pulsating heat pipe. It is made up of meandering capillaries. Tubes that are parallel to one another CHP split by OHPEvaporator, adiabatic, and evaporator sections are the three primary parts. Especially the section on the condenser in many aspects, it varies from CHP. like;

There is no wick structure.

1. a large number of capillary tube turns,
2. High heat transmission rate, for example.
3. OHP can be generated in at least three different ways:

- Closed loop heat pipe (CLOHP/CLOHP), also known as closed loop oscillating/pulsating heat pipe. Two capillary tube ends are frequently closed in this method, either at two separate ends or by merging two ends at a common point.
- Open loop heat pipe (OLOHP/OLPHP), also known as open loop oscillating/pulsating heat pipe. Two ends of the tubes are exposed to the surroundings
- Flow control valve in a closed loop. A flow control valve is used to regulate the flow of the working fluid in this situation.

CLOHP is more efficient than other forms of oscillating heat pipes, according to OHP.

The construction of a CLOHP is simple, but understanding the working concept of a CLOHP requires knowledge of its thermodynamics, fluid dynamics, and heat transport principles [6], which are all difficult to understand.

2.3. PHP'S OPERATIONAL METHOD

A PHP is partially filled with the working fluid after it has been emptied. In tiny diameter pipes, surface tension forces cause liquid slugs and vapour plugs to develop in the tube [8]. PHP's operating principle can be described as a constant oscillating motion of its working fluid, with phase change and forced convection heat transfer providing heat transport capabilities. The thermodynamic events in the PHP provide the necessary force for pulsing motion production and perpetuation [7].There is a temperature gradient between the evaporator and the condenser since PHP is not an isothermal system. Furthermore, there is a temperature differential between the locations of each turn. As a result, an inconsistent pressure difference is formed, which is accountable for the PHP's oscillating motion. The system tends to become unsteady as it heats the evaporating area and cools the condensing section [8]. Furthermore, there is always a tendency in real systems to generate chaos and enhance entropy [7]. A continual oscillating flow is produced in the PHP as a result of all of the above elements.Because the vapour plug is enveloped by a thin coating of liquid, it is not in direct touch with the pipes inside surface. The liquid slugs also form a meniscus shape due to the surface tension effect. The thickness of the liquid film and the curvature angle between the liquid slugs and the inner wall are determined by the working fluid characteristics and mutual actions of the wall and fluid. Furthermore, gravity effects must be taken into account [8].

3. EXPERIMENTAL ANALYSIS

3.1. EXPERIMENTAL SETUP

A five-turn OLPHP is made by bending a copper tube into a serpentine shape at first. The copper tube's internal and external diameters are set to 1.78 and 3.1 mm, respectively. These dimensions ensure that the working fluid flows in a slug plug pattern [7]. Temperature readings are taken with six K type thermocouples, three in the evaporator (Te1, Te2, and Te3) and the remainder in the condenser (Tc1, Tc2, and Tc3). At the evaporator, a nickel chrome electrical heater is wrapped around the copper tube, while the condenser provides cooling water flow. In order to supply desired power in an electrical heater, a DC power supply is used. The configuration of the heat pipe is CLPHP is separated into three sections: evaporator, condenser, and adiabatic portion, each measuring 150, 150, and 150 mm in length. HOHP container Copper Every loop serpentine helical shape with five turn and pitch distance 5mm and radius 50mm. Wall thickness 1.25 mm Liquid filled ratio 50%During the experiment, the evaporator and adiabatic part are insulated to avoid heat loss. The experimental set-up is depicted schematically in Fig. 2.

3.2. WORKING FLUID FILLING RATIO

The volume of working fluid charged inside the tube divided by the total volume of HOHP tubes is known as the filling ratio of working fluid. If the filling ratio is too low, there will be insufficient liquid slugs in the evaporator zone to initiate fluid oscillation, and the evaporator will dry out. There will not be enough vapour bubbles to pump the liquid if the filling ratio is too high, and the heat pipe will behave as a single phase thermosyphon. As a result, the filling ratio in HOHP must be carefully chosen. In general, a working fluid filling ratio of 60% is preferred for developing various types of HOHP.Wilson et al. [9] visualised and examined four HOHPs to see how fluid movement of vapour bubbles and liquid slug affects temperature distribution and heat transmission performance. They employed HOHP with nanofluids with and without magnetic field as the working fluid in both open and closed ends. They discovered that both the working fluid and the connecting turns in closed loop HOHP had reduced mobility. With water as the working fluid, they discovered the same flow pattern in closed and open loop HOHP. They came to the conclusion that improving the flow in connecting turns would improve HOHP performance.However, more research into the ferrofluids' convective heat transfer in an inclined HOHP is required. In the current work, a ferrofluid containing kerosene and iron (III) oxide was applied to an inclined, closed-loop HOHP in the presence of a magnetic field in order to determine the system's thermal efficiency and determine the critical HOHP angle. This is the angle at which the greatest amount of heat is transferred [10]. At a filling ratio of 60%, the changes in thermal resistances, the difference in vapour temperature between the evaporator and the condenser, and the heat transfer coefficient in different angles were investigated.

3.3. NUMBER OF OSCILLATING HEAT PIPE TURNS

The number of turns in pulsing heat pipe tubes can alter HOHP's thermal conductivity as well as the gravitational force's effect. If the number of spins is increased, each tube turn will absorb less heat, resulting in vapour bubbles or liquid slug in the tubes. The primary operating principle of HOHP is pressure differential, which is created by heating these tubes. If the number of tubes is low, HOHP will not be able to operate in all orientations; however, if the number of tubes is high, it will be able to operate in all orientations.Charoensawan et al. [11] studied the effects of internal diameter, gravity, working fluid, and number of turns on the thermal performance of oscillating heat pipes. They discovered that gravity has an impact on HOHP performance, and that there is a crucial number of turns required to bridge the gap between vertical and horizontal orientations.

