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Experimental Analysis of Metal Oxide Nanofluids in Heat Pipe Thermal Performance

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Abstract

Due to the constant need for high speeds and the continuous reduction of hardware components, efficient heat management has become one of the most important problems in many technologies in recent years. The thermal performance of the equipment can be improved in a variety of ways, including the use of a heat pipe or a thermosyphon heat pipe, which is an excellent heat carrier. Thermo-syphon heat pipe equipment is simple in design, has low heat consumption, good heat dissipation, good performance, and is inexpensive. Water, methanol, ethylene glycol, and their mixtures, which are good transfer fluids, are common working fluids in heat pipes and thermosyphon heat pipes. Heat transfer performance is greatly improved by suspending nano sized particles in water.

A thermosyphon heat pipe with moist air and a water-cooled condenser were designed and tested in this experimental study. To investigate the effect of active parameters on the performance characteristics of the test unit, an analysis was performed for all active fluids. Water-soluble nanofluids are found to be more efficient than conventional water as working fluids suitable for thermosyphon heat pipes. To investigate the outcome of nanofluids on heat pipe performance, 〖Al〗_2 O_3+H_2 O Working fluids were prepared and synthesized. The performance parameters of that heat pipe show its heat capacity, heat transfer, and heat, and different working fluid parameters are compared to the performance parameters via the angle of the heat pipe curve. Heat input, nanoparticle concentration, and working water temperature filling level are all factors to consider. Thermal performance and thermal conductivity are set up to be superior with Al_2 O_3+H_2 O. It was discovered that the ideal ratio for all working fluids in a given operating condition is 4% by weight of nanoparticles and a 90° angle of inclination of the thermosyphon heat pipe. It was also discovered that the performance of the thermosyphon heat pipe is affected by the refrigerant type used in the condenser section. The test results show that the system performs better with water cooling than with air cooling.

1. INTRODUCTION

1.1 GENERAL: In recent years, the rapid development of electricity, industry, and the use of electronic components has increased the speed of the attraction of heating systems. Heat generation and dissipation are critical for the reliable operation of all electronic components, from microprocessors to high-voltage converters. Because electronics are packed into small packages that dissipate heat, design is critical. Heat resistance is used to avoid these problems. Electronic products require more cooling than traditional metal heat sinks due to the connection and power consumption. Using a heat pipe to meet these requirements is an excellent tool for heat

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management. Gaugler (1944) invented the heat pipe concept. He used cables to create a heat transfer system for the cooling system. Grover et al. (1964) also invented this device and coined the term heat pipe. The heat pipe industry has recently accepted the heat pipe as a dependable, cost-effective solution to high-end and cool styles. The heat pipe's heat transfer mechanism demonstrates that the heat transfer efficiency ranges from one hundred to several thousand times that of the copper component. The main benefits of heating pipes are their durability, low cost, simplicity, and dependability.

A heat pipe transports heat using ordinary heat transfer fluids such as air, water, ethylene glycol, and engine oil. However, when compared to dryness, these common working fluids have a very low temperature. To tackle these issues, the present research focuses on strengthening the thermal weakness of water by incorporating solid particles into it. The theory of the model of electrical conductivity of various solids was introduced by James Clerk Maxwell (1863). The classical Maxwell model was used to examine the heat conduction of a mixture of solid particles and water. This probe appears to be made up of millimeter- or micro-sized particles. The difficulty of using microparticles is that they settle easily in water, causing deterioration, congestion, and pressure drops. Higher particle concentrations are required for better results when heating these suspensions. Because of these factors, conventional solid-liquid suspensions cannot be used as heat transfer fluids. Despite these efforts, the issues associated with technical barriers persist. Nanoparticles with an average size of less than 100 nm are now possible, thanks to advances in nanotechnology. The mechanical, optical, electrical, and thermal properties of these nanoparticles vary.

1.2 HEAT PIPES: A heat pipe is a type of heat transport device that has a high heat transfer capacity. As exposed in Figure 1.1, a heat pipe is a closed, hollow cylindrical vessel with an inner wall surrounded by a closed shell or wick filled with high-pressure fluid. Before closing, the hot tap is removed and filled with working water; the air in the water adjusts the internal pressure. Heat is used to drive evaporation and water evaporation by creating pressure in the pipe. This causes the vapor to flow along the pipe to the cooler, where it cools and the vapor temperature drops. Due to the pressure created in the wick structure, it is then returned to the evaporator.

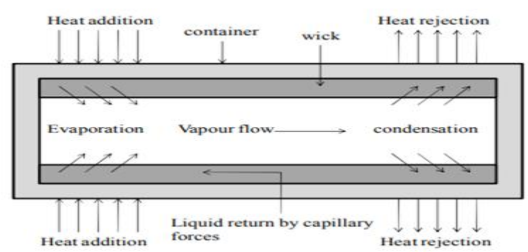

Fig. 1.1 Layout of a heat pipe

1.2.1 Heat Pipe Design: Material selection, heat pipe length and diameter, operating temperature, heat pipe temperature reduction, heat pipe shape, electricity resistance, the shape of the hot pipe cable, the effect. of heat pipe bending and distortion, oil resistance, and heat pipe dependability should all be considered in heat pipe design.

1.2.2 Heat Transport Limitations: A heat pipe's maximum heating capacity is determined by more than a few limiting factors that must be considered when designing the heat pipe. Figure 1.2 depicts five important heat pipe parameters. Limits of heat transfer are determined by the thermal conductivity of the operating temperature and include the

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viscosity limit, sonic limit, penetration limit, encapsulation limit, and boiling limit.

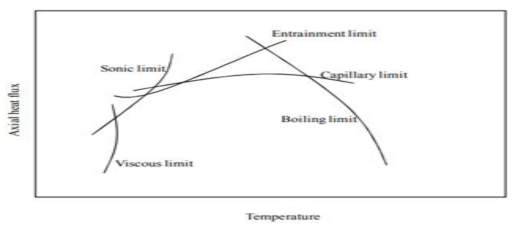

Fig. 1.2 limitations of Operational Temperatures

1.2.3 Viscous limitations: The caking zone is the loss of steam caused by frictional forces in the heat pipes. It is most frequently found in heat pipes and long condenser units. The viscous limit is not a pipe failure but rather a limit on heat transfer efficiency under certain conditions.

1.2.4 Sonic limit: In any part of the pipe, the sonic limit for steam flow reaches the speed of sound. It is not possible to increase the axial heat speed while improving heat removal in the condenser if the mass flow is choked at the point where the sonic speed is obtained. Because the pipe is protected from overheating by heat storage, better heat removal from the condenser makes the sound last longer.

1.2.5 Entrainment limit: The absorption zone increases the capacity of the water circulation system. However, because the part that changes the heat is not included, the increase in heat transfer occurs only when the water absorbs a large amount of energy before entering. Because imaginary heat transfer is less effective than steady heat transfer, increasing the circulation rate is insufficient to meet heat transfer requirements. The water flow increases until the capillary pressure can no longer keep up with the flow rate, and hot and dry spots form in the evaporation area.

1.2.4 Capillary limit: Capillary pressure's function is to move used water from the condenser to the evaporator via a cable in the heat pipe. The air flow speed is greater than the speed of release from the force of the compressed air, resulting in dryness. As a result, the thermodynamic cycle is interrupted, causing the heat pipe to malfunction. The wicking limit is usually reached at high vapor pressure, when water evaporation is nearly complete.

1.2.2.5 Boiling limit: When radial heat flows through the heat pipe, the boiling point occurs, and the nuclear boiling point occurs in the wick structure. The formation of steam, which flows through channels in the wicks and is amplified by nuclear boiling, causes hot spots to appear. This increases the circulation speed, which exceeds the capacity of the heat pipe and causes the operation to be disrupted. The boiling point is determined by the thermal properties of the working fluid.

1.3 CLASSIFICATIONS OF HEAT PIPES

The following heat pipe designs are used to recycle surplus heat for practical use.

