SYNTHETIZATION OF BANANA-STEM FIBRE NANOPARTICLES TO PROMOTE THERMAL CONDUCTIVITY OF NANOFLUIDS IN COOLING SYSTEMS

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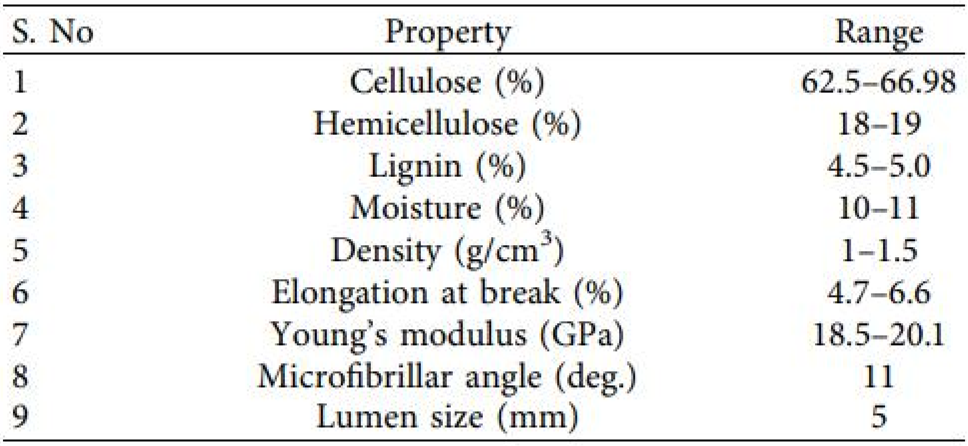
ABSTRACT

Cooling is one of the most significant and challenging aspects of heat transfer applications; for instance, heat from power generation requires a high amount of cooling. Most chemical processes are exothermic reactions, which demands faster and more effective cooling at different stages. Recent studies shows that researchers are strongly concerned on how to properly utilize the value of banana fibre and turn it into a treasure. In this study, the thermal conductivity of nanofluids prepared from banana-stem fibre nanoparticles have been investigated both as a function of concentration of banana-stem fibre nanoparticles as well as temperature ranges between 20 and 60 °C. For decades, water or a mixture of water and antifreeze has been used in automotives radiators as coolants for exchanging heat. As thermal conductivity offered by these fluids is low, hence their applications in modern equipment have reached their upper limits. Advancement in nanotechnology had result in a new kind of fluids known as "nanofluids", whose thermal performance is greater compared to conventional coolants. The focus of this research is on the application of banana stem fibre nanoparticles nanofluid in a cooling system. Nanofluids of different volumetric concentrations (0.3, 1.5 and 3%) were prepared and then experimentally their heat transfer performance was determined using transient hot-wire apparatus. Based on the calibration results from the transient hot-wire method, the measurement error was estimated to be within 2%. The investigated thermophysical properties of the prepared nanofluids at different volume fractions (0.3,0.6,0.9,1.2 and 1.5%) and water were simulated using computational fluid dynamics (Auto desk CFD) software for its cooling performance. From the result of water simulation, the inlet and outlet temperatures generated by the solver are 23.80 and 104.87oC respectively. While from the results of nanofluid simulation at 0.3% volume fraction of nanofluid the solver generated the inlet and outlet temperature as 9.41oC and 110.23oC, while for 0.6 volume fraction of nanoflid the solver generated inlet and outlet temperature as 7.01oC and 103.81o C. In addition, the solver generated the inlet and outlet temperature of 0.9% volume fraction of nanofluid as 10.88oC and 104.44oC. For 1.2% volume fraction of nanofluid the solver generated inlet and outlet temperature as 9.26 and 102.63oC. Finally, the solver generated the inlet and outlet temperature for 1.5% volume fraction as 9.20 and 102.57°C respectively. Therefore, it was concluded that the nanofluids prepared from banana nanoparticles give better predictions for the effective thermal conductivity enhancement and effective cooling medium in heat exchanger.

INTRODUCTION

Natural fibres today play an important role as reinforcement in bio composites due to their properties such as biodegradability, nontoxicity, recyclability, and light weight [1]. The most important components of natural fibres are hemicelluloses, cellulose, lignin, pectin, and waxes [2]. Banana fibre is a natural fibre that has gained popularity as an eco-friendly product because it is practical, long-lasting, and biodegradable. The primary source of banana fibre is the stalk, which is an agricultural waste that is typically discarded in a careless way that harms the environment [3]. Banana is one of the most common fruits in the world and is officially certified by the United Nations Agricultural Organization (FAO) as one of the four major food crops in developing countries [1]. Banana fibre is found in the bast of banana straws. It belongs to natural fibre composed mainly of lignin, cellulose, and hemicellulose. Therefore, it is called lignocellulosic fibre, which has been discovered to have a cellulose content of 60-65%, 6-19% hemicellulose, 5-10% lignin, 3-5% pectin, ash 1-3%, and 3-6% extractives [4].

Banana fibre blends are mainly divided into blended, and fibre hybrid reinforced composites, which can give full play to the excellent properties of different types of fibre and play a role in building on its strengths and avoiding its weaknesses [5]. At the same time, banana fibre blends are made up of natural fibre, which not only makes reasonable use of sustainable resources and agricultural waste but also is degradable and friendly to the environment. Blended fabrics are a mixture of chemical fibre and other natural fibres, such as cotton, silk, linen, and other natural fibre spun and woven into a textile product [6]. Such blended textiles not only retain the relative advantages of natural fibre but also add the style of chemical fibre [7].



S. No	Property	Range
1	Cellulose (%)	62.5–66.98
2	Hemicellulose (%)	18–19
3	Lignin (%)	4.5–5.0
4	Moisture (%)	10–11
5	Density (g/cm^3)	1–1.5
6	Elongation at break (%)	4.7–6.6
7	Young's modulus (GPa)	18.5–20.1
8	Microfibrillar angle (deg.)	11
9	Lumen size (mm)	5

Table 1. Physical properties of banana fibre [8]

It has been a keen interest of researchers for quite a long time to enhance the heat transfer in devices used in industries and in our daily life to increase their performance and efficiency. In the past different techniques like free and forced convection, and extended surfaces were used for transferring heat at a higher rate. As every technique has its limits, so these techniques reached to their upper limits. Hence in the recent era, scientists were forced to find new ways to enhance the heat transfer of nanofluids and as a result, today, we have come across a term known as nanofluids. Nanofluids are fluids consisting of nano meter sized particles known as nanoparticles dispersed in a base fluid.

Radiators have wide applications ranging from industrial machines to automobiles. Automobile manufacturers are in tough competition to improve automobiles efficiency and performance, they cannot overlook the heat sink (radiator) used in automobiles. It is an important part of an automobile which is used to keep the engine cool. Up till now less work is done to increase the efficiency of a heat exchanger (radiator). An approach to achieve this goal is to use nanofluids in a heat exchanger (radiator) to enhance heat transfer. A significant importance is given to use of nanofluids in heat exchangers of different types, however not much studies have been reported about use of nanofluids in car radiator. Yu et al. [2007] presented a review and summarized that 15% to 40% enhancement in heat transfer can be attained by using different kinds of nanofluids.

Lee et al. [1999] by using transient hot wire method, found the thermal conductivity of aluminum oxide-ethylene glycol, aluminum oxide-water, copper oxide-ethylene glycol and copper oxide-water. Thermal conductivity was found to vary with the shape and size of the particles along with the thermal properties of the nanoparticles and base fluid. Xie et al. [2010] used ZnO, MgO, Al2O3 and TiO2 nanoparticles in 45 vol. % of EG and 55 vol. % of distilled water acting as a base fluid. They found that the enhanced coefficient of heat transfer by the above stated nanofluids during a laminar flow in a copper tube of a circular cross section having a constant wall temperature. It was observed that Al2O3, MgO and ZnO showed greater coefficient of heat transfer enhancement. MgO showed peak value of enhancement of about 252% at 1000 Reynolds number. Xuan and Li. [2003] reported that nanofluids have higher thermal conductivities in comparison with pure water. Their experimental investigation consisted of water based nanofluid (containing Cu nanoparticles) passing under constant heat flux from a straight tube. It showed a negligibly small effect over power consumption caused by nanofluid friction factor at less concentration. Chandrasekar et al. [2010] found that the thermal conductivity increased by increasing volume concentration. Das et al. [2003] reported the increase in thermal conductivity of nanofluids with increasing temperature and also reported that it could not be predicted by thermal conductivity effective model. They found that the conduction of heat will be more if the particles in the nanofluid are more because it will result in a greater surface area for the transfer of heat.

Peyghambarzadeh et al. [2011] tested a car radiator using Al_2O_3/water nanofluids and recorded a heat transfer enhancement of 45% at about 1% volumetric concentration. Peyghambarzadeh et al. [2011] again tested a car radiator using Al_2O_3 mixed with EG and water respectively. They recorded a 40% enhancement in heat transfer as compared to the base fluids under same conditions. Duangthongsuk and Wongwises [2010] used TiO_2/water nanofluid and performed an experiment by flowing it in a regime of turbulent flow to analyse the thermal behaviour and drop in pressure. They found that the drop in pressure for nanofluids was slightly greater than the base fluid and by an increase in volumetric concentration its value increased. Esfea et al. [2014] performed an experiment and found that by adding nanoparticles of MgO in less than 1% volumetric concentration in base fluid caused a heat transfer enhancement of the fluid. It was found that the pressure drop in the nanofluid was higher as compared to base fluid, but without having any significant increase in power consumption. Leong et al. [2010] tested a car radiator to find the thermal performance of copper-ethylene glycol nanofluids. It was found that by only 2 vol. % of Cu/EG nanofluids an overall coefficient of heat transfer of about 164 W/m2 K was recorded as compared to the 142 W/m2 K shown by base fluid. Dittus et al. [1930] found the viscosity and thermal conductivity of ZnO/EG nanofluids experimentally. They found that by using 5% concentration of nanoparticles about 26.5% of enhancement in thermal conductivity could be achieved. Ali H.M and ALI M [2015] used different volumetric concentrations of water based MgO nanofluids in a car radiator to find the thermal performance of MgO. They found that at 0.12 % volumetric concentration of MgO in base fluid (water) and flow rate of 8 LPM, a peak heat transfer enhancement of up to 31% was obtained.

Experimental Procedure

Raw banana stems were collected from the farm and process in two phases i.e. extraction of banana fibre from banana stem, and ball milling of banana fibre. In the extraction face, the leaves and flowers were removed from the stem of matured banana tree. The stems were cut into pieces of different length and sizes. The pieces were then placed into a bucket filled with water to a level such that they were completely submerged and airtight bucket for 14 days. The decomposed stem was removed from the water after two weeks and washed with fresh water. The fibre was then separated from the soft tissue. These fibres make up the vascular tissue that contains both the vessels and the sclerenchyma fibres. The fibres were washed to remove all the epidermal and thick-walled woody xylem cells and sun dried for 21 days. The dried fibre was then re-assembled for production of nanoparticles. The prepared banana stem fibre ready for ball milling is shown in Figure 1.

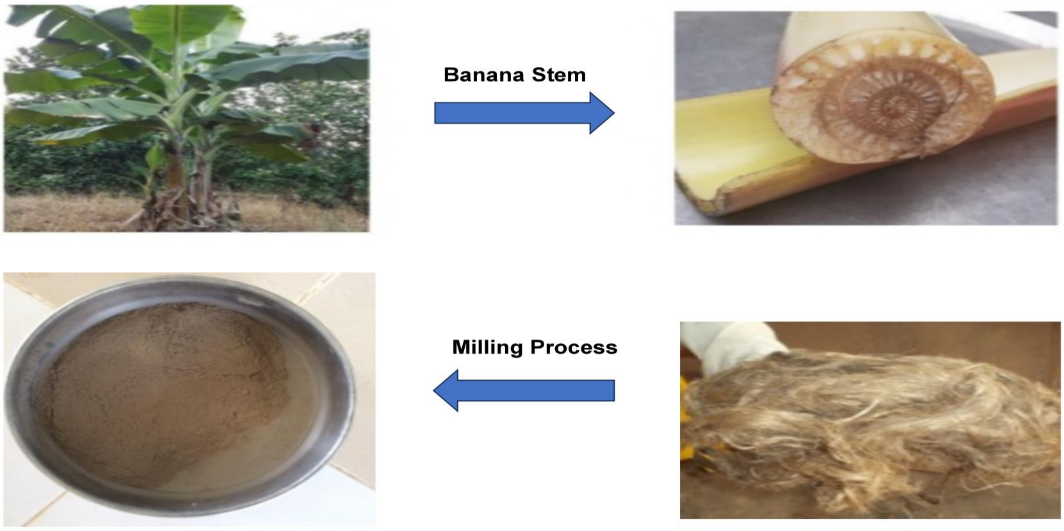


Fig. 1. Banana Stem Processing

The dried banana fibre was put into a ball milling machine where the dried banana fiber was turned into powder. The sample was transferred to a container and sieved using different sizes of sieving apparatus (100um, 75um, 50um and 30um). After sieving, the powdered particles obtained were found to be in micro-sizes (50um). The 50 micrometre size particles were taken back to ball milling machine for further processing. After sieving, the powder particles was characterize using Transmission electron microscopy (TEM) and X-ray diffraction (XRD) processes where the powder particles were found to be in nano. The powdered form of the sample is shown in Figure 1 and the TEM image is shown in Figure 2.

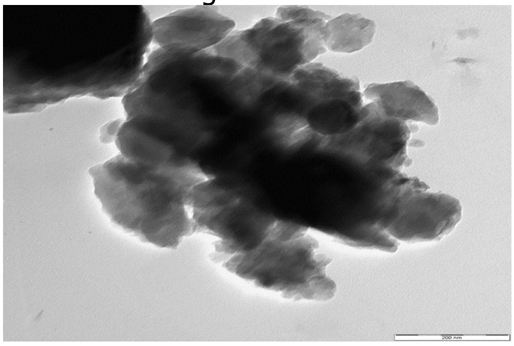


Figure 2: TEM image of banana stem fibre nanoparticles

The preparation of the nanofluids was carried. Two-step methods that are common and suitable for commercial scale production was used to prepare the nanofluids' samples. Ultrasonication was done for proper homogenization. The homogenization process was carried out in a 100 ml beaker and placed in the thermal bath during preparation due to the high energy impact of the process. For each volume fraction, the equivalent mass of nanoparticles was determined using the mass and densities of the base fluid and the nanoparticles.

A digital highland weighing balance (HCB 1002) (max: 1000g and accuracy of ±0.01g) weighing balance was used to measure the sample during preparation. Different volume fractions (0.3%, 0.6%, 0.9%, 1.2% and 1.5%) of nano fluid were prepared by dispersing banana fibre nano particles (sample) into deionize water (base fluid). The process of preparing nanofluids was the same for all the volume fractions (0.3%, 0.6%, 0.9%., 12% and 1.5%), but the quantity of the nanoparticles powder (Mass of samples) added to the based fluids was not the same for all the volume fractions. The solution was stirred using a magnetic stirrer and sonicated continuously for 40minutes, this ensured uniform dispersion of nanoparticle in the base fluid.

Sedimentation method was used to test the stability of the prepared nanofluids. The nanofluid prepared was kept for 72 hours, to observe its stability. After 72 hours it was observed that there was sedimentation of nanoparticles at the bottom of the beaker. From observation it shows that there is need to add surfactants to the solution of the prepared nanofluids. The surfactants keep particles dispersed in base fluids by electrostatic repulsive forces among the particles and hydrophobic surface forces due to physical absorption of surfactant in the solution. Therefore, another nanofluids was prepared and 0.1% 0f dodicylsulfate surfactants was added and an ultrasonic sonicator was used for 40 minutes to homogenize the solution (nanofluids) for better stability, and the solution (prepared nanofluids) was again kept for observation. After 20 days of observation, a negligible sedimentation of Banana stem nanoparticles was seen or observed, the nanofluids are stable when the concentration or particle size of supernatant particles keeps constant.

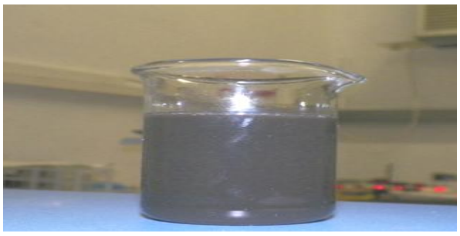


Figure 3. Prepared nanofluids

Wang et al. [1999] studied thermal conductivity of Al2O3 and CuO nanofluids with a particle size of 20 nm. Each was suspended in water, vacuum pump oil, engine oil, and ethylene glycol. The steady state method was used to measure thermal conductivity. Their results showed that the thermal conductivity of both nanofluids were higher than that of the base fluids and varying with concentration level. The engine oil and ethylene glycol base fluids yielded higher enhancement than other types of base fluids. When compared with the theoretical model, a thermal conductivity ratio of the nanofluids was found to be higher. Eastman et al. [2001] conducted an experiment to measure the thermal conductivity of Cu-ethylene glycol nanofluid with an average copper particle size of 10 nm and concentration level of 0.6 vol. %. A transient hot-wire method was used for measurement. They found that nanofluids had higher thermal conductivity when the concentration level increased. Moreover, acid-added nanofluids had increased thermal conductivity. At 0.3 vol. % concentration level, thermal conductivity of acid-added Cu nanofluid increased dramatically by 40%. Their experimental results were higher than those obtained from the classical model.

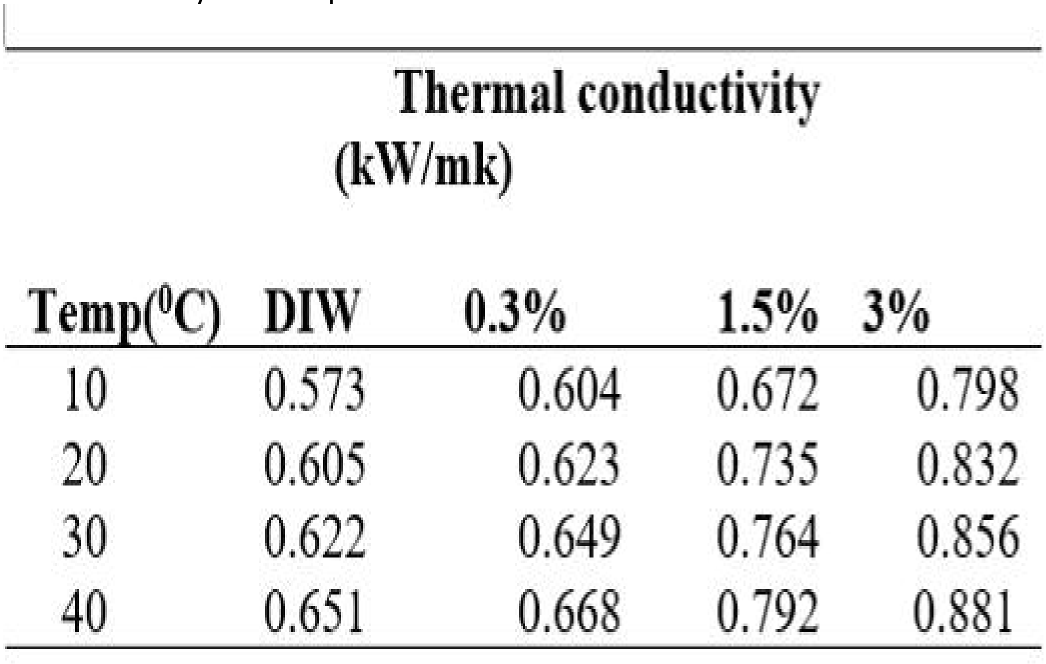
Chon and Kihm [2015] studied the increase in thermal conductivity of a nanofluid due to Brownian motion. Al2O3-water nanofluid at the concentration of 1 vol. % was used in their experiment. The particle sizes used were 11 nm, 47 nm, and 150 nm in a temperature range of 20-70 ºC. They reported the thermal conductivity of the nanofluid increased more than the base fluid and rise with the increase of temperature. They also establish that smaller particle sizes give higher thermal conductivity. They asserted the increase in thermal conductivity of the nanofluid resulted from Brownian motion or micro-convection mechanism. They argued the increase of temperature caused a greater Brownian motion mechanism.

Thermal Conductivity of Prepared Nanofluids

Thermal conductivity of Banana fibre nanofluids was measured on a KD2 Pro Thermal Property Analyzer based on the transient hot wire method. A schematic diagram of the KD2 Pro Thermal Analyser and KD2 Pro Thermal Instrument is shown in fig. 4. The cylindrical testing cell of the Analyzer has 30 mm diameter and 60 mm length. After loading nanofluids into the cylindrical testing cell, the single-needle sensor of the instrument was immersed vertically in the centre of nanofluids. To stabilize the environmental temperature, the cylindrical testing cell was first placed in a thermostatic bath for 20 minutes before measurement. Thermal conductivity of three different volume fractions (0.3%, 1.5% and 3%, and D I Water) was measured. Average values of four repeated temperature points measurements were used (10 0C, 20 0C, 30 0C and 40 0C), for all the volume fractions, the interval between each measurement was an hour.

Figure 4. KD2 Pro Thermal Analyser

The thermal conductivity result is presented below.



Thermal conductivity
(kW/mk)

Temp(^{0}C)	DIW	0.3%	1.5%	3%
10	0.573	0.604	0.672	0.798
20	0.605	0.623	0.735	0.832
30	0.622	0.649	0.764	0.856
40	0.651	0.668	0.792	0.881

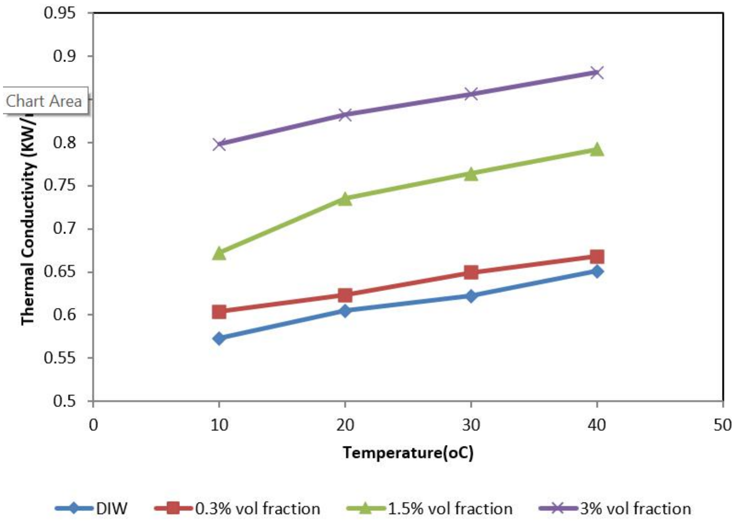


Table 2. Thermal Conductivity Measurement Result

Simulation of prepared nanofluids as coolant

The prepared banana nanoparticles nanofluids were simulated using computational fluid dynamics (Auoto desk CFD) software for its cooling performance as shown below.

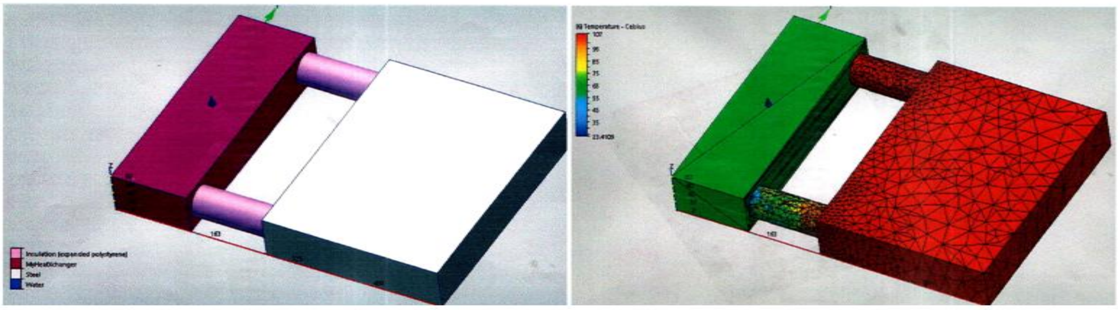


Figure 5. Simulation Materials.

The prepared nanofluid was poured into the heat exchanger (radiator). As soon as the system was activated, the coolant from the outlet of the heat exchanger flowed through the engine environment and produces large amount of heat. The heat produced by the engine was absorbed by the coolant which eventually reduced the engine temperature. This heated coolant flowed from the engine outlet to the inlet of the heat exchanger. Once the hot coolant reached the heat exchanger, it circulated through a series of heat exchanger nodes (fins). The heat exchanger fan extracted this heat and reduced the temperature of the heated coolant. The procedure continued for as long as the engine was running. The boundary condition adopted in this simulation was that the maximum temperature was set to 107^0C. The meshed model used in the simulation had 11363 numbers of nodes and 38250 numbers of elements. The simulation was carried out at different volume fractions of nanofluids (0.3, 0.6, 0.9, 1.2, and 1.5%) and water respectively.

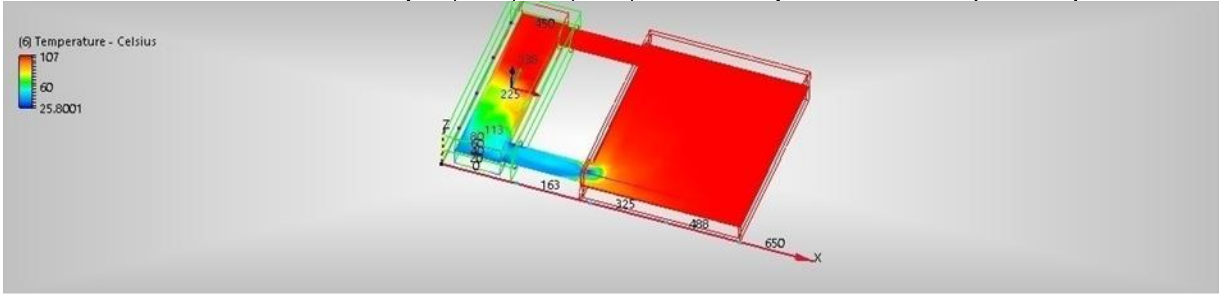


Figure 6. Water Simulation

Water	Volume 7	Density	Piecewise Linear
		Viscosity	0.001003 Pa-s
		Conductivity	0.6 W/m-K
		Specific heat	4182.0 J/kg-K
		Compressibility	2185650000.0 Pa
		Emissivity	1.0
		Wall roughness	0.0 meter
		Phase	Linked Vapor

inlet 1 (heat exchanger outlet - part 1)	inlet bulk pressure	0.247266
	inlet	23.4109° C
	inlet mach number	1.88654e-
	mass flow in	0.00498319
	minimum x,y,z of opening	0.0
	node near minimum x,y,z of	164.0
	Reynolds number	0.102733
	surface id	16.0
	total mass flow in	0.00498319
	total vol. flow in	5e-06
	volume flow in	5e-06
outlet 1 (heat exchanger inlet - part 1)	mass flow out	3.70163 kg/s
	minimum x,y,z of	0.0
	node near minimum	153.0
	outlet bulk pressure	0.0 N/m^2
	outlet bulk	104.912 C
	outlet mach number	3.097e-12
	Reynolds number	76.4095
	surface id	14.0
	total mass flow out	3.70163 kg/s
	total vol. flow out	0.00387955 m^3/s
	volume flow out	0.00387955 m^3/s

Figure 7. Water Simulation Results

The simulations result shows that as volume fraction increases inlet and outlet temperatures are decreasing while the Reynolds numbers are increasing. It was also observed that as volume fraction increases the thermal conductivity increases. The result is in good agreement with those of other researchers such as Yu et al. (2007) who carried out CFD analysis of heat transfer performance in a car radiator with nanofluids as coolants. Their investigation revealed that heat transfer coefficient increases significantly with the increase in particles loading. Das et al. (2003) in their study investigated the heat transfer performance of copper oxide and alumina based nanofluids in a different loading of ethylene glycol/water mixtures as coolants in a flat tube radiator system. Significant improvement in the convective heat transfer coefficient was found using nanofluid coolants over base fluid alone. In another study by Leong et al. (2010), heat transfer properties were investigated using copper nanoparticles at different loading in ethylene glycol/water nanofluid system. It was found that the higher concentrations of nanoparticles are more effective for cooling applications.

Leong et al (2010), also studied the effect of Reynolds number on the thermal performance of a car radiator and found that at constant volume flow thermal performance of radiators significantly improved at high Reynolds numbers. Finally, the thermal conductivity average heat transfer coefficient was found to increase with increase in Reynolds number.

DISCUSSION OF RESULTS

The thermal conductivity of banana fibre nanofluid with de-ionized water at 0.3%, 0.6% and 3% with temperatures 100C, 200C, 300C and 400C is shown in table 5 and figure 6. From the result, thermal conductivity values increased with increase in temperature. The increase is above that of the base fluid. Thermal conductivity of de-ionized water and sample nanofluid increases almost linearly with temperature (10 to 40 ºC) at various volume concentration (0.3%, 1.5% and 3.0%) of nanoparticles of banana fibre nanofluid. The thermal conductivity increase is less at lower temperatures in relation to increases in thermal conductivity at higher temperatures (20 - 40 º C). The lowest value of thermal conductivity was 0.604 kW/mk at 100C (0.3% volume fraction) while the highest value of thermal conductivity was 0.881 Kw/mk at 40 0C (3% volume fraction). This shows a minimum and maximum thermal conductivity enhancement of 5.2% and 35.3% respectively with mixture of deionized water and banana nanoparticles nanofluid.

CONCLUSION

This study investigated the thermal conductivity enhancement of banana fibre nanoparticles nanofluids. Thermal conductivity of base fluid and thermal conductivity of banana nanoparticles nanofluids increases almost linearly with temperature (10 to 40 ºC) at various volume concentration of nanoparticles (banana fibre) nanofluids. This increment in the thermal conductivity is more at high temperature (10ºC to 40 ºC). The same is true for higher value of volume concentration of nanoparticles. The mechanism behind the thermal conductivity enhancement such as Brownian motion, micro convection, explains the conductivity enhancement. Brownian motion assisted micro convection are responsible for the Thermal conductivity enhancement. Brownian or random motion increases with increases in temperature that is why the thermal conductivity increases with temperature. The thermal conductivity of banana nanoparticles increases with rise in volume concentration (0.3%, 0.6% and 3%) loading, at various temperatures. The enhancement in thermal conductivity with respect to volume concentration shows almost linear behaviour at various temperatures. At a particular value of temperature corresponding enhancement in thermal conductivity is less in the volume concentration range from 0.3 to 3.0%. The reason behind this behaviour is clustering of nanoparticles at higher concentrations.

From the results, the lowest value of thermal conductivity of banana nanoparticles nanofluids was found to be 0.604 kW/mk at100C and 0.3% volume fraction while the highest value of thermal conductivity was found to be 0.881 Kw/mk at 40 0C and 3% volume fraction. This shows a minimum and maximum thermal conductivity enhancement of 5.2% and 35.3% respectively, as compared with mixture of base fluid (deionized water) and banana fibre nanoparticles nanofluid.

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