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Experimental Investigation of Heat Transfer Characteristics of Al_2O_3/Water and SiO_2/Water Nanofluid in Thermosyphon

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Abstract: This paper deals with the study of heat transfer characteristics of aluminum oxide and silicon dioxide nanofluid (Al_2O_3/water and SiO_2/water) in heat pipe. A heat pipe is a simple heat transfer device that can transfer a large amount of heat from the evaporator to the condenser. In this study, the concept of heat transfer will be applied to analyze heat characteristics and heat transport ability of the nanofluid. The type of nanofluids used for the experiments are Al_2O_3/Water and SiO_2/Water Nanofluid at three different nanoparticle volume fractions. The main objective of this research is to study the thermal enhancement of the nanofluid by focusing on the specific heat capacity and compared it with the base fluid. For this research, a test rig will be fabricated and nanofluid will be prepared using aluminum oxide and water as the nanoparticle and base fluid, respectively. Steps and processes regarding the fabrication of the test are discussed in detail. The result showed that performance of the thermosyphon is enhanced with the presence of nanoparticles in the working fluid. The specific heat capacity decreases as the concentration of nanoparticles in the working fluid increases. The efficiency of the thermosyphon is also improved by using nanofluid as the working fluid.

Keywords: *Thermosyphon, Heat pipe, Heat transfer, nanofluid, Thermal enhancement*

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1. Introduction

Due to the restriction of energy resources and ever-increasing demand for energy, optimizing energy resources has become an important aspect in various industries. There is a large range of applications of heat exchangers in the industry. There are various ways to increase the performance of heat exchangers. Heat exchangers are mostly used in industrial applications like process plants, food industry, heat recovery systems, refrigeration, nuclear industry, power generation, etc.

Heat Pipe Heat Exchanger (HPHE) is a type of heat exchanger in which heat is transferred indirectly using a liquid. HPHE transfers heat mainly by using a

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set of heat pipes or thermosyphons between fluids with a temperature difference [1]. Heat pipes are known as two-phase heat transport systems. A heat pipe is essentially a hollow metal pipe with both ends sealed off in which it is filled with a certain amount of liquid known as the working fluid. The inner surface of a heat pipe is lined with a wicking structure where the working fluid is contained. In a HPHE, the end of the heat pipe that is exposed to the higher temperature acts as the evaporator, where the working fluid absorbs the heat and evaporates and travels to the cooler end [2]. The other end of the heat pipe that is exposed to the lower temperature acts as the condenser, where the evaporated working fluid releases heat and condenses, with the help of the capillary forces in the wicking structure, the working fluid is absorbed and is brought back to the evaporator end.

A thermosyphon is simply a heat pipe without a wicking structure in the inner surface of the hollow tube [3]. Thermosyphons are capable of dissipating heat over a large distance with a small temperature difference. Thermosyphons rely on gravity to return the condensed fluid from the condenser end to the evaporator end of the thermosyphon. Due to this fact, the lower end of a thermosyphon is always the evaporator and the upper end is the condenser [4]. With the presence of gravitational force, thermosyphons perform better than heat pipes because the wicks in heat pipes add resistance to the working fluid that is flowing down from the condenser to the evaporator. Meyer and Dobson et al. [5] investigate a heat pipe recovery heat exchanger for a mini-drier. Figure 1 below illustrates the principal difference between the thermosyphon and heat pipe. The study concluded that the use of thermosyphon in a mini drier is able to give a 32% saving of R2 321 per annum instead of wicked heat pipe.

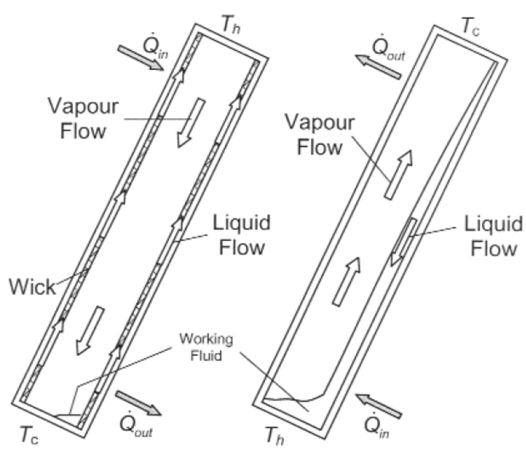

Fig. 1 Principal difference between the heat pipe (left) and thermosyphon (right) [5].

The heat transfer capability is one of the key aspects that has been the interest to many researchers. Over the years, countless experiments have been conducted on heat transfer enhancement. Heat transfer of a thermosyphon can be enhanced by optimizing its design and operational parameters. Recent studies have proved that the rate of heat transfer can be improved using nanomaterial technology [6]. Conventional working fluids such as water, glycol and alcohol have low thermal properties which attribute to low thermal performance of thermosyphon. It is a known fact that solid material has thermal properties superior than fluids. Using nanomaterial technology, a small fraction of tiny particles with a mean diameter of 1 nm to 100 nm known as nanoparticles is added into the base fluid (conventional working fluid) to form nanofluid. Nanofluids have shown better thermal properties when compared to conventional fluids [7].