1. Thermo syphon
2. Variable conductance heat pipe
3. Diode heat pipe
4. Vapor chamber or flat heat pipe
5. Capillary-piped loop heat pipe

1.3.1 Thermo-syphon

Figure 1.3 depicts a thermosyphon heat pipe schematic. Thermo-syphon heat pipes are high-effective thermal conductivity passive heat transfer devices. A thermosyphon heat pipe's effective coefficient of thermal conductivity is orders of magnitude greater than that of highly conductive solid materials such as copper. A thermosynthesized heat pipe is a device that transfers heat from one location to another. The thermosyphon heat pipe is made up of three sections: evaporator,

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adiabatic, and condenser. Heat is absorbed in the evaporator section and rejected in the condenser section. The adiabatic section is completely insulated. A vacuum pipe is used to evacuate the heat pipe, which is then filled with the working fluid. It is also referred to as a gravity-assisted wickless heat pipe because it is used to force condensate back into the evaporator. As a result, the condenser must be located above the evaporator.

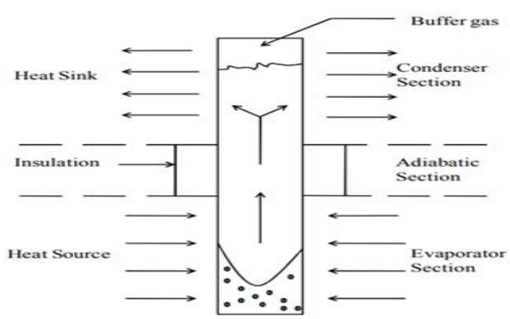

Fig. 1.3 Thermo syphon heat pipe

1.3.2 Variable conductance heat pipe: By pipeing non-controllable gas (NCG) into the condenser while maintaining a constant evaporator temperature and reducing heat, a variable control heat pipe (VCHP) allows variable control heat to enter the evaporator. When the air temperature is high, air escapes from the condenser, causing the condenser's surface to rise.

2. LITERATURE

Arul Selvan and Velraj (2011) calculated the surface and vapor heat of a heat pipe condenser cooler in steady and transient conditions. The results showed that the good cooling performance was due to the low convective heat transfer coefficient in the condenser, and it also shows that in order to increase the efficiency of the heat pipe, a cold water heater with a strong heat transfer can be used, and a greater heat transfer can be achieved by increasing funds in the sector.

According to Senthil Kumar et al. (2011), the heat pipe filled with self-watering fluids is more efficient, with a higher temperature difference and a lower temperature of the entire pipe. in the water. The results revealed that the aqueous solution of yen-pentanol outperformed the aqueous solution of yen-butanol. The reason for this is that it has better solidification properties than normal water and a negative surface-pressure gradient, and it also demonstrates the efficiency of self-hydrating fluids to improve heat pipe performance.

Brusly Solomon et al. (2012) attempted to assess the heat of a heat pipe using two different cables (coated and uncoated). Mesh-type fibers (100 mesh/inch) were used in this study with no nano-deposit. A simple dipping and drying method is used to coat the surface with copper particles with an average size of 80–90 nm.

Visinee Trisaksri and Somchai Wongwises (2007) provided an overview of recent advances in liquid-water heat transfer research. The presence of suspended nanoparticles improves the heat transfer performance of ordinary fluids.

Reiyu Chein and Jason Chuang (2007) investigated microchannel heat sink operation with nanofluids and compared theoretical and measured results. Ridha Ben Mansour et al. (2007) investigated the effect of physical property inhomogeneity on the efficiency of convection heat transfer by nanofluids.

Recent research on nanofluids and recent research on fluid flow and thermal behavior of nanofluids in pressurized and free convection flow are summarized by Xiang-Qi Wang and Arun Mujumdar (2007). Many researchers' findings were compared, and CuO nanoparticles of 36 nm size and ethylene glycol-base water, which have higher thermal

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conductivity than other nanoparticle dispersions, were chosen.

Xuefei Yang and Zhen-hua Liu (2010) presented a method for optimizing silica nanoparticles for the preparation of a variety of functional nanofluids. Direct contact with silanes on the surface of silica nanoparticles in silica solutions was used to determine capacity (commercial solutions and stable solutions were used). Following that, the nanoparticles were used to prepare nanofluids in which the nanoparticles dispersed well and could hold good pipes. After six months of standing nanofluids, functional nanoparticles can still be dispersed freely. Finally, it was discovered that a unique property of nanofluids is that no porous layer forms on the heated surface after boiling.

Vasu et al. (2008) conducted a theoretical study and the NTU estimation method on a flat tube heat exchanger using Al_2O_3 and H_2O nanofluid as a coolant. The NTU calculation method and Al_2O_3 and H_2O nanofluids for cooling are used to perform a detailed analysis of the parametric studies of density heat transfer. The effect of air inlet temperature, the effect of air and coolant mass flow rate, the effect of coolant temperature, and the effect of nanoparticle volume concentration are all factors considered in the theoretical analysis. This paper concluded that $Al_2O_3 + H_2O$ nano fluid is similar to normal water, and it was discovered that the freezing point of $Al_2O_3 + H_2O$ nano fluid is higher. The rate of heat transfer in nanofluids is faster than in water and decreases as the volume fraction of nanoparticles increases.

Lower and upper thermal boundaries of nanofluids were developed by Chandrasekhar and Suresh (2010), and theoretical data was compared to published experimental results. The comparison demonstrates that the experimental data considered are between newly developed and existing regions. This paper demonstrates the importance of particle structure, Brownian motion, and nanolayers in improving the heat transfer of nanofluids. In addition, a more accurate theoretical model for predicting the thermal conductivity of nanofluids can be developed to better understand the role of these parameters.

Kyu Hyung Do and Seok Pil Jang (2010) investigated the thermal performance of a rectangular valve tube heat pipe using water-based Al_2 and O_3 nanofluids as working fluids. Solving the single wall load equation and the long-term Young-Laplace equation of phase change yields the axial variations of wall temperature, evaporation rate, and condensation rate. As thin, porous coatings, the physical properties of nanofluids, including high-quality composite nanoparticles, can be observed. The main result of increasing the thermal efficiency of the heat pipe using nanofluids is a thin, porous coating layer composed of nanoparticles suspended in nanofluids. The effects of the volume fraction and size of the nanoparticles on thermal performance were studied, and the results showed the ability to increase thermal performance up to 100% even though the Al_2O_3 nanofluid in water with a concentration of less than 1.0% was used for demonstration. In conclusion, compared to previous experimental results, the thermal efficiency of the nanofluid heat pipe decreases as the size of the nanoparticles increases.

Adi Utomo et al. (2012) investigated the thermal conductivity, viscosity, and heat transfer coefficient of water using alumina and titania nanofluids with primary particle diameters of 50–60 nm and 20–30 nm, respectively. Two horizontal stainless steel sections with inside diameters of 4.57 mm and 10 mm were used in the experiment. A particle tracking model was used to simulate flow and heat transfer in the nanofluid, and a continuous model was used to model flow and heat transfer. The results demonstrated that small titanium nanofluids (20–30 nm) can be effective with low heat transfer when compared to alumina nanofluids (50–60 nm). The relative viscosity of the alumina nanofluid in this study is slightly higher than predicted by the Einstein-Batchelor model. Because of the formation of aggregates, the authors concluded that the tensile strength of alumina and titania nanowater was higher than predicted by the Eisntein-Batchelor model. A uniform flow model was used in 3D numerical simulation to predict the macroscopic thermal behavior of nanofluids.

3. METHODOLOGY

3.1 PROBLEM STATEMENT

The thermal performance of a micro-heat pipe using nanofluids based on aluminum is investigated in this study. Aluminum oxide nanofluid fluid is used in this experimental study. The effect of nanoparticle concentration on the fundemental fluid is also investigated.

3.2 OBJECTIVES

The primary goal of this experimentation is to investigate the performance of a thermosyphon effect heat pipe using aluminum metal oxide nanofluids in conjunction with water. To reach the main goal, the following tasks must be completed using both experimental investigations:.

1. a) Building and testing a heat pipe.
2. b) Investigation of the setup under various operating conditions.
3. c) Valuation of experimental performance and system technical feasibility.

3.3 APPROACH

Figure 3.3 depicts the steps involved in evaluating the performance of the MHP.

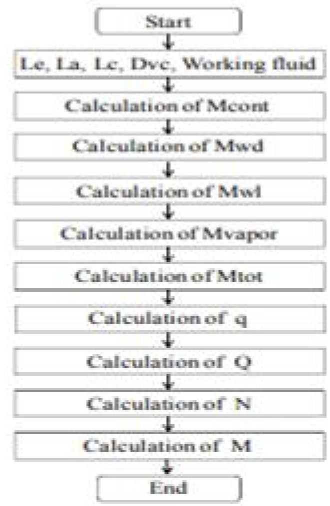

Fig. 3.3: Project Approach Flow Chart

The evaporator length (L_e), adiabatic length (L_a), condenser length (L_c), vapor core diameter (D_vc), and working fluids such as acetone, methanol, and water are the input parameters. These inlet parameters are used to compute total heat pipe length, effective heat pipe length, and other parameters.

3.4 THERMODYNAMIC ANALYSIS

A mathematical model performs the thermodynamic analysis. The mathematical model for the heat pipe is derived from the micro-heat pipe's continuity and momentum equation (MHP). For various diameter ratios and effective lengths of heat pipes, simulation has been performed for parameters such as effective evaporator length, condenser length, heat transfer rate, mass of working fluids, and number of heat pipes required. The necessary equations for the performance study were derived by applying the following assumptions to the governing equations: unsteady, compressible, and laminar vapor flow.

Heat flux per heat pipe

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Condenser heat transfer rate

The heat that the condenser's working fluid releases

$Q_c = mC_p \Delta t$

Number of heat pipes

It takes a certain number of heat pipes to remove the heat that is given to the evaporator.

$N = Q/q$

Total mass of heat pipes used in laptops

The quantity of heat pipes used

$M = N M_{tot}$

4 EXPERIMENTAL STUDIES

4.1 INTRODUCTION

The primary goals of this work are to design an experimental setup and collect experimental data on a thermosyphon system in order to evaluate its performance. An experimental system is created to achieve these objectives. This chapter describes the experimental setup, program and procedure, method of parameter measurement, operation of the water charging process, and data reduction.

4.2 COMPONENTS OF THE SYSTEM

The heater coil, auto transformer, voltmeter, ammeter, thermocouples, digital temperature indicator, condenser, evaporator, and adiabatic part of the thermosyphon are the main components of the test setup. All thermosyphon heat pipes were evacuated using a 0.2-bar vacuum pipe. Figures 4.1 and 4.2 show a schematic of the experimental setup with air- and water-cooled condensers. Straight copper tubes of 800mm length, 250mm, 300mm length, and 250mm length for the evaporator, adiabatic, and condenser sections, respectively, are used as the test section of the air cooler condenser, and copper tubes of 800mm length, 250mm, 220mm, and 330mm length for the evaporator, adiabatic, and condenser sections, respectively, are used as the section test water cooling condenser.

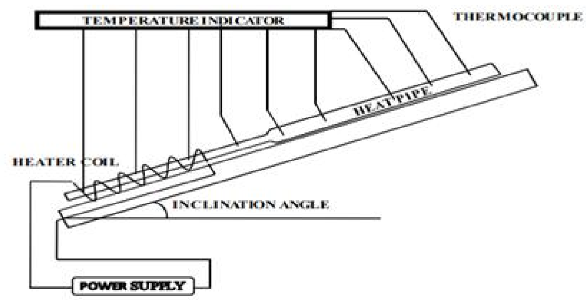

Fig. 4.1: Schematic of the Experimental System (Air-Cooled Condenser)

Calibrated K-type thermocouples are placed on top of the test piece to measure the temperature of the outside wall. Three thermocouples are connected to the evaporator, and the remaining thermocouples are connected to the adiabatic and condenser sections. The surface temperature of the air-cooled condenser is measured using three thermocouples, and the inlet and outlet temperatures of the cooling water in the water-cooled condenser are measured using two thermocouples. In the heating section, a coil-type heater (maximum 500 W) is used as a heat source. The heater coil's terminals are connected to an auto-transformer, where the heat flow can be adjusted by varying the voltage. Over the heater coil is thick insulation, and an adiabatic section uses glass wool to reduce heat.

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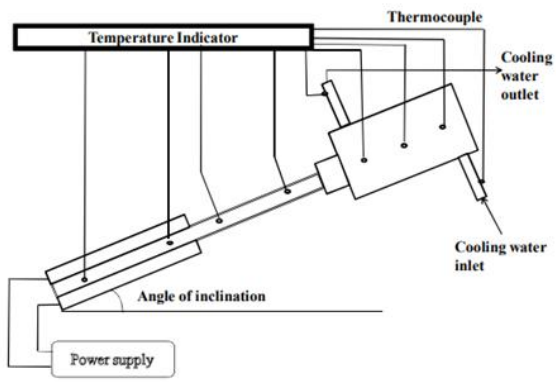

Fig. 4.2 Schematic of the experimental system

4.3 COMPONENT DETAILS

Table 4.1 contains a description of the standardisation test's components. Figures 4.3 and 4.4 show a schematic of thermocouple positions for air and water cooled condensers. Figures 4.5 and 4.6 show images of the thermo syphon and installation setup.

Table 4.1 Details of the components of the experimental system

	Air cooled condenser	Water cooled condenser
Length of evaporator section (mm)	250	250
Outer diametere of evaporator (mm)	6	6
Length of the adiabatic section (mm)	300	220
Length of the condenser section (mm)	250	330
Outer diametre of of condenser section (mm)	8	8
Thickness of heat pipe (mm)	1	1
No of thermocouples (Nos)	11	11
No of Heaters in Evaporator (Nos)	1	1
Insulating material	Glass wool	Glass wool
Working fluid	$Al_2O_3 + H_2O$	$Al_2O_3 + H_2O$

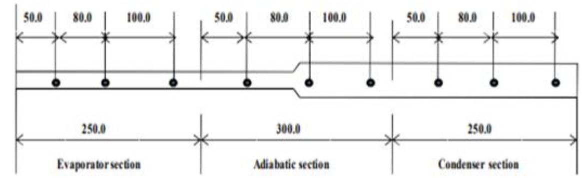

Fig. 4.3 Schematic of thermocouple positions (air cooled condenser)

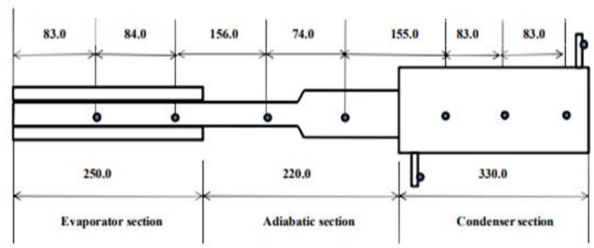

Figure 4.4 Schematic of thermocouple positions (water cooled condenser)

Figure 4.5 Photograph of thermo syphon heat pipe

1. Ammeter 2. Voltmeter
3. Temperature indicator

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4. Auto transformer

5. Heater coil 6. Glass wool

7. Condenser

Fig. 4.6 Experimentation Setup

5.RESULTS AND DISCUSSION

The system's performance was assessed by varying the working parameters. The following sections demonstrate the effect of various parameters on system operation.

5.1 Effect of Wall Surface Temperatures on Heat Pipe with Air-Cooled Condenser

The surface temperature distribution thermosyphon temperature of half the charge of working water at a time with an inclination of right angle is shown in Figure. If nanofluid is used instead of pure water, the temperature of the heat pipe rises. It shows the surface temperature of the heat pipe is with Nanofluid is less than pure water.

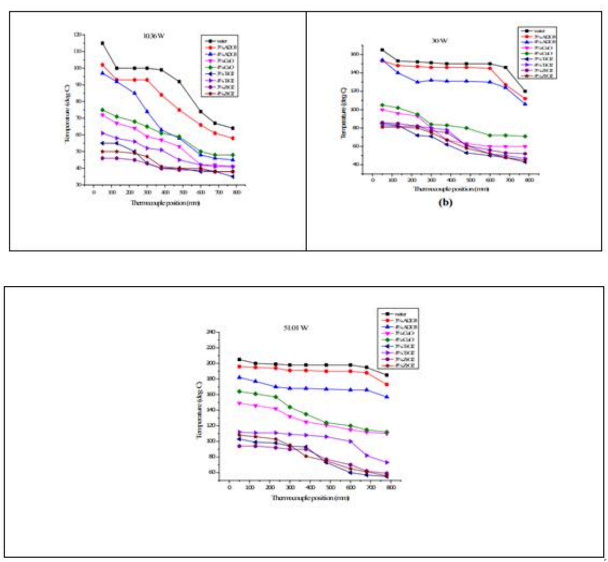

Fig. 5.1: Surface temperature of heat pipe position versus various heat inputs and concentrations of nanofluids with an air-cooled condenser

The average surface temperature appears to have decreased by 4% wt. Al_2O_3 nano fluid when compared to 3% wt. Al_2O_3 nano fluid and pure water. This is due to increased conductive heat transfer along the tube while decreasing convective heat transfer across the wall as the concentration of nanoparticles in the fluid increases.

5.2 Heat Pipe with Water-Cooled Condenser

Figures 5.2 show the results of the ground test temperature distribution along the length of the heat pipe for different input powers. An axial distance of 0.25 m indicates the evaporator, followed by an adiabatic zone of 0.22 m and a condenser zone of 0.33 m. The mean temperature inside the heat pipe rises as the input power is increased. The method of explosion and condensation in the evaporator and condenser sections is obviously visible and almost uniform at this temperature once it reaches stability.

The adiabatic zone experiences a temperature reduction when water is cooled in the condenser section, showing that a heat component is moving through the heat pipe's wall in an axial direction. The evaporator surface temperature reaches more than 100 °C once the system is established in a steady state. In the study being conducted today, water was chosen as the heat source. The thermosyphon heat pipe's temperature increases when Al_2 and O_3 nanofluids are employed in place of other nanofluids and pure water. This might be the case since the evaporator and condenser have a lower temperature difference than fresh water does.

Surface temperature range appears to be reduced by 4.1% wt. Al_2O_3 nano fluids when compared to 3.1% wt. Al_2O_3 nano fluids and pure water because increasing the amount of nano particles in the water increases the conductive heat transfer along the tube while decreasing the temperature of the air transfer to the wall.

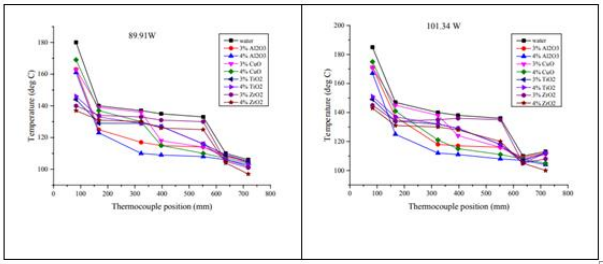

Fig. 5.2: Surface temperature of heat pipe position versus various heat inputs and concentrations of nanofluids in a water-cooled condenser

6. CONCLUSION

Previous chapters presented and discussed the output of an analysis of the performance of a thermosyphon heat pipe system using aluminum metal oxide nanofluids. This chapter presents the main findings from the theoretical and experimental analyses. An investigational study on a thermosyphon heat pipe system using aluminum metal oxide nanofluids yielded the following results: A thermosyphon heat pipe system experimental study was carried out. The thermosyphon heat pipe's heat transport efficiency is higher with aluminum metal oxide nanofluids than with water at all concentrations. By increasing the input energy and decreasing the average evaporator surface temperature, the thermal performance of the thermosyphon heat pipe is improved. The thermal conductivity of alumina nanofluid decreases from 1.84 to 0.31 W while increasing from 10.36 to 101.3 W. The nanoparticle's high concentration and charging volume improve fuel efficiency while significantly reducing heat transfer in the heat pipe when compared to the base fluid. The condensation heat coefficient is slightly higher than the boiling heat transfer coefficient. Heat transfer coefficient rises from 108.09 to 198.65, and heat output rises from 30 to 101.3W. It is discovered that $Al_2O_3 + H_2O$ outperforms the literature in terms of heat resistance. The system efficiency is much higher for the water-cooled condenser.

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