3.4. EVAPORATOR AND CONDENSER

These variables have a significant impact on HOHP performance and can alter flow patterns within the heat pipe. If the evaporator does not receive enough heat fluxes at the start, the oscillating motion of the working fluid will not begin, and if the condenser does not dissipate enough heat, the heat transfer from the OHP will be reduced.Kim et al. [12] investigated the influence of temperature fluctuations in the heating and cooling sections on the performance of oscillating heat pipes by applying periodic fluctuations and random noises to the temperatures of the heating and cooling sections. They looked examined the effects of the periodic component's amplitude and frequency, as well as some random component standard fluctuation, on the heating and cooling sections.They looked examined the effects of the periodic component's amplitude and frequency, as well as some random component standard fluctuation, on the heating and cooling sections. They discovered that when the amplitude and frequency of the periodic variation of the wall temperature increases, the frequency of the liquid slug oscillation decreases. The shift in standard deviations, on the other hand, had no effect on the PHP's performance.

3.5. EXPERIMENTAL PROCEDURE

Before charging the fluid into the HOHP, the device was emptied by providing 0.5 Pa suction pressure for 15 minutes via a vacuum pump connected to a 3-way valve. The vacuum pump was then isolated using the 3-way valve, and the fluid was charged into the HOHP (see Fig. 2). An electrical monitoring system and a Variac were used to link an electric heater to the source of energy in order to investigate the effect of varied heat loads on the evaporator segment. The heat input was calculated using standard current and volt metre data. The tests were carried out with different heat inputs ranging from 10 to 90 W. The current and voltage uncertainties were 0.016 A and 0.4 V, respectively. Temperatures at the condenser and evaporator were monitored using a set of K-type thermocouples, a display system, and a portable data recorder. The temperature measurement uncertainty was determined to be 1 K, as defined by the temperature monitoring plan. The geometric dimensions of the HOHP are provided. The steady state is defined as a temperature change of less than 0.1 °C during 10 minutes [13]. The power is then escalated to the next level, and the heat pipe's performance is assessed. The results are published after repeating the operation with 10–90 W heat inputs and 0^0–90° pipe inclinations. In this investigation, Fe2O3 nanoparticles (2 vol. percent), Oleic acid as a surfactant, and Kerosene as a base fluid were used. The characteristics of Fe_2O_3 nanoparticles are presented. A stirrer was used to mix the Fe_2O_3 nanoparticles with the base fluid. The fluid was also sonicated for 5 hours using an ultrasonic oscillator [14]. The power supply for this bath sonicated was 45 kHz, and the operational frequency was 45 kHz. The sedimentation level of the suspension tested in this study is depicted. The nanoparticles clearly dispersed well in organic thinners. A 0.374 T magnetic field was created by a 2-A electrical current in the current study. The HOHP was shut off for five days after each run. To repeat the test, the heat pipe was turned back on. The results of the testing showed no discernible change. The exceptional repeatability could be owing to the fact that the random mobility of nanoparticles in the base liquid, along with the effect of buoyancy, resulted in a homogeneous nanofluid after nanoparticles remained stationary for an extended period of time. The test results can be easily repeated for a uniformly dispersed nanofluid.

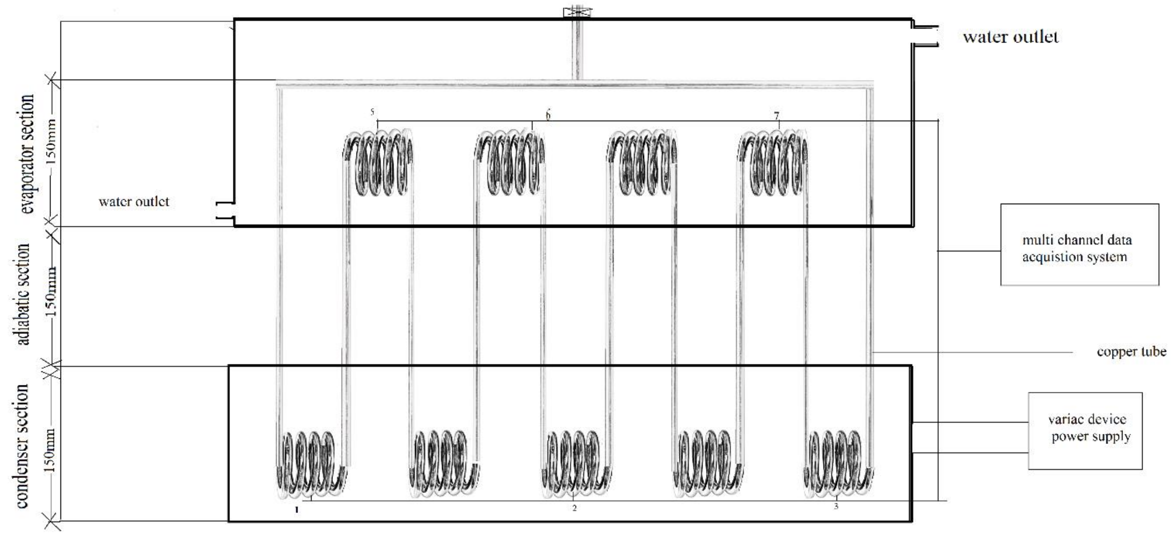


Fig.no.2. schematic of the experimental setup

4. RESULTS AND DISCUSSIONS

The data from four condenser thermocouples were used to calculate the average condenser temperature (Tc-avg). The temperature remained steady during the test due to the relatively large flow of water in the condenser. The mean evaporator temperature (Te-avg) was calculated using the signals from the four evaporator thermocouples. The observed temperatures in this study indicate the HOHP's start-up performance. This is because the temperature of the working medium rises, allowing more heat to be evacuated in the condenser section.

