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Analysis of the Performance of Radiator Tube with Angular Bend Using Low Concentration Particles

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***Abstract*—The analysis of the performance of radiator tube with angular bend using low concentration particles presents a numerical investigation under different boundary conditions on the heat transfer performance of a radiator tube with an angular bend. The investigation is centered on the application of nanofluids of aluminium oxide and copper oxide, with aluminium being the chosen material for the automobile radiator tube. At 100, 120, and 140 degrees Celsius as the inlet temperatures, the nanofluids are examined. To evaluate the car radiator tube's heat transmission efficiency, a number of parameters are examined. During analysis heat transmission is enhanced by higher input temperatures, and copper oxide nanofluid can boost heat transfer efficiency by up to 15%. Furthermore, a higher Reynolds number accelerates the transfer of heat.**

***Keywords*— Nanofluid, angular bend tube, Rate of Heat Transfer, Pressure drop, Heat transfer coefficient.**

Nomenclature:

N	Kinematics Viscosity
ρ	Density
Cp	Specific heat Capacity
k	Thermal conductivity
H	Heat transfer coefficient
V	Velocity
Dh	Hydraulic Diameter
Di	Diameter of the inner tube
Do	Diameter of the outer tube
Ah	cross-sectional area of the inner tube passing hot fluid
Ac	cross-sectional area of the inner tube passing cold fluid
Δp	Pressure drop
U	Overall heat transfer coefficient
Q	Heat Transfer heat
Re	Reynold's number
Nu	Nusselt Number
ΔT	Temperature gradient
K	Kelvin
°C	Degree Celsius

INTRODUCTION

In spite of significant growth during the past years, researchers have focused on developing various methods to meet growing energy demands. Improving the performance of heat exchange devices is a potential method to reduce energy consumption. Research focuses on improving industrial device's heating/cooling performance and enhancing heat transfer for longer equipment lifespan. Heat transfer rate and pumping power are key factors in heat exchange device design. For high-density fluids, heat transfer is more crucial than friction loss in radiator operation [1]. The radiator plays a crucial role in a vehicle's cooling system, dissipating excess heat from the engine to ensure its proper functioning. Countless studies have been conducted to enhance its performance. To enhance the heat transfer performance of radiators, there are various approaches such as fluid modification, geometric modification, and enhancing the thermal conductivity of the heat exchanger material. Traditionally, water and ethylene glycol have been utilized as heat transfer fluids for cooling car radiators. Unfortunately, these liquids have suboptimal thermophysical properties that limit their heat transfer efficacy. Improving the heat transfer performance of these fluids would result in better engine performance. In the pursuit of enhancing the thermal conductivity of conventional fluids, various methods involving micro and millimeter sized particles have been attempted. By increasing the heat transfer efficiency of these fluids, engines can operate more efficiently, leading to better fuel economy and lessened environmental impact [2-3].

Fluid modification involves the use of nanofluids, which contain nanoparticles of metals, oxides or carbon allotropes, to improve the fluid properties. Geometric modification introduces roughness to the surface of the radiator. Scientists are primarily focused on developing nanofluids, as the nanoparticles offer high thermal conductivity. Examples of metal nanoparticles are copper, gold, and silver, while metal oxide nanoparticles such as aluminium, silica, titania, bismuth oxide, and zirconia are also used. The chemical stability of the nanoparticles is crucial. Granqvist et al. [4] initially discovered ultrafine particles later on known as nanoparticles, which have size in nanometres. It was choi [5] who introduced that nanofluid is a diluted mixture of nanoparticles. When added to base fluids, the thermo-physical properties of the fluids are improved. The heat transfer properties are affected by factors such as particle volume concentrations, size and shape, material, base fluid properties, and temperature.

Ali and Arshad [6] conducted an experiment to evaluate the angle effect of pin fin heat sink channel using nanofluids with GNPs. They studied three heat sinks with channel angles of 22.5°, 45°, and 90°. The heat sink with a channel angle of 22.5° showed better thermal performance compared to the other two. They analyzed thermal resistance, convection heat transfer coefficient, and log mean temperature difference. Arshad and Ali [7] also compared the thermal and hydrodynamic performance of graphene nanoplatelets nanofluids with distilled water on an integral fin heat sink. They observed greater pumping power for GNPs nanofluids compared to distilled water. At a Reynolds number of 972, using GNPs nanofluids achieved a minimum base temperature of 36.81 °C and the highest convective heat transfer enhancement of 23.91%. Pumping power varied with flow rate and heat flux, with the maximum being observed for the GNPs nanofluid at a heat flux of 47.96 kW/m2.

Naraki et al [14] studied the overall heat transfer coefficient of a car radiator using CuO-water nanofluid as the coolant. They found that the heat transfer performance improved as the particle concentration increased while keeping the flow rate of nanofluids constant, compared to the conventional fluid used in radiators. Ali et al [15] conducted an experimental study to enhance heat transfer in car radiators using ZnO/water and MgO/water nanofluids. They added surfactant SHMP to stabilize the ZnO/water nanofluid in a 1:5 ratio with particles and maintained a pH of 2.2. To enhance the stability of the MgO nanofluid, they lowered the pH of the mixture. The heat transfer rate increased up to an optimum flow rate, after which the particles started to stick on the surface, causing a decrease in heat transfer rate. Elias et al [16] investigated the thermo-physical properties of nanofluids containing Al2O3 nanoparticles in a water/ethylene glycