Nanotechnology Perceptions
ISSN 1660-6795
www.nano-ntp.com

Comparative Analysis Of Thermal Performance Of Al2O3 Mono Nano Fluid And Al2O3 – Cu Hybrid Nano Fluid In Car Radiator

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In this paper Al2O3 and Copper nano particles dispersed in base fluid water have been utilized to make nano fluid which is utilized as a coolant in car radiator. There are four different concentration of 0.1%, 0.2%. 0.3% and 0.4% Al2O3 nano particles are dispersed individually in base fluid water then mixture of Al2O3 and Cu nano particles are dispersed in base fluid water and analyze the thermal characteristics in car radiator. Heat transfer performance are compared for Al2O3 mono nano fluid and Al2O3 - Cu hybrid nano fluid in car radiator for four different flow rate of 10 lpm, 12 lpm, 14 lpm, 16 lpm. It is found from various heat transfer characteristics that hybrid combination Al2O3 – Cu gives higher heat transfer rate as compare to mono nano fluid Al2O3 in radiator.

Keywords – Nano fluid, Car Radiator, Heat transfer rate, Al2O3, Al2O3 – Cu.

1. Introduction

In the area of heat transfer enhancement of heat exchangers use of nano fluid is very common in various research papers from several decades. Preparation of nano fluid have been done by dispersing nano particles in base fluid. Moreover the thermal conductivity value of metals are higher as compare to base liquid due to molecular arrangement. Hence particles of solid material enhances the thermal conductivity of the solid dispersed fluid. Hence the utilization of nano fluid in many heat exchanger devices such as car radiator, condenser, evaporator and electronic cooling devices are being investigated [1-4]. Preparing nanofluids stands as a crucial step in leveraging nanoparticles to enhance the thermal conductivity of traditional heat

transfer fluids. Researchers explore various nanoparticle types—metallic (such as Cu, Al, Fe, Au, and Ag), non-metallic (including Fe_3O_4, Al_2O_3, TiO_2, CuO and SiC), and carbon nanotubes. The thermal conductivity of nanofluids depends on nanoparticle size, shape, and material composition. Generally, nanofluids containing metallic nanoparticles exhibit higher thermal conductivity than those with non-metallic (oxide) counterparts. Smaller particle sizes correlate with increased thermal conductivities. Additionally, nanofluids containing spherical nanoparticles show a less pronounced enhancement in thermal conductivity compared to those with cylindrical (nano-rod or tube) nanoparticles [5].
Experimental research on the thermal conductivity enhancements of Al_2O_3/water and CuO/water nanofluids have been conducted by Das et al.[6] individually. Their findings revealed that nanofluids with smaller CuO particles exhibit greater conductivity enhancement with increasing temperature. Moreover, the enhancement is significantly amplified for Al_2O_3/water nanofluids as well. They also noted that the effect of particle concentration is more pronounced for Al_2O_3/water nanofluids.

Xie et al. [7] conducted an experimental study on the thermal conductivity of nanometer-sized Al_2O_3 suspensions in water, oil, and ethylene glycol (EG). Their findings indicated that incorporating nanoparticles into base fluids significantly increases the thermal conductivities of the suspensions. The enhancement in thermal conductivity ratios was observed to grow with the volume fraction of nanoparticles. However, for suspensions containing the same nanoparticles, the improvement in thermal conductivity ratio diminished as the thermal conductivity of the base fluid increased.
Eastman et al. [8] demonstrated in their experimental work that a nanofluid comprising Cu nanometer-sized particles dispersed in ethylene glycol (EG) exhibits a significantly higher effective thermal conductivity than pure EG. They found that the effective thermal conductivity of EG increased by up to 40% with the addition of approximately 0.3% Cu nanoparticles. This enhancement was greater than that observed in EG-based nanofluids containing either CuO or Al_2O_3 nanoparticles at the same particle volume fractions. They concluded that nanofluids with Cu nanoparticles directly dispersed in EG show significantly improved thermal conductivity compared to those containing oxide particles. The substantial improvement in effective thermal conductivity for nanofluids with metallic particles offers considerable potential for transforming industries reliant on the performance of heat transfer fluids.