$$T_{c\text{-}.avg} = \frac{\text{sum of temperature in condensor section}}{\text{total number of temperature}}$$

$$T_{e\text{-}avg} = \frac{\text{sum of temperature in evaporator section}}{\text{total number of temperature}}$$

The thermal resistance of the HOHP was calculated as a measure of thermal performance.

$$R = \frac{T_e - T_c}{Q_{in}}$$

Where

Q_{in}=VI

I stands for the current measured by the digital multimeter, and V stands for the voltage of the input to the electrical flat heater. V denotes the voltage of the input that goes into the electrical nichrome wire, and I represents the electricity current measured by the digital multimeter.

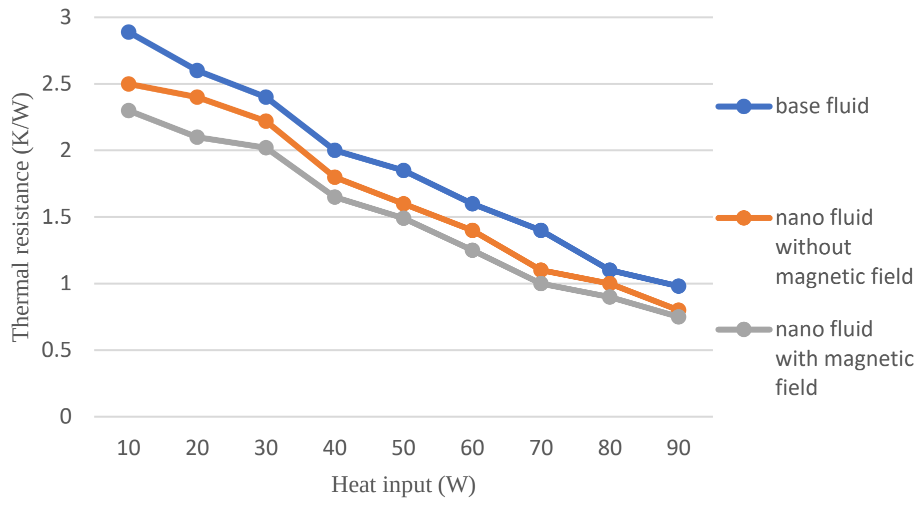


Fig.no.3a) thermal resistance at 0^0 angle

At 0^0 angle thermal resistance We noticed that the thermal resistance of the base fluid, nano fluid with magnetic field, and without magnetic field changes with each heat input. When three base fluids are compared, the thermal resistance of the remaining two fluids in these processes is increased.

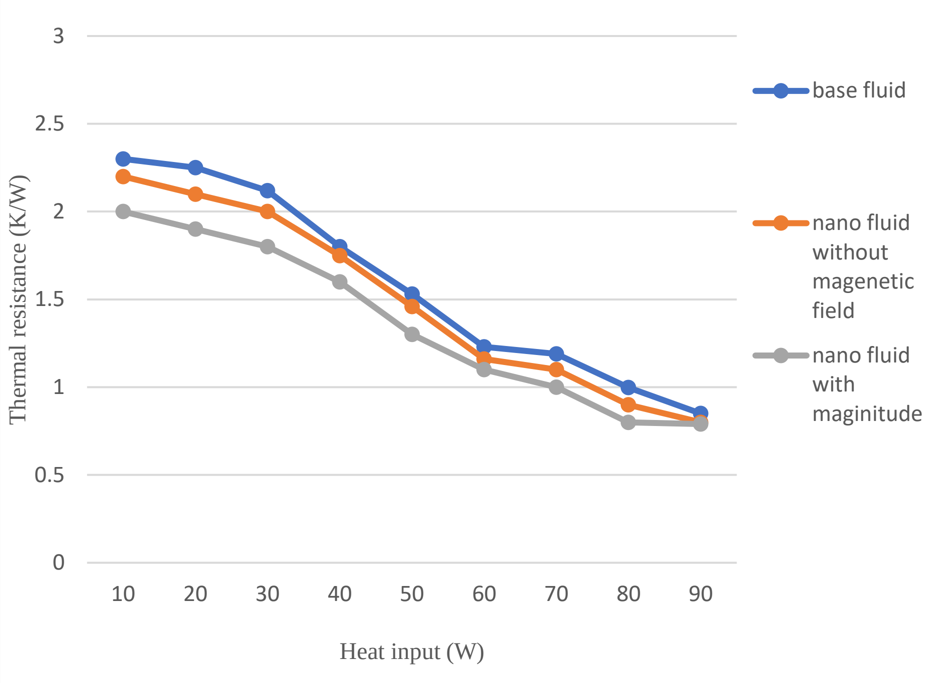


Fig.no.3b) thermal resistance at 15^0 angle

we noticed that the thermal resistance of the base fluid, nano fluid with magnetic field, and withoutmagnetic field changes with each heat input at a 15-degree angle. When three base fluids are compared, the thermal resistance of the remaining two fluids in these processes is greater. Thermal resistance decreases as compared to 0 angle.

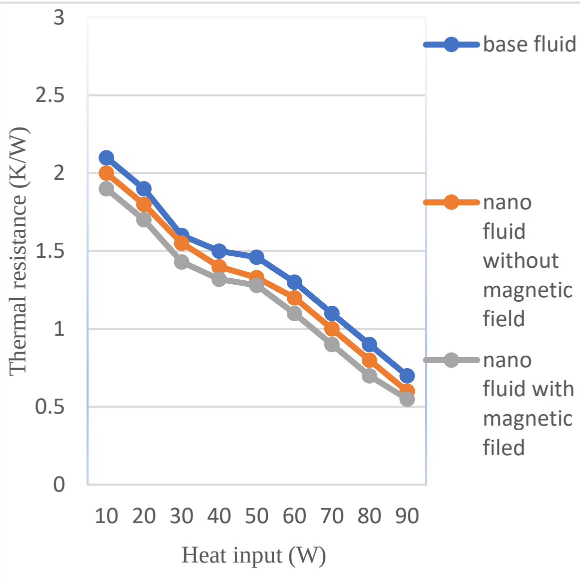


Fig.no.3c) thermal resistance at 30^0 angle

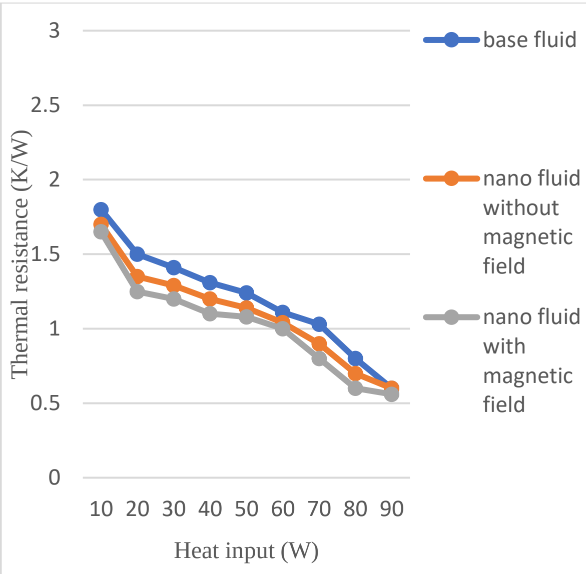


Fig.No.3d) thermal resistance at 45^0 angle

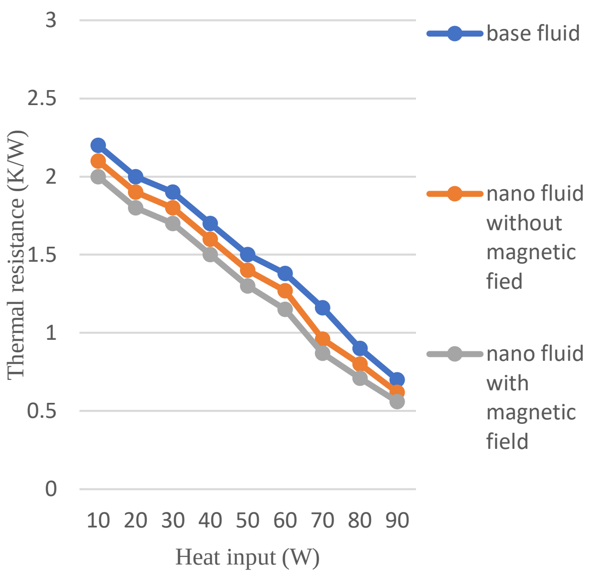


Fig.No.3e) thermal resistance at 60^0 angle

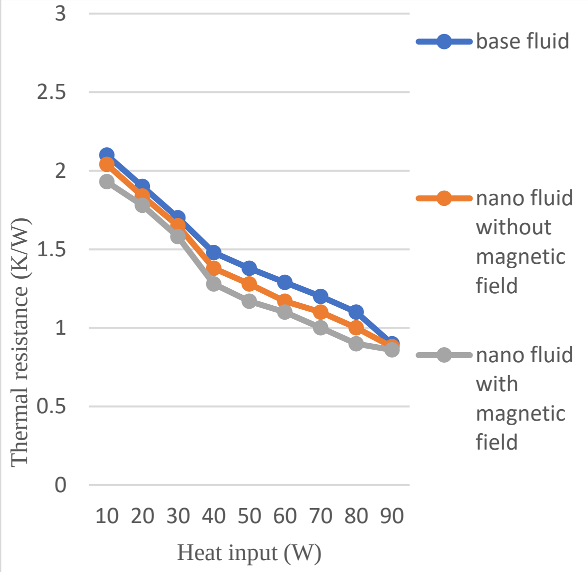


Fig.No.3f) thermal resistance at 75^0 angle

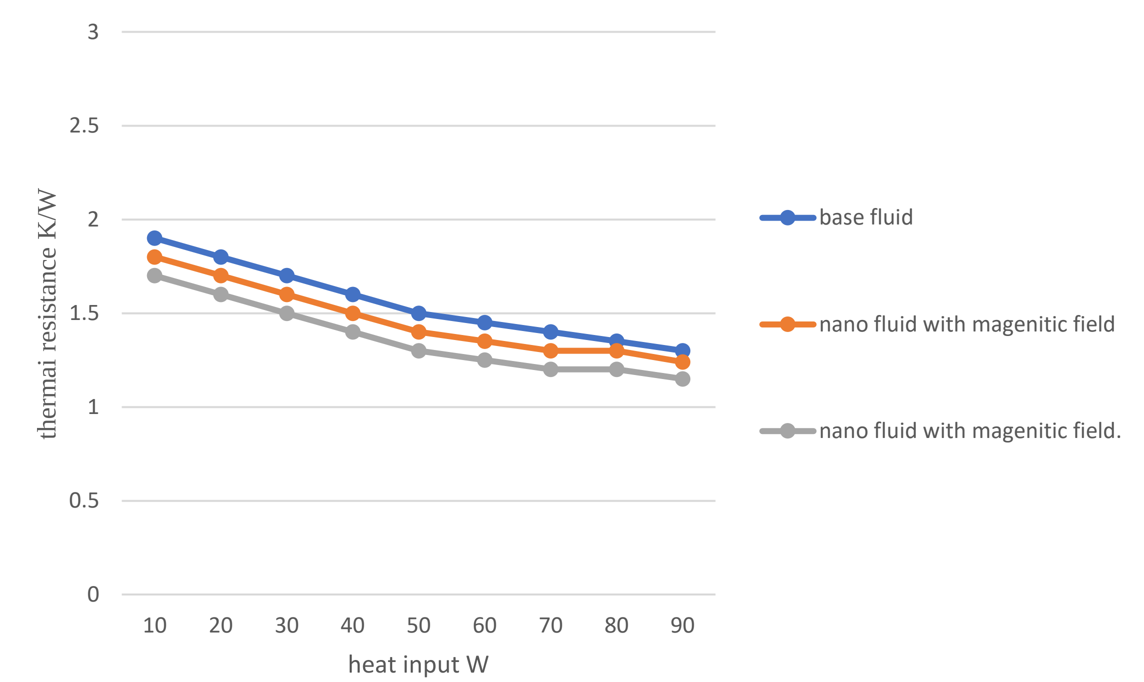
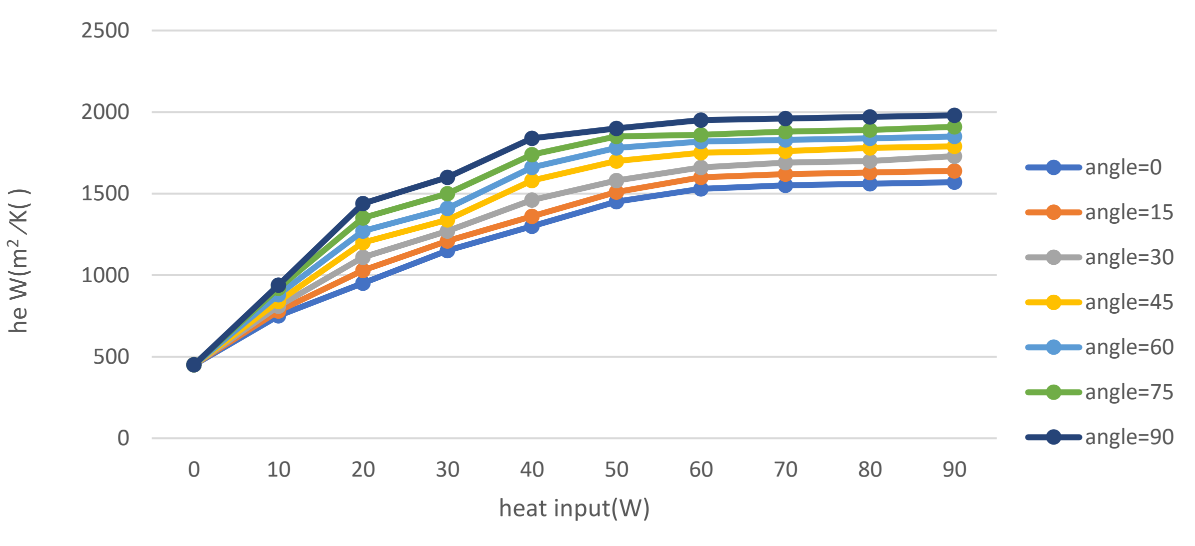


Fig.No.3g) thermal resistance at 90^0 angle

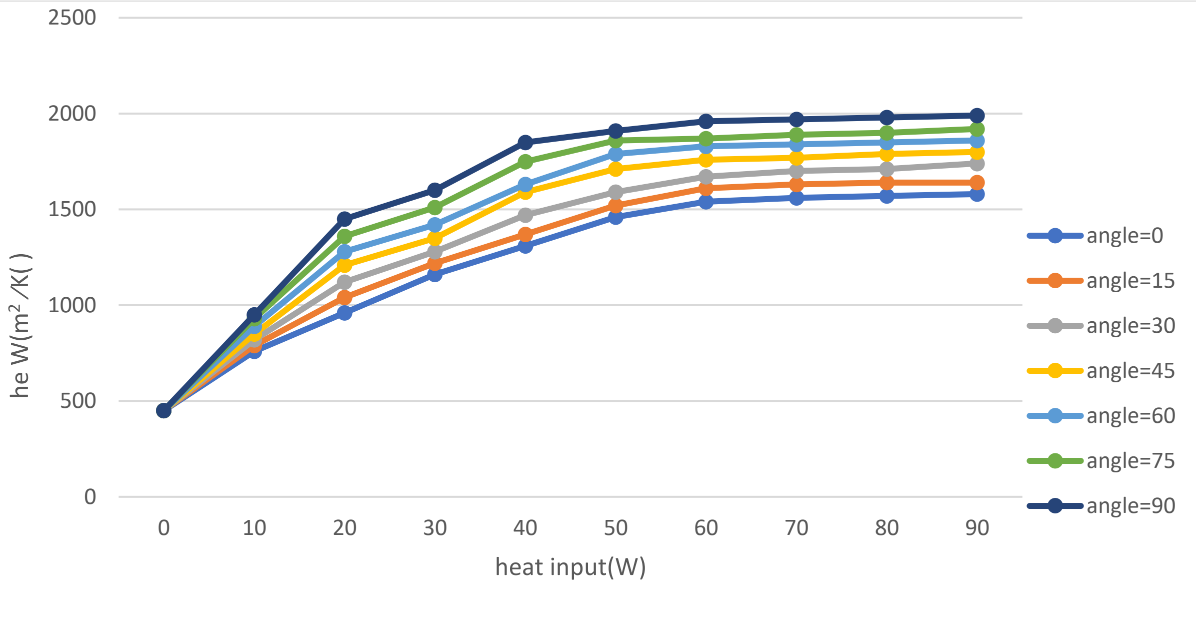
Figure 3.a. depicts the effect of magnetic field on thermal resistance 3.g. figure. Because the surface tension force is prominent in the HOHP, an uneven chain of liquid and vapour develops within the pipe. The input heat flux in the evaporator raises the pressure of the vapour plugs.The output heat lowers the pressure in the condenser. As a result, the installation angle of the HOHP can be changed [17]. As seen in the graph, the total thermal resistance of the Fe2O3 nanofluid-charged HOHP decreased as compared to the kerosene-charged HOHP. As a result, the Fe2O3 nanoparticles can be stated to increase the heat transmission of the HOHP, especially when a magnetic field is