Ghaderian et al [8] used a thermosyphon system circulation technique with CuO/water as working fluid to increase the performance of the evacuated tube solar collectors. At a higher temperature, nanofluid can absorb more heat compared to conventional fluids. The large difference between the cold and the hot fluid gives better natural circulation to the thermosyphon for better heat circulation. Hence, the system performance is increased. However, at higher concentrations of nanoparticles, the performance of the system is decreased due to agglomeration, instability, higher density and viscosity. The use of CuO/water nanofluid with 0.03% nanoparticle volume fraction enhanced the performance of the evacuated tube solar collector system up to 14% compared to using water as the working fluid.

Kiseev et al. [9] study the effect of nanoparticle volume fraction on the performance of loop thermosyphon. Fe_2O_3/water is used as the working fluid for the experiment. Increased volume fraction of nanofluid from 0 to 2% shows an increasing pattern of heat transfer coefficient. However, after 9 years, the thermal physical properties of nanofluid were 90% different compared to the first measurement in 2012. This is due to the agglomeration and instability of the nanoparticles inside the system. Hence, to make sure that the performance of the system is sustained, a good stability nanofluid is crucial as a working fluid especially in a small diameter channel as the loop thermosyphon.

Graphene nanofluid having 29% higher thermal conductivity compared to deionized water has made it a good substitute as the working fluid for the thermal system. Das et al. [10] study the effect of power inputs, temperature, and angles of inclinations on the thermophysical of graphene nanofluid in a thermosyphon. The experimental set-up consisted of an evaporator, adiabatic section and condenser. The use of graphene nanofluid as the working fluid causes a reduction in thermal resistance and the value is decreasing with increasing particle volume fraction from 0.02 to 0.01. While the angle of inclination of the thermosyphon does not give many significant changes to the thermal resistance and also wall temperature distribution.

Gupta et al. [11] use two-dimensional analysis to investigate the thermal performance of heat pipe using CeO_2/water as working fluid in which the result is validated through experimental analysis. The use of nanofluid in heat pipe causes higher thermal performance of heat pipe by reducing the wall temperature value. CeO_2/water with a 1% volume fraction gives the highest thermal performance and beyond the limiting value of volume fraction, thermal performance is decreased. The small contact angle between the inner surface of the heat pipe and nanofluid causes higher surface wettability that results in higher thermal performance.

Several types of nanofluid has been studied as a working fluid in closed thermosyphon including Cu/water nanofluid [12] andAl_2O_3/methanol [13]. Both studies concluded that the presence of nanofluid in thermosyphon has increased Nusselt number and performance of the thermal system. However, having a higher concentration of nanoparticles will lead to higher viscosity that can deteriorate the thermal performance of the system. Even though the investigation and analysis of nanofluids in thermosyphon have been carried out by many researchers, however the knowledge regarding the relationship between the four main thermal physical properties of nanofluid including thermal conductivity, specific heat, density and viscosity on the thermal performance of thermosyphon and its natural convective heat transfer ability is still very limited. Hence, this paper will focus on the study of the effect of four aforementioned thermal physical properties to the natural convective heat transfer of thermosyphon.

Another similar experimental study was conducted by M.R. Sarmasti Emami et al [14] on the effect of aspect ratio and filling ratio on the thermal performance of inclined two-phase closed thermosyphon under normal operating conditions. Only distilled water was used as the working fluid in the thermosyphon. Experiments were carried out with aspect ratios of 15, 20 and 30 with filling ratio ranging from 20% to 60% for inclination angles ranging from 15° to 90°. The dimensions of the thermosyphon were 16mm, 14mm and 100mm for the outer diameter, inner diameter and overall length respectively. The thermosyphon was made out of copper material. Best thermal performance was produced for the thermosyphon with s filling ratio of 45% at an inclination angle of 60° and for all three aspect ratios.

K.S. Ong and Md. Haider-E-Alahi [15] explored the performance of thermosyphon charged with R134a. They conducted several experiments to investigate the effects of temperature variation between condenser and evaporator section, mass flow rate of the coolant and fill ratio. The inside and outside diameter of the thermosyphon were 25.5mm and 28.2mm respectively and was made of copper material. The total length, condenser length and evaporator length were 780mm, 300mm and 300mm respectively. The gathered results showed that as the temperature variation between condenser and evaporator section increases, the mass flow of the coolant and fill ratio increases, the transferred heat flux also increases.

P.G. Anjankar and Dr. R.B. Yarasu [16] performed an investigation on the effect of coolant flow, condenser length and heat load on the performance of two-phase closed thermosyphon. A copper tube which was sealed at both ends was used as thermosyphon. The evaporator length and overall length were 300mm and 1000mm respectively. The experiment was conducted with condenser lengths of 450mm, 400mm and 350mm. the internal and external diameters of the thermosyphon were 26mm and 32 mm respectively. Results were obtained and indicated that with a condenser length of 450mm and heat input of 500W at a flow rate of 0.0027kg/s, the thermal performance was higher.

In this study, Al_2O_3 nanoparticles and SiO_2 nanoparticles are used to prepare the nanofluid. The thermosyphon used in the test rig was made out of copper material. Experiments on heat transfer of thermosyphon using nanofluid and conventional working fluid were carried out and compared. In this study, distilled water is used as the conventional working fluid and also as the base fluid of nanofluid. The efficiency of a typical thermosyphon ranges between 45% and 65%. Increasing the number of the thermosyphons, increases the heat transfer efficiency. However, the increase in efficiency is not directly proportional to the number of thermosyphons. Fully exploiting the operational parameters is one way to overcome the problem, as operational parameters is the vital part in enhancing the rate of heat transfer for the thermosyphon. Enhancing the heat transfer rate will directly increase the performance of the system. Heat transfer enhancement is proven possible using nanomaterial technology. In recent times, researchers have proved that the heat transfer characteristic of thermosyphon can be enhanced by using nanofluid as the working fluid. Nanofluid is formed by colloid suspensions of nanoparticles in a base fluid. The objectives of this project are to fabricate a test rig of a thermosyphon that is compatible to operate using nanofluid as the working fluid and to investigate the effect of nanoparticles on the performance of the thermosyphon by focusing on the thermal physical properties of the working fluid.

2. Experiment

2.1 Nanofluid Preparation

Nanofluid is prepared using Al_2O_3, SiO_2 and water as base fluid in two-step methods. The prepared nanofluid is then tested for the quality of suspension before proceeding to the next step. Two step method was used to prepare nanofluid with mass concentrations of 0.01%, 0.03% and 0.05%. This method is effective in synthesizing oxide nanoparticles.

The Al_2O_3/water nanofluid and SiO_2/water nanofluid are synthesized using the two-step method. For this method, the nanoparticles are purchased in powder form. Figure 2 illustrates the Al_2O_3 nanoparticles in powder form that is used in this project. Table 1 shows thermal physical properties of water and nanoparticles used in the experiment. For the experimental investigation, the thermosyphons needed a 30% filling ratio, which is about 87g of fluid. Hence, a batch of 150 g of nanofluid is produced for every concentration. The nanoparticles and the base fluid are weighed before mixing. A densimeter of 0.01g resolution is used to accurately weight the nanoparticle and the base fluid. 0.02 g, 0.05 g and 0.08g of Al_2O_3 and SiO_2 nanoparticles are used to synthesize 150 g of aluminum oxide-water nanofluid with 0.01%, 0.03% and 0.05% mass concentrations respectively using two given equations below [17]:

The mass fraction in the nanoparticle oil suspension,

$$\omega_{\mathrm{n}} = \frac{m_{\mathrm{n}}}{m_{\mathrm{n}} + m_{\mathrm{o}}} \tag{1}$$

Volume fraction of nanoparticle in the nanoparticle oil suspension,

$$\varphi = \frac{\omega_{\mathrm{n}}\rho_{\mathrm{o}}}{\omega_{\mathrm{n}}\rho_{\mathrm{o}} + (1-\omega_{\mathrm{n}})\rho_{\mathrm{n}}} \tag{2}$$

Where ω is nanoparticle concentration in base fluid (water), φ is the volume fraction of nanoparticle, m_{n} is mass nanoparticles used in grams (g), m_{o} is mass water used in grams (g), ρ_{n} is the density of nanoparticles and ρ_{o} is the density of oil. After weighing both nanoparticle and water, both components are mixed and placed in a digital sonifier for sonication process, the second step of the nanofluid synthesis, for an hour. During this process, the mixture absorbs the energy from the ultrasonic waves produced by the sonication machine causing a rise in the temperature of the mixture. Observation revealed that there is a slight reduction in the mass of the nanofluid after the sonication process because some of the water particles vaporize This loss in water mass could affect the concentration of the nanofluid. To determine if there is a significant change in the concentration of the nanofluid, the mixture is weighed before and after the sonication process. Using this data, the concentration is calculated before and after the process, and the results are tabulated in table 2 below. The concentration remains the same. The loss in water during sonication process does not have a significant effect on the concentration of the nanofluid.

Sonication process uses a digital sonifier that exerts ultrasonic waves onto the mixture to thoroughly disperse the nanoparticles evenly in the mixture, figure 3 below illustrates the digital sonifier used in this project. This process also slows down and decreases the agglomeration of the nanoparticles. For this project, the nanofluid had to suspend without agglomeration for at least 2 hours, during which the experiment can be conducted to obtain reliable results. Hence, the sonication process for the mixture of Al_2O_3 and SiO_2 nanoparticles and water was carried out for an hour at an amplitude of 25%.

Fig. 2 Al_2O_3 nanoparticles in powder form that is used to prepare the nanofluid.

Table 1 Thermal physical properties of Al_2O_3 and SiO_2 nanoparticles

Material	Properties			
	Thermal conductivity (W/m K)	Specific heat capacity (J/ kg K)	Density (kg m^3)	Viscosity (kg/ m s)
Water at 300 K	0.546	4187	997	4.66×10^{-4}
Al_2O_3	17.65	525	3970	-
SiO_2	1.3	680	2650	-

2.2 Design Criteria of the Thermosyphon Test Rig

The thermosyphon (container) is made out of material with good thermal conductivity. The thermosyphon (vessel) does not have any chemical reaction with the working fluid. The thermosyphon (vessel) is resistant to corrosion and erosion. The thermosyphon (vessel) is able to withstand thermal stresses during expansion and contraction. The material used to fabricate the thermosyphon (vessel) is compatible with the working fluid. The inside of the thermosyphon has to be in vacuum condition

Fig. 3 Digital sonifier for the sonication process

Table 2 Concentration of nanofluid before and after sonication process

		Nanofluid		
		1	2	3
Before Sonication	Mass of nanoparticles	0.02g	0.05g	0.08g
	Total mass nanofluid	150g	150g	150g
	Concentration of nanofluid	**0.01%**	**0.03%**	**0.05%**
After Sonication	Mass of nanoparticles	0.02g	0.05g	0.08g
	Total mass nanofluid	145.86g	145.39g	145.95g
	Concentration of nanofluid	**0.01%**	**0.03%**	**0.05%**

Figure 4 illustrates the concept design of the test rig used in this study. One end of the thermosyphon is sealed shut while the other end is sealed using a rubber stopper. This will ease the process of replacing the working fluid between conventional fluid and nanofluid. The middle section, which is the adiabatic section is insulated using an insulator to maximize heat transfer from the evaporator end to the condenser end of the thermosyphon while at the same time reduce heat loss. Since it is a wickless heat pipe, the thermosyphon is tilted at an angle to bring down the condensed fluid from the condenser end to the evaporator end with the help of gravity. The evaporator end is submerged in hot cooking oil. Temperature indicators are placed at three different places, each one at every section of the thermosyphon.

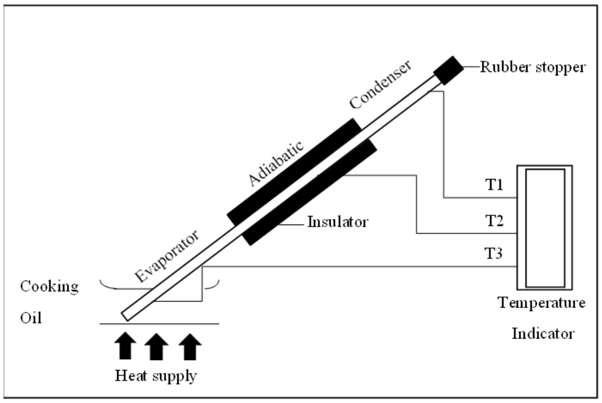

Fig. 4 Test rig concept design

2.3 Fabrication of Thermosyphon

The vessel of the thermosyphon is constructed by having the copper vessel cap brazed to one end of the copper vessel. The surface of both the cap and vessel are cleaned to ensure a strong adhesive between the brazing surface and the filler metal. Before the brazing process, the cap and the vessel are aligned in position and held in place. Then, the first part of the brazing process is done in which the ends of the copper cap and vessel are heated until they reached the brazing temperature using a gas-air torch. The metals area heated uniformly for an even fill and completely seal of the joint. At this point, the second part of the brazing process is done where the filler metal is applied. The filler metal is dipped in flux powder to avoid formation of oxides during the heating process. Figures 5 and 6 below illustrate the first and second step of the brazing process, respectively.

Fig. 5 First step of brazing process, the heating of the copper cap and vessel

Fig. 6 Second step of brazing process, applying the filler metal which was dipped in flux powder

The area of brazing is checked for leaks. It is vital to ensure that the seal was leak prove as it would compromise the performance of the thermosyphon. A visual inspection is first done on the brazing area. There is an even coat of the filling metal that joints both ends of the copper cap and vessel. Another leak detection test was done by filling the vessel with water. No sign of leakage is detected.

The next step is to fill the vessel with water and create a thermosyphon. The vessel is filled with a 30% filling ratio. With the other end kept open, the vessel filled with water is heated while observing for any sign of water vapor releasing from the open end. When water vapor begins to release out of the vessel, a rubber cork is forced down into the thermosyphon and it will tightly shut the thermosyphon. To confirm that the rubber cork is sealing the thermosyphon tight, drops of soapy water are dripped on the joint between the vessel and the rubber cork. There was no bubble formation, confirming that the thermosyphon is indeed air-tight. To avoid any possible risk of leakage, duct tape is used to tape around the vessel and rubber cork. After allowing it to cool to room temperature, the thermosyphon is ready for operation. Figure 7 below illustrates the test rig used in carrying out the experimental investigation for this project.

A test run is conducted to test if the thermosyphon can operate under the desired conditions. The evaporator end of the thermosyphon which was at a 50° tilt was carefully submerged into a cup of hot cooking oil. Reading was taken for approximately 5 minutes. The results indicated that the thermosyphon is working in transferring heat from the

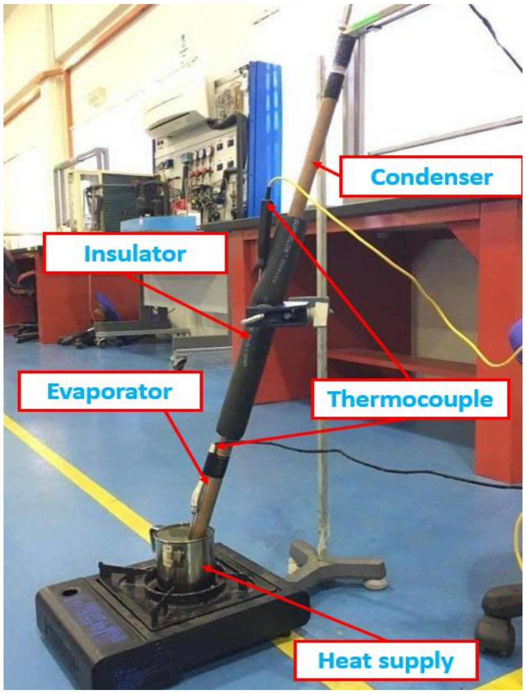

Fig. 7 Test rig setup used for experimental investigation

hot end to the cooler end. This test also proved that the test rig is working and it is ready for the experimental investigation. The cooking oil first heated up to 250°C - 280°C. During this heating process, the thermosyphon was separated. After achieving the desired temperature of the cooking oil, it was removed from the heat supply. At this point, the evaporator end was carefully submerged into the hot cooking oil. The temperature reading at all three points were recorded every 30 seconds for a total time of 10 minutes.

Fig. 8 Suspension of 0.05% nanofluid after day 1 of synthesis

Fig. 9 Suspension of 0.05% nanofluid after day 2 of synthesis

Fig.10 Suspension of 0.05% nanofluid after day 3 of synthesis

3. Result and discussion

3.1 Stability analysis

Another criteria that are tested in the preparation of nanofluid is the duration of the suspension. Since no surfactant is used in the synthesis of the nanofluid, the durability and stability of the prepared nanofluid are in question. To confirm that the nanofluid would not agglomerate and just end up being a mixture of water and nanoparticle, the prepared nanofluid is bottled in a contained and left for several hours. For every hour, the nanofluid is examined for any form of precipitation. Figures 8, 9 and 10 illustrate the suspension of nanofluid with a concentration of 0.05% aluminium oxide nanoparticle for the first, second and third day, respectively.

Observation from Figure 8 shows that the nanofluid is a chalky solution which indicates a good suspension after 24 hours after synthetization. There are no signs of any agglomeration occurring, if there is, it is not significant. In Figure 9 however, there is an obvious sign of agglomeration as a layer of precipitated aluminium oxide nanoparticles is seen at the bottom of the container. Three days later, as shown in Figure 10, the initially chalky solution is now been less chalky and clearer. This indicates that the suspension is not good, hence the nanofluid is not effective beyond this point. In order to making sure that the result is valid for experimental analysis, nanofluid solution prior to one day of synthetization is used for experimental since the solution is well homogenized within the time period.

3.2 Temperature Analysis

The data obtained from experimental analysis for nanofluid flowing inside the thermosyphon at various nanofluid concentrations are recorded and tabulated below.

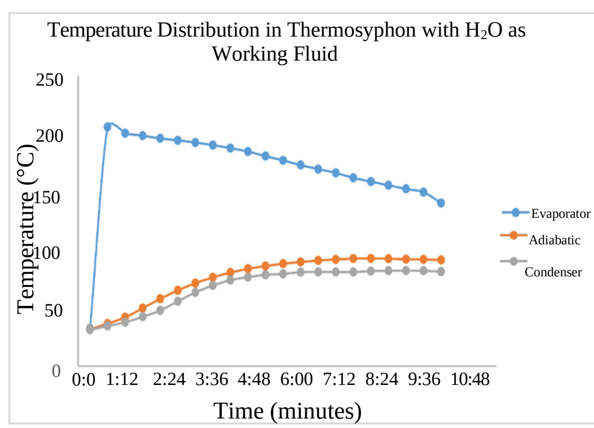

Fig. 11 Graph of temperature distribution in thermosyphon with water as working fluid

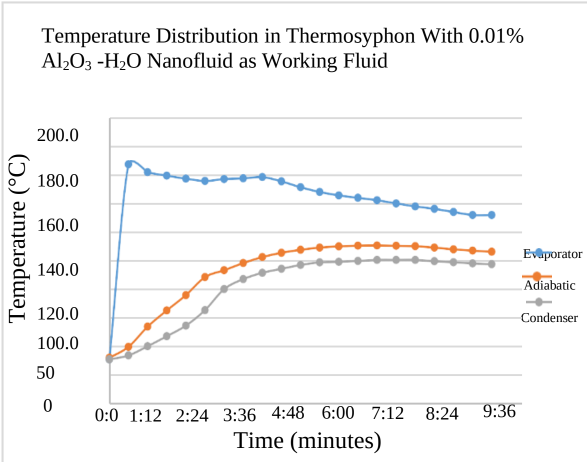

Fig. 12 Graph of temperature distribution in thermosyphon with 0.01% Al_2O_3/H_2O nanofluid as working fluid

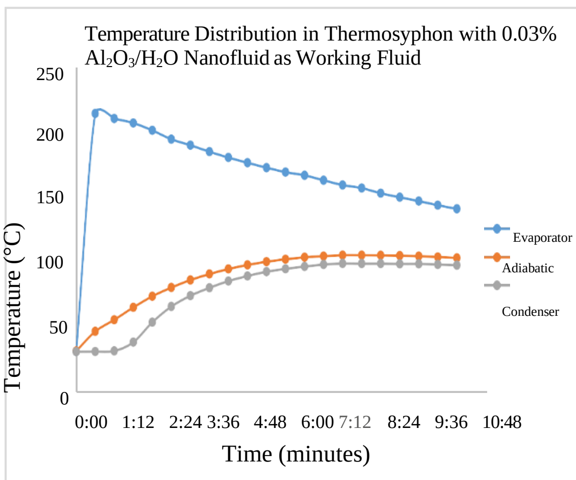

Fig. 13 Graph of temperature distribution in thermosyphon with 0.03% Al_2O_3/H_2O nanofluid as working fluid

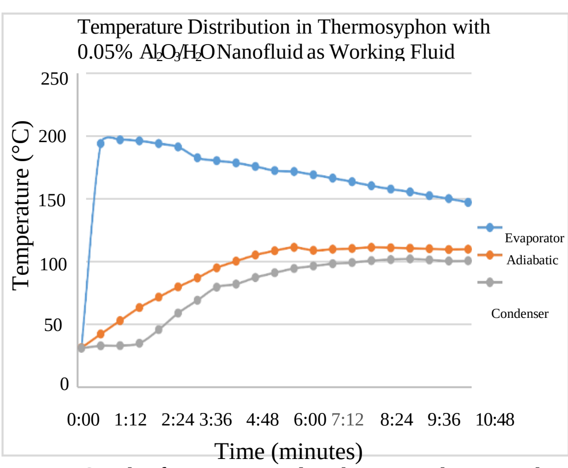

Fig. 14 Graph of temperature distribution in thermosyphon with 0.05% Al_2O_3/H_2O nanofluid as working fluid

Figures 11, 12, 13 and 14 illustrate the temperature distribution with variation of time. On the evaporator end, the maximum temperature for each experiment varies, ranging from 191.8°C to 214.5°C. The primary reason is because the heat source, the cooking oil, is heated using a stove and it was difficult to achieve a constant temperature for each experiment. The stove used did not have the sensitivity in controlling the fire to an exact temperature.

The graphs show that the temperature at the condenser section comes to an almost steady state after 6 minutes. The difference is that the temperature at which it begins to be steady varies with the type of working fluid used for the experiment. The highest temperature is achieved by using 0.05% aluminium oxide nanofluid as the working fluid at 102.2°C. Then followed by using working fluid of 0.03% aluminium oxide nanofluid and 0.01% aluminium oxide nanofluid at 100.6 °C and 99 °C respectively. The lowest temperature at 77.9 °C is obtained by using water as the working fluid. Working fluid with the presence of nanoparticles (nanofluid) gives higher performance up to 27% as compared to working fluid without nanoparticles. On the other hand, comparing the performance between nanofluids, the maximum temperature at the condenser increased by 1.6°C as the mass concentration of nanoparticles increased from 0.01% to 0.02% to 0.05%. The experimental results prove that the presence of nanoparticle in the working fluid aided in the heat transfer process of the thermosyphon. Moreover, this has been validated by researchers M.G Mousa [18] and Putra et al [19] from their studies.

3.3 Specific Heat Capacity Analysis

To further analyze the results obtained from the experiments, the specific heat capacity for every working fluid is calculated. Specific heat capacity is defined as the amount of heat absorbed per unit mass of a substance to increase the temperature by one degree Celsius. Equation (3) is used to calculate the specific heat capacity by assuming that the nanoparticle suspended in the fluid and base fluid are in thermal equilibrium. This equation is proven to yield accurate results [20].

$$C_{p,wf} = \frac{\varphi\left(\rho c_p\right)_n + (1-\varphi)\left(\rho c_p\right)_f}{\varphi \rho_n + (1-\varphi)\rho_f} \quad (3)$$

Where subscript $_{wf}$ denotes the working, $_n$ denotes the nanofluid, $_p$ denotes the particle and $_f$ denotes the base fluid. To use Equation (3), volume fraction and specific heat capacity of nanofluid and base fluid had to be determined. The specific heat capacity of both nanoparticle and base fluid is 0.88 J/g-K and 4.186 J/g-K respectively. Volume fraction, φ, is calculated using Equation (4).

$$\varphi = \frac{V_n}{V_n + V_f} \tag{4}$$

Where V_n and V_f are the volume fraction of nanoparticles and base fluid respectively. Substituting the mass and density of nanoparticles and base fluid into Equation (4) gives us Equation (5).

$$\varphi = \frac{\frac{m_n}{\rho_n}}{\frac{m_n}{\rho_n} + \frac{m_f}{\rho_f}} \tag{5}$$

The specific heat capacity for each working fluid is calculated and presented in Table 2, and it shows that the specific heat capacity decreases as the concentration of the nanoparticles in the fluid increases. Although the decrease in the specific heat capacity value is not drastic, it shows that nanoparticle has a positive effect on enhancing the thermal properties in thermosyphon. The nanofluid was prepared using Equation (1), which uses weight concentration and when referring to Table 3, the conversion of the weight concentration of the nanoparticles in working fluid to volume fraction has significantly reduced. This significant reduction in value is due to the higher density of the nanoparticles. Nevertheless, enhancing the specific heat capacity with a very low volume fraction just shows the effectiveness of the nanoparticles. A significant drop in specific heat capacity can be achieved by increasing the volume fraction of the nanoparticles in the working fluid. Since the main purpose of the working fluid is its ability to change phase to transfer the heat faster, this reduction in specific heat capacity that less energy is needed to increase the temperature of the working fluid. Hence the phase change of the working fluid with the presence of aluminum nanoparticles happens at a higher rate than the working fluid without the nanoparticles. Therefore, at the evaporator, the working fluid turns into steam with lesser energy and at the condenser, it condenses and releases heat much faster. This enhancement indicates that the power consumption can be reduced as less energy is used for the thermosyphon to operate.

Table 3 Specific heat capacity respective to its working fluid

3.4 Efficiency

Working Fluid	m_n (g)	ρ_n (g/cm^3)	$c_{p,n}$ (J/g-K)	m_n (g)	ρ_n (g/cm^3)	$c_{p,n}$ (J/g-K)	φ	$c_{p,wn}$ (J/g-°C)
Water	150.00	1	4.186	-	-	-	0.00000	**4.186**
0.01% Al_2O_3-H_2O	145.84	1	4.186	0.02	3.9	0.88	0.00004	**4.185**
0.03% Al_2O_3-H_2O	145.34	1	4.186	0.05	3.9	0.88	0.00009	**4.185**
0.05% Al_2O_3-H_2O	145.87	1	4.186	0.08	3.9	0.88	0.00014	**4.184**

The efficiency of the thermosyphon with different working fluid can be determined using the following equation,

$$\eta = \frac{Q_{out}}{Q_{in}} \times 100 \tag{6}$$

Where Q_{out} is heat output and Q_{in} is heat input. The heat input was not recorded during the experiments because an electric heater was not used as the heat source. Since the heat input was not taken during the experimental investigation, the heat input is assumed to be the same for all the conditions. Having the heat input assumed to be constant, the only variable that can affect the efficiency of the thermosyphon is the heat input. Equation 7 shows the formula to calculate heat output. To obtain the heat output, the heat loss has to be determined by using equation 8.

$$Q_{out} = Q_{in} - Q_{loss} \tag{7}$$

$$Q_{loss} = mc_p\varphi \tag{8}$$

Assuming the mass of the working fluid and the temperature difference between the evaporator and condenser are constant for all conditions. The only variable that affects the heat loss is the specific heat capacity. Result shows that specific heat capacity decreases as the concentration of the nanoparticles increases. Therefore, as the specific heat capacity decreases, the heat loss also decreases. Using Equation 7, it can be said that the heat output increases as the heat loss decreases. Based on Equation 6, the efficiency of thermosyphon increases as the heat output increases. Hence, the presence of nanoparticles in the working fluid improves the efficiency of thermosyphon.

From the analysis, it shows that the presence of nanoparticle in the working fluid reduces the specific heat capacity of the working fluid. Using the calculated value of the specific heat capacity and a few assumptions, the efficiency of the thermosyphon for each working fluid was determined. In conclusion, the efficiency of the thermosyphon increases as the specific heat capacity reduces, meaning the nanoparticles enhances the thermal properties of the thermosyphon.

4. Conclusion

The experimental investigation of the effects of Al_2O_3 nanoparticles on thermal characteristics of thermosyphon has been conducted with the aim to reduce power consumption and enhance the performance of the thermosyphon. This experimental investigation has achieved the objectives proposed at the beginning of the project. Firstly, the thermosyphon test rig is compatible to operate using nanofluid as the working fluid. The thermosyphon is manufactured using a copper pipe with a thickness of 3mm.

Secondly, investigating the effect of nanoparticle on the performance of the thermosyphon by focusing on the specific heat capacity of the working fluid have proven that the performance of the thermosyphon is enhanced. Based on specific heat analysis, the presence of nanoparticles in the working fluid reduces the specific heat capacity of the working fluid. This reduction in specific heat capacity is directly proportional to the concentration of nanoparticles in nanofluid. As a result, there is an increase in the efficiency of the thermosyphon with respect to the concentration of nanoparticles in the working fluid. This shows that the overall power consumption can be reduced by having nanoparticles in the working fluid of the thermosyphon.

4.1 Future recommendation

Although this experimental investigation fulfilled the objectives of this project, there is still room for improvement. In the future, an electric heater can replace the hot oil as the heat source. Instead of using air as the heat sink, future experimental investigations can use water to dissipate the heat at the condenser end. The heat output can be determined by the change in water temperature. This will provide more accurate heat input and output values to calculate the thermal conductivity and efficiency. Therefore, assumptions can be reduced and more accurate results can be obtained.

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References

[1] E. Firouzfar and M. Attaran, "A Review of Heat Pipe Heat Exchangers Activity in Asia," *Int. Sch. Sci. Res. Innov.*, vol. 2, no. 11, pp. 266–271, 2008.

[2] J. Wang, Y. Li, Y. Wang, L. Yang, X. Kong, and B. Sundén, "Experimental investigation of heat transfer performance of a heat pipe combined with thermal energy storage materials of CuO-paraffin nanocomposites," *Sol. Energy*, vol. 211, no. September 2019, pp. 928–937, 2020, DOI: 10.1016/j.solener.2020.10.033.

[3] S. Kloczko and A. Faghri, "Experimental investigation on loop thermosyphon thermal performance with flow visualization," *Int. J. Heat Mass Transf.*, vol. 150, p. 119312, 2020, DOI: 10.1016/j.ijheatmasstransfer.2020.119312.

[4] A. J. Robinson, K. Smith, T. Hughes, and S. Filippeschi, "Heat and mass transfer for a small diameter thermosyphon with low fill ratio," *Int. J. Thermofluids*, vol. 1–2, p. 100010, 2020, DOI: 10.1016/j.ijft.2019.100010.

[5] A. Meyer and R. T. Dobson, "A heat pipe heat recovery heat exchanger for a mini-drier," *J. Energy South. Africa*, vol. 17, no. 1, pp. 50–57, 2006, DOI: 10.17159/2413-3051/2006/v17i1a3364.

[6] H. Ghorabaee, M. R. S. Emami, F. Moosakazemi, N. Karimi, G. Cheraghian, and M. Afrand, "The use of nanofluids in thermosyphon heat pipe: A comprehensive review," *Powder Technol.*, vol. 394, pp. 250–269, 2021, DOI: 10.1016/j.powtec.2021.08.045.

[7] Y. Xuan and W. Roetzel, "Conceptions for heat transfer correlation of nanofluids," *Int. J. Heat Mass Transf.*, vol. 43, no. 19, pp. 3701–3707, 2000, DOI: 10.1016/S0017-9310(99)00369-5.

[8] J. Ghaderian *et al.*, "Performance of copper oxide/distilled water nanofluid in evacuated tube solar collector (ETSC) water heater with internal coil under thermosyphon system circulations," *Appl. Therm. Eng.*, vol. 121, pp. 520–536, 2017, DOI:

10.1016/j.applthermaleng.2017.04.117.

[9] V. Kiseev and O. Sazhin, "Heat transfer enhancement in a loop thermosyphon using nanoparticles/water nanofluid," *Int. J. Heat Mass Transf.*, vol. 132, pp. 557–564, 2019, DOI: 10.1016/j.ijheatmasstransfer.2018.11.109.

[10] S. Das, A. Giri, S. Samanta, and S. Kanagaraj, "Role of graphene nanofluids on heat transfer enhancement in thermosyphon," *J. Sci. Adv. Mater. Devices*, vol. 4, no. 1, pp. 163–169, 2019, DOI: 10.1016/j.jsamd.2019.01.005.

[11] N. K. Gupta, A. Barua, S. Mishra, S. K. Singh, A. K. Tiwari, and S. K. Ghosh, "Numerical study of CeO2 /H2O nanofluid application on thermal performance of heat pipe," *Mater. Today Proc.*, vol. 18, pp. 1006–1016, 2019, DOI: 10.1016/j.matpr.2019.06.541.

[12] L. S. Sundar, A. H. Misganaw, M. K. Singh, A. M. B. Pereira, and A. C. M. Sousa, "Efficiency, energy and economic analysis of twisted tape inserts in a thermosyphon solar flat plate collector with Cu nanofluids," *Renew. Energy Focus*, vol. 35, no. December, pp. 10–31, 2020, DOI: 10.1016/j.ref.2020.06.004.

[13] M. Moradgholi, S. Mostafa Nowee, and A. Farzaneh, "Experimental study of using Al2O3/methanol nanofluid in a two phase closed thermosyphon (TPCT) array as a novel photovoltaic/thermal system," *Sol. Energy*, vol. 164, no. February, pp. 243–250, 2018, doi: 10.1016/j.solener.2018.02.055.

[14] M. R. Sarmasti Emami, S. H. Noie, and M. Khoshnoodi, "Effect of aspect ratio and filling ratio on thermal performance of an inclined two-phase closed thermosyphon," *J. Sci. Technol. Trans. B Eng.*, vol. 32, no. 1, pp. 39–51, 2008.

[15] K. S. Ong and M. Haider-E-Alahi, "Performance of a R-134a-filled thermosyphon," *Appl. Therm. Eng.*, vol. 23, no. 18, pp. 2373–2381, 2003, DOI: 10.1016/S1359-4311(03)00207-2.

[16] P. G. Anjakar and D. R. B. Yarasu, "Experimental analysis of condenser length effect on the performance of thermosyphon," *Int. J. Emerg. Technol. Adv. Eng.*, vol. 2, no. 3, pp. 494–499, 2012.

[17] D. Dhinesh Kumar and A. Valan Arasu, "A comprehensive review of preparation, characterization, properties and stability of hybrid nanofluids," *Renew. Sustain. Energy Rev.*, vol. 81, no. February 2017, pp. 1669–1689, 2018, DOI: 10.1016/j.rser.2017.05.257.

[18] M. G. Mousa, "Effect of nanofluid concentration on the performance of circular heat pipe," *Ain Shams Eng. J.*, vol. 2, no. 1, pp. 63–69, 2011, doi: 10.1016/j.asej.2011.03.003.

[19] W. N. Septiadi, K. Astawa, I. G. A. P. Arvikadewi, D. Febraldo, and G. J. P. Putra, "Boiling phenomenon of graphene nano-coating wick heat pipe," *Evergreen*, vol. 7, no. 2, pp. 297–302, 2020, DOI: 10.5109/4055236.

[20] S. U. Ilyas, R. Pendyala, M. Narahari, and L. Susin, "Stability, rheology and thermal analysis of functionalized alumina- thermal oil-based nanofluids for advanced cooling systems," *Energy Convers. Manag.*, vol. 142, pp. 215–229, 2017, DOI: 10.1016/j.enconman.2017.01.079.