In a conventional automotive radiator, the coolant consists of a mixture of antifreeze and water. This coolant absorbs heat from engine components and transfers it to the radiator, where it is released into the atmosphere through a series of passageways and tubes. The ideal coolant should be cost-effective, chemically inert, have a low viscosity, high thermal capacity, and should not cause corrosion within the cooling system. [9] Gulhane and Chincholkar [10] conducted an experimental study on the use of water-based Al_2O_3 nanofluid at low concentrations in a car radiator. Their results indicated that the heat transfer coefficient increased with higher particle concentrations, flow rates, and inlet temperatures of the coolant, achieving a maximum enhancement of 45.87% compared to pure water. Ray and Das [11] compared three different nanofluids—aluminum oxide (Al_2O_3), copper oxide (CuO), and silicon oxide (SiO_2)—in the same base fluid, a 60:40 mixture of ethylene glycol and water, used as a refrigerant in a car radiator. They found that a nanofluid with a 1% volumetric concentration of nanoparticles had superior properties compared to higher concentrations. Specifically, the Al_2O_3 nanofluid resulted in a 35.3% reduction in pumping power and a 7.4% reduction in heat transfer surface area. The CuO nanofluid showed slightly lower improvements, with reductions of 33.1% in pumping power and 7.2% in heat transfer surface area. The SiO_2 nanofluid exhibited the lowest performance but still managed to reduce pumping power by 26.2% and the heat transfer surface area by 5.2%. Ali et al. [12] investigated the addition of ZnO nanoparticles to a base fluid at various volumetric concentrations (1%, 8%, 2%, and 3%). They varied the fluid's flow rate between 7 and 11 liters per minute (LPM) with Reynolds numbers ranging from 17,500 to 27,600. Their findings revealed an increase in heat transfer for all concentrations of nanofluids compared to the base fluid. The highest increase, 46%, was observed with a 2% volumetric concentration. However, increasing the concentration to 3% resulted in a decrease in heat transfer. Additionally, varying the inlet temperature from 45 °C to 55 °C led to a 4% increase in heat transfer velocity. Moghaieb et al. [13] performed an experimental analysis using Al_2O_3 nanofluid and water in a car engine cooling system. They studied the convective heat transfer of the nanofluid with nanoparticle diameters ranging from 21 to 37 nm. The results demonstrated that the convective heat transfer coefficient was directly proportional to flow velocity and inversely proportional to temperature. They found that the heat transfer was 78.67% higher than that of the traditional fluid in a car radiator when using a 1% volumetric concentration of nanoparticles.

Hybrid nanofluids represent an innovative class of nanofluids where multiple types of nanoparticles are combined, resulting in superior thermal properties compared to those containing a single type of nanoparticle. Nine et al. [14] developed an Al_2O_3–MWCNT-water nanofluid and observed an 8% increase in thermal conductivity compared to pure Al_2O_3 nanofluid. Various studies have explored different hybrid nanofluids, such as Ag-MWCNT [15], Nanodiamond-Fe_3O_4, and MWCNT-Fe_3O_4 for applications in lubrication, heat transfer (thermal conductivity), and electrical conductivity enhancement. Layered double hydroxide (LDH) nanofluids are a specific type of hybrid nanofluid that combines two or three metal ions (both bivalent and trivalent) into a single nanoparticle. Chakraborty et al. [16] prepared a Cu-Al LDH-water nanofluid using the co-precipitation technique and reported a 16.1% increase in thermal conductivity for a 0.8 vol% nanofluid.

Nano fluid Preparation

The most commonly used technique for creating nanofluids is the two-step synthesis method. This approach is cost-effective and straightforward. In the two-step process, nanoparticles are initially produced through physical or chemical means, and then they are dispersed into base fluids using magnetic stirring.[17-18]. The initial crucial stage in experimental investigations involving nanofluids is the preparation process. In this study, Al_2O_3 and Cu nano particles with base fluid water hybrid nanofluids ranging in volume fractions from 0.1% to 0.4% were prepared utilizing a two-step method (refer to Fig. 2). There are three major steps for preparation of stable nano fluid. First step is nano particle preparation which we have skipped by borrowing directly from outside. Second stage is magnetic stirring process which uniformly mix the mixture using stirring the sample by 1400 rpm speed. Last stage of the process is sonication process which will break down agglomeration of nano particles. The desired volume concentration of the nanofluid was achieved by dispersing a specific quantity of Al2O3 and Cu nanoparticles in deionized water employing a probe sonication vibrator (modern college of pharmacy nigdi, India) at 20 kHz and magnetic stirrer process Fig. 1b. To ensure uniform dispersion and stable suspension, crucial factors influencing the final properties of nanofluids, the nanofluids were subjected to continuous vibration for 4 hours [19].

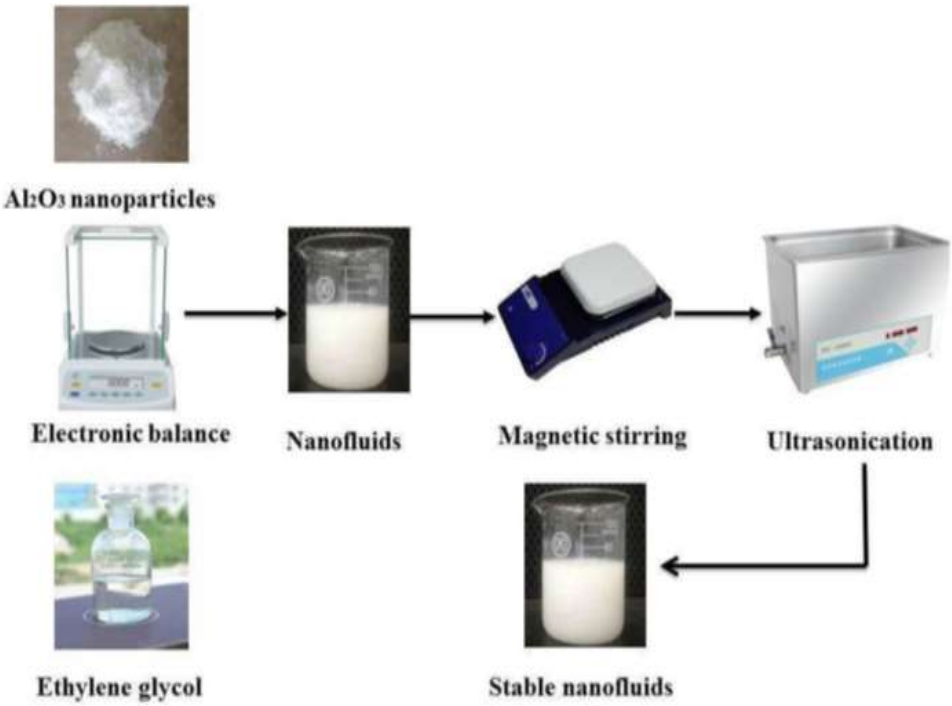
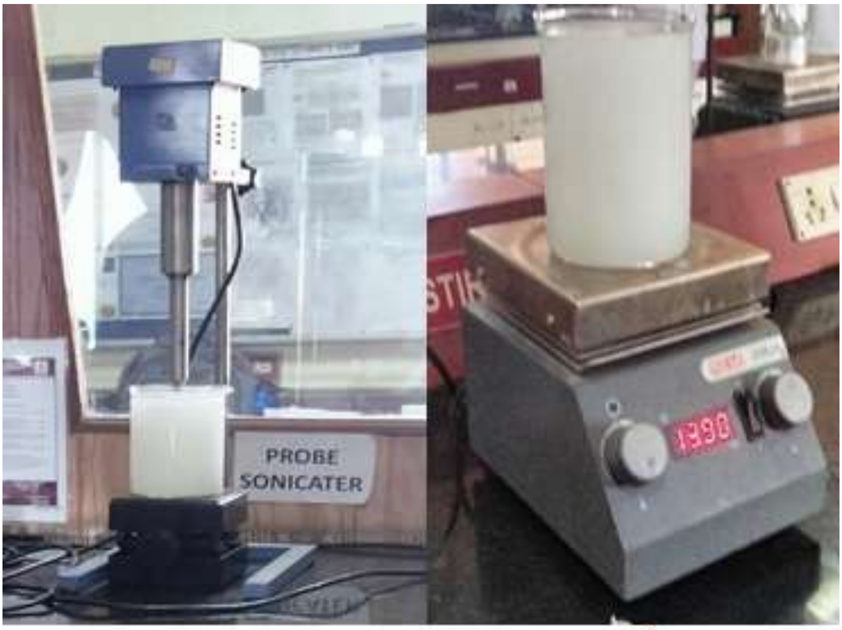


Figure 1 Nano fluid Preparation Steps[1]



a b

Figure2 a. probe sonication b. magnetic stirrer

a. b.

Figure 3 a. Al2O3/water nano fluid sample b. Al2O3 with Cu /water nano fluid sample

Although nanofluids offer superior heat transfer enhancement, their stability and cost-effectiveness remain significant challenges. Therefore, the stability and thermophysical properties of Al2O3-H2O and Cu-H2O nanofluids have been investigated, as detailed in reference [20]. The prepared nanofluids demonstrated good stability after 10 days of standing. Stability was monitored using an observation method, revealing that prolonged sonication results in a more homogeneous mixture of nanoparticles. In this study, the nanofluids were sonicated for 30 minutes. As shown in Figures 3a and 3b, the stable Al2O3-H2O and Al2O3+Cu-H2O nanofluids were effectively used for radiator cooling.

2. Nano fluid Physical properties

By positing that the nanoparticles are evenly distributed throughout the base fluid meaning the particle concentration remains consistent across the system—we can assess the effective thermophysical characteristics of the nanofluids at various temperatures and concentrations using conventional formulas typically employed for two-phase flow analysis [21]. Equation 1 represent volume concentration formula for Nano fluid sample. Equation 2 and 3 represent density and specific heat calculations, which are repeatedly used in thermal calculations. Similarly thermal conductivity of nano fluid has been calculated using equation 4.

Volume concentration $$\varphi = \frac{\frac{w_p}{\rho_p}}{\frac{w_{bf}}{\rho_{bf}} + \frac{w_p}{\rho_p}} \tag{1}$$

$$\rho_{nf} = \varphi \rho_p + (1 - \varphi)\rho_{bf} \tag{2}$$

$$C_{p_{nf}} = (1 - \varphi)\left(\frac{\rho_{bf}}{\rho_{nf}}\right) C_{p_{bf}} + \varphi \left(\frac{\rho_p}{\rho_{nf}}\right) C_{p_p} \tag{3}$$

In the equations provided above, the subscripts "p," "bf," and "nf" denote the particles, base fluid, and nanofluids, respectively. "φ" represents the volume fraction of the nanoparticles added to the base fluid. Table 1 outlines the properties of Al2O3 and Cu nanoparticles at room temperature.

Table 1. . **Specification Sheet for Al2O3 and Cu Nano particle**

Geaometry Parameters	Al2O3	Cu
Purity	99.5 %	99.5 %
APS	30-50 nm	30-50 nm
Molecular wt.	101.96 g/mol	63.546 g/mol
Color	White	Dark Brown/Very Dark Brown
Density	3.9 g /cm3	8.96 g /cm^3
Melting Point	2040 ^{O}C	1084.6 ^{O}C
Boiling Point	2977 ^{O}C	2562 ^{O}C

The thermal conductivity of Al2O3/ water and Cu/ water nano fluid can be calculated using following equation [22].

$$k_{nf} = \frac{k_p + (n-1)k_{bf} - \varphi(n-1)(k_{bf} - k_p)}{k_p + (n-1)k_{bf} + \varphi(k_{bf} - k_p)} k_{bf} \quad (4)$$

3. Experimental Set up

The line diagram of experimental set up is shown in fig.4. The volume flow rate is observed from rotameter. There are total 5 thermocouples are used for temperature measurement. Two thermocouples are used for inlet nanofluid and inlet air temperature to radiator respectively. Similarly two thermocouples are used for outlet nanofluid and outlet air temperature respectively. The Nano fluid is heated by the heater to a specific temperature before flowing through the pipes to the radiator. For circulation of heat transfer fluid pump is arranged with constant heat load condition. Heater is situated in tank for constant heat load as in case of automobile engine. Forced convection fan is utilized for cooling of heat transfer surface of radiator. The flow control mechanism is governed using bypass valve arrangement which is arranged before rotameter. As we control bypass valve similarly flow rate will vary accordingly. In the experimental setup, the heat transfer rate, water flow rate, and air flow were investigated. To model the operating conditions, four different volume concentrations and four different flow rates were studied. The inlet coolant fluid temperature to the radiator was kept constant at 80°C until a steady-state regime was achieved using a heat bath.

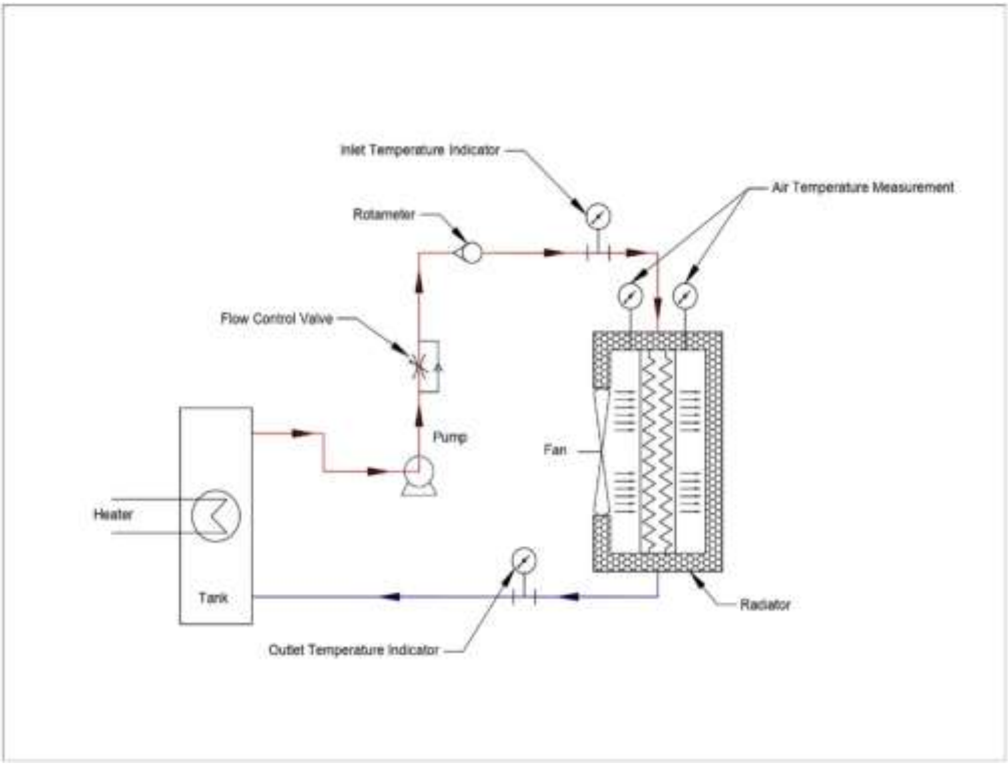


Figure 4 Line diagram of experimental set up

4. Top of Form
5. Result and discussion

6.1 Result validation

Thermal performance calculation of radiator has been carried out using energy balance verification. Energy balance of radiator has been carried out using air control volume and water control volume. The following equation is used for energy balance of heat. It is based on conservation of energy principle.

$$\dot{Q}_{water} = \dot{m}_{water} . C_{pw} . \Delta T_{water} \quad (5)$$

$$\dot{Q}_{air} = \dot{m}_{air} . C_{pa} . \Delta T_{air} \quad (6)$$

If we consider no heat loss to surrounding then heat transfer rate in water should be equal to heat transfer rate in air. For validation of experimental calculation error on energy balance has been shown for 40 ⁰ C and 50 ⁰ C inlet water temperature. There are total six calculations have been performed for error analysis as shown in figure 5.

$$\text{error }(\%) = 100.\frac{\dot{Q}_{water} - \dot{Q}_{air}}{\dot{Q}_{water}} \quad (7)$$

Above error has been verified up to 10 %, which shows that the experimentation results are verified as shown in fig.4. Error percentage is higher at 40 ºC As we know that increasing flow rate will directly enhance the heat transfer rate. The amount of heat released from radiator inlet and outlet pipes should be equal to the amount of heat gain from air side which passes through radiator fins. These will be possible in ideal heat transfer condition but practically due to losses we have verified that error up to 10 % can be justified for energy balance condition.

6.2 Thermal performance

There are 4 different volume percentages of nano particles have been utilised for nano fluid preparation. Four different flow rate for each volume percentages have been used for heat transfer fluid. It is observed from fig. 5 that as we increase volume percentage of nano particles in nano fluid heat transfer rate increases. It shows from fig. 7 and 8 that overall heat transfer coefficient and effectiveness of radiator increases with flow rate and large volume percentages of Nano particles. Overall heat transfer coefficient of 0.3 % volume fraction hybrid nano fluid has highest value. It is observed from figure 8 that 0.3 % and 0.4 % volume fraction hybrid nano fluid have approximately same effectiveness value. It is observed from fig 4 that error is maximum for higher flow rate side.

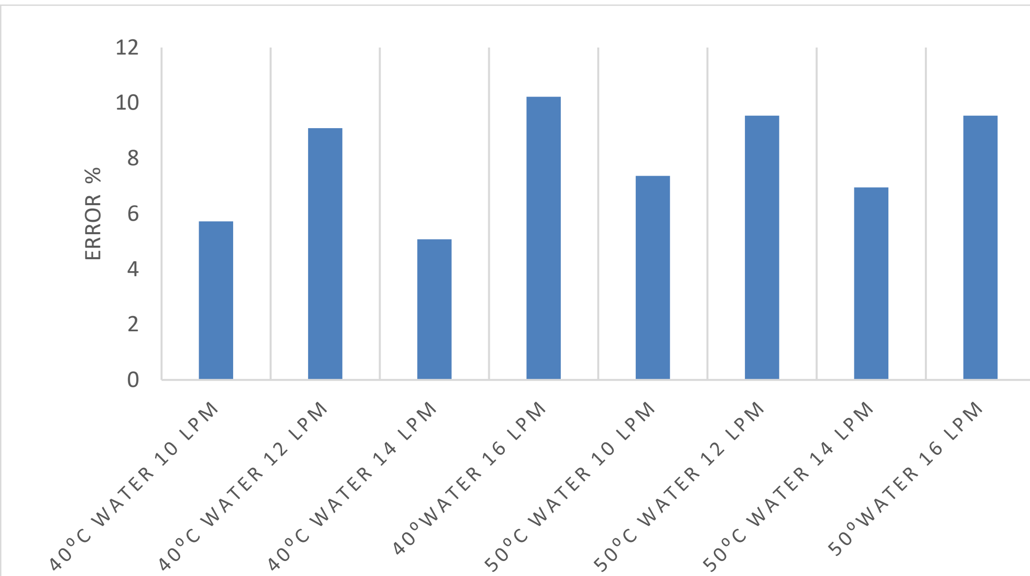


Figure 5 Energy balance error in % in between water control volume with air control volume

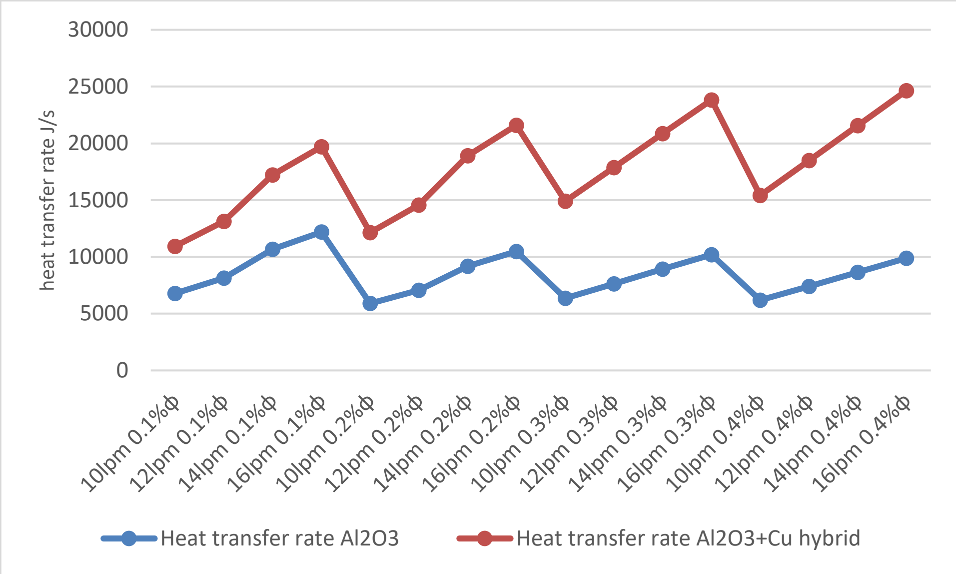


Figure 6 heat transfer rate in W for Al_2O_3 vs Al_2O_3+Cu nano fluid

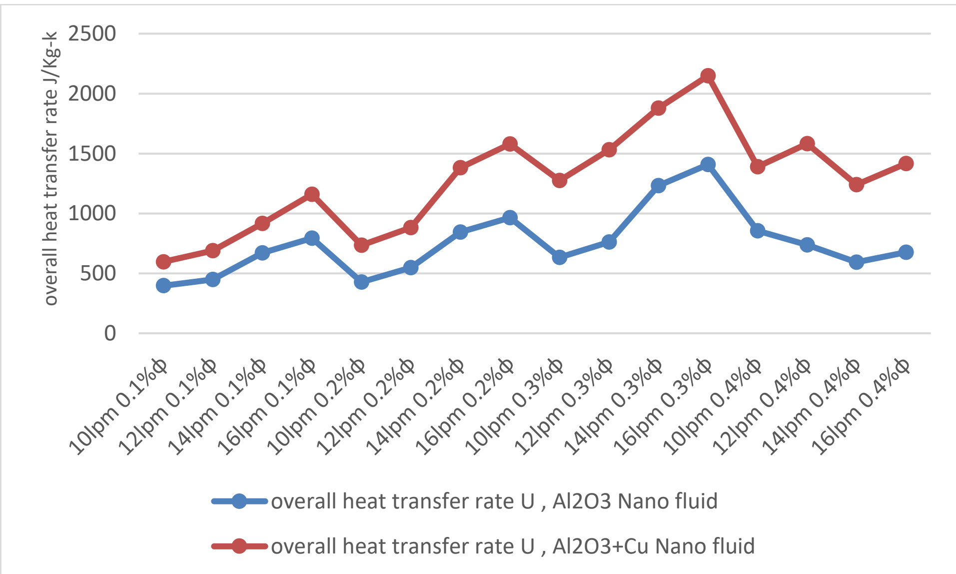


Figure 7 overall heat transfer coefficient for Al_2O_3 and Al_2O_3+Cu nano fluid

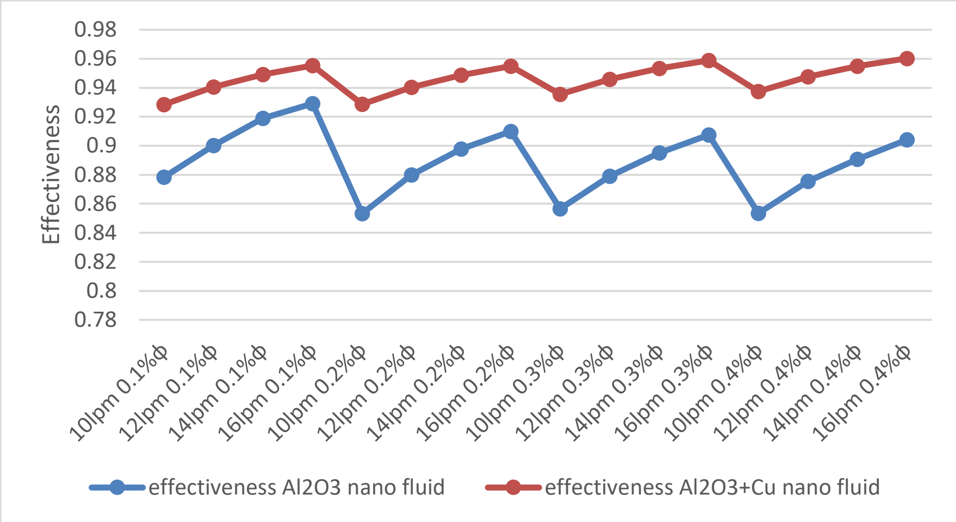


Figure 8 Effectiveness of radiator for Al2O3 and Al2O3+Cu nano fluid

Conclusion

- In this work, the automobile radiator is selected as a heat exchanger device. There are different flow rate and volume fraction of nano particles are selected as heat transfer fluid. The following observation has been observed after experimental research.
- It is observed that as we increase volume concentration of nano particles in nano fluid thermal conductivity gets increases.
- The thermal conductivity value of nano fluid is higher as compare to water as a base fluid.
- Selected Hybrid nano fluid (Al2O3 + Cu) have higher heat transfer rate as compare to mono nano fluid (Al2O3).
- As we increase volume fraction of nano particles in heat transfer fluid overall heat transfer rate and effectiveness of radiator increases. But 0.3 % and 0.4 % volume fraction have approximately same effectiveness value for higher flow rate. Although the overall heat transfer rate for 0.3 % volume fraction hybrid nano fluid have higher value as compare to 0.4 % hybrid nano fluid.

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Nomenclature:

w	weight of Nano fluid
ρ	density
φ	volume fraction
C_P	specific heat at constant pressure
K	thermal conductivity
Q	heat transfer rate
ΔT	temperature difference
Lpm	liter per minute
nm	nano meter

Superscript and subscript:

nf	nano fluid
P	nano particle
bf	base fluid
n	no of nano particle sample
w	water
a	air