present.Because the magnetic field reduces the thickness of the boundary layer and increases convection heat transfer, this is the case. The magnetic field pulls the nanoparticles toward the evaporator walls, roughening the surface. It has the potential to improve boiling heat transfer [18].



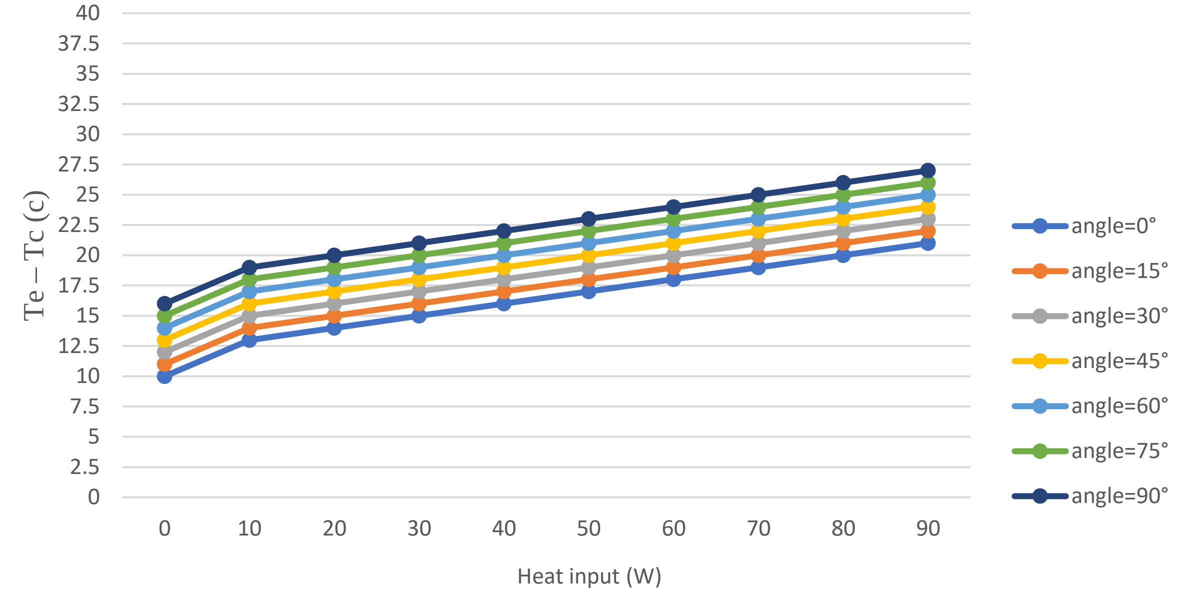
a)under magnetic field

Fig.no.4.a) variation of the evaporator's heat transfer coefficient versus the heat flux in different angles.

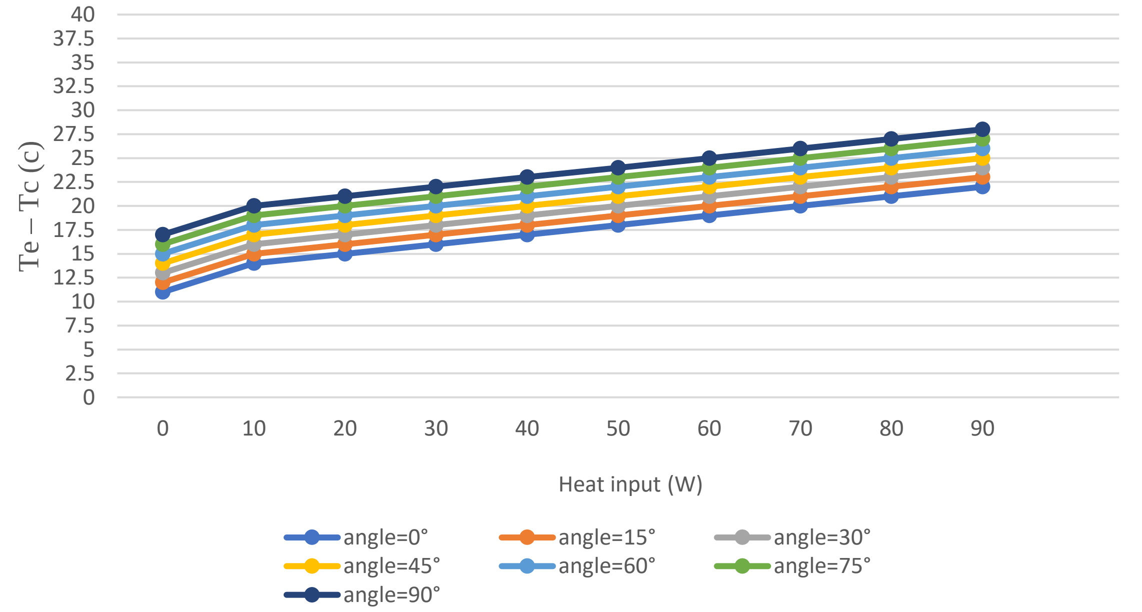


b)without magnetic field

Fig.no.4.b) variation of the evaporator's heat transfer coefficient versus the heat flux in different angles.



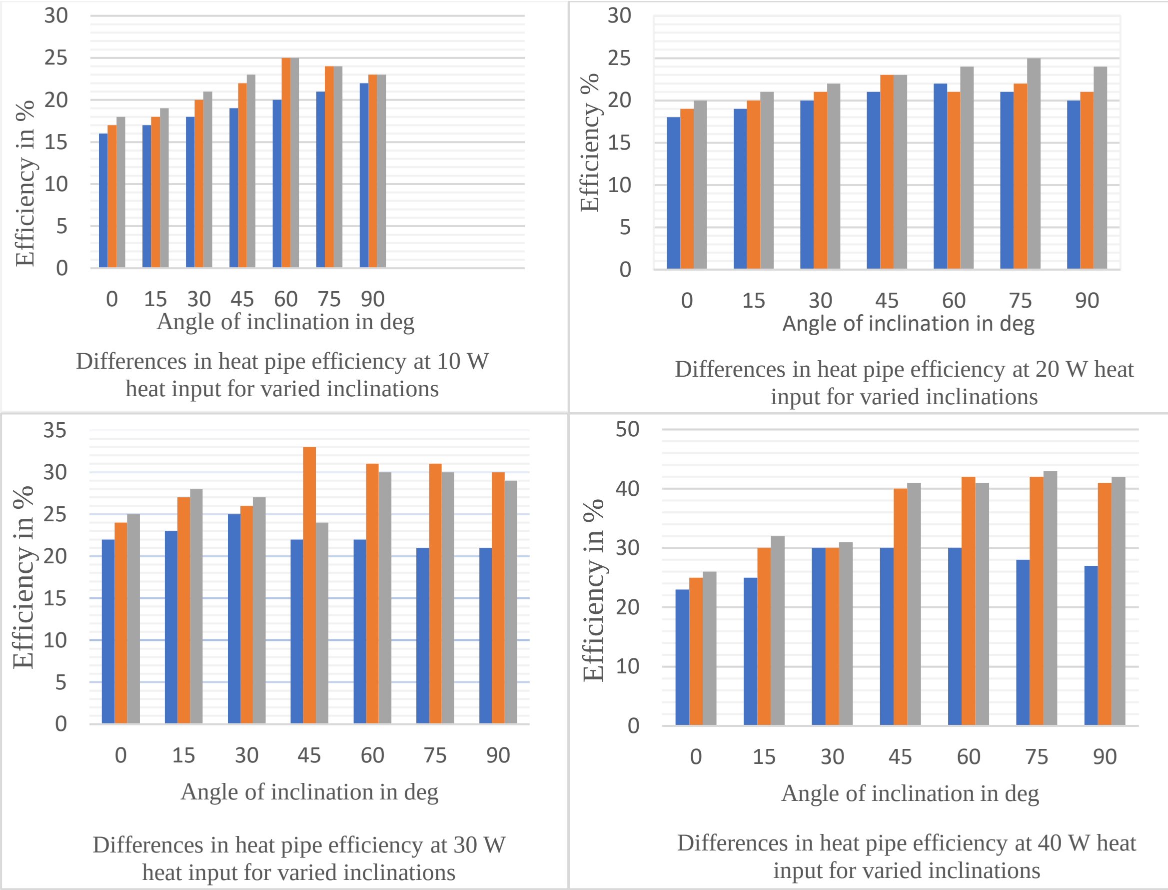
a)under magnetic field



b)without magnetic field

Fig.no.5a&b.) The difference in vapour temperature between the evaporator and the condenser in various angles.

In varied input heat fluxes, the difference in vapour temperature between the condenser and evaporator units is shown in Fig. 5(a) and 5(b). The temperature differential and the input heat had a positive linear relationship. The temperature differential between the condenser and the evaporator was minimised when Fe_2O_3 nanoparticles were introduced. Figure 4b shows how magnetic fluid application reduces evaporator temperature by improving flow circulation and movement, which enhances heat transfer coefficient.As a result, the temperature of the condenser rises in comparison to its previous state [19]. Similarly, as the heat input rose, the evaporator's heat transfer coefficient increased (Fig. 4(a) and (b)). It could be due to the fact that when Fe2O3 was added under the magnetic field, the temperature differential between the condenser and the evaporator was reduced.The temperature differential between the evaporator and the condenser [20]. Nonetheless, the heat transfer coefficient for the ferrofluid in the presence of a magnetic field is larger than in the absence of a magnetic field.



Differences in heat pipe efficiency at 10 W heat input for varied inclinations

Differences in heat pipe efficiency at 20 W heat input for varied inclinations

Differences in heat pipe efficiency at 30 W heat input for varied inclinations

Differences in heat pipe efficiency at 40 W heat input for varied inclinations

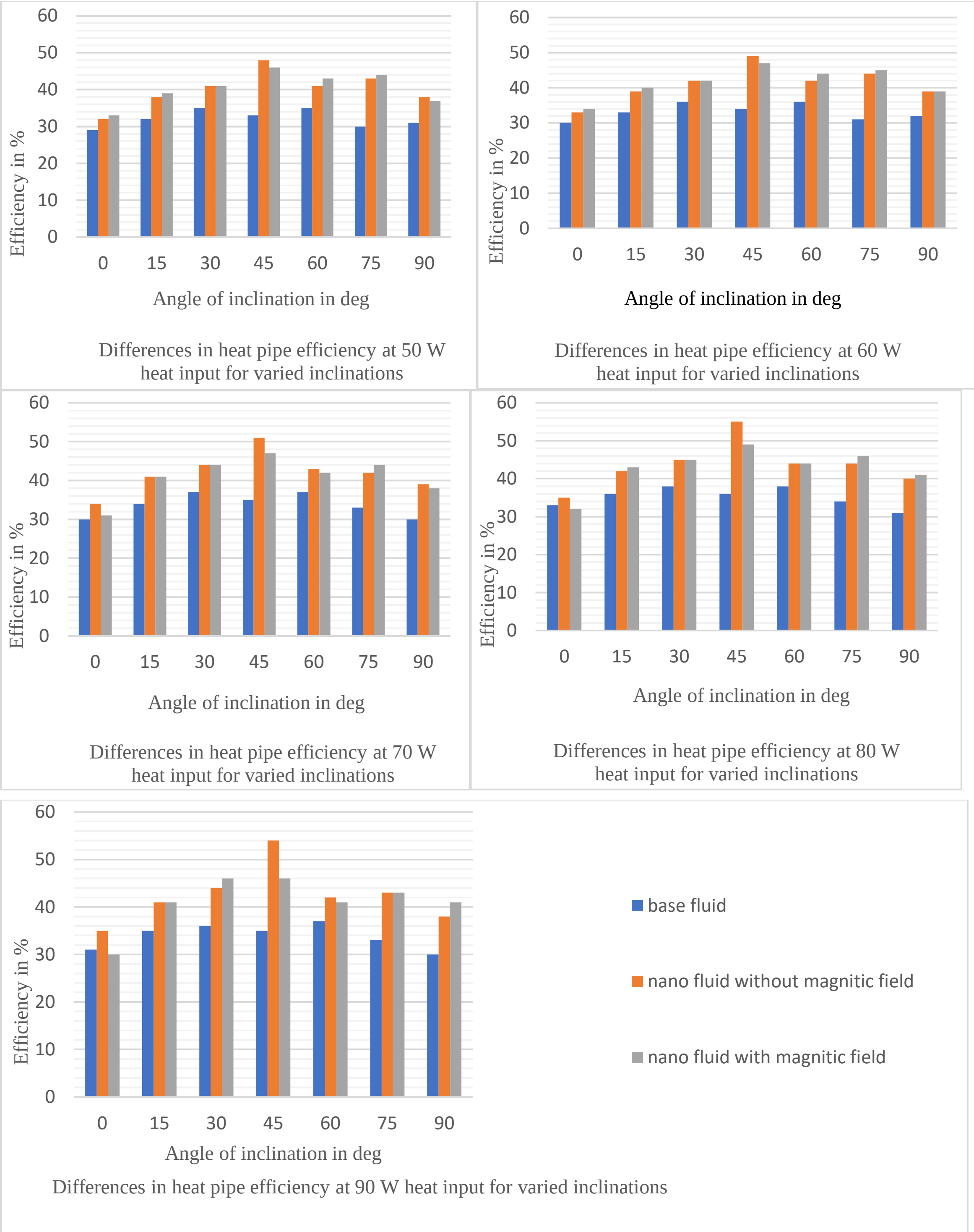


Fig no 6. Differences in heat pipe efficiency at different inclination angle

The heat pipe's thermal efficiency is determined by the ratio of the condenser fluid's cooling capacity rate at the condenser section to the provided power at the evaporator section. Figure 6 depicts the variance in heat pipe thermal efficiency as a function of heat pipe inclination angle. The thermal efficiency of the heat pipe increases with increasing values of the angle of inclination for copper nanofluid with regard to the horizontal position of the heat pipe, as shown in all of the figures The reason for this is that as the temperature of the working medium rises, more heat can be evacuated in the condenser section. The flow of working fluid between the evaporator and condenser sections is affected not only by the capillary action of the wick, but also by the gravitational pull. In contrast, the heat pipe's thermal efficiency begins to deteriorate. It's because the rate of creation of liquid film inside the condenser is faster, resulting in a larger thermal resistance value.Because of the enhanced heat capacity and thermal conductivity of the working fluid, the copper nanoparticles contained in the copper nanofluid have a significant impact on heat transfer augmentation. As a result, nanofluids improve the thermal efficiency of heat pipes when compared to the base working fluid. The thermal efficiency of the heat pipe improves when base fluid is employed as a working fluid rather than nano fluids, according to this investigation.

6. CONCLUSION

The heat transfer improvement of Fe_2O_3 nanoparticles distributed in Kerosene in a closed-loop helical oscillating copper heat pipe was investigated in this study. The influence of the magnetic field and the inclination angle was also examined. From the findings, the following conclusions can be drawn:

- Nanofluids can lower the thermal resistance of helical oscillating heat pipes in comparison to kerosene, improving their thermal performance and heat transfer coefficient. This enhancement is considerably more noticeable in the case of the Fe_2O_3 nanofluid in a magnetic field.
- The inclination angle of a heat pipe has a significant impact on its performance. The performance improves from 0 to 75 degrees, but degrades between 75 and 90 degrees due to faster condensate returns, which affect the evaporation unit's function. In regard to the horizontal axis, the optimal angle of inclination for Fe_2O_3 is 75.
- As the input heat flux rose, the heat pipe's heat transfer coefficient increased.
- After applying a magnetic field to the ferrofluid, the difference in vapour temperature between the condenser and the evaporator was significantly reduced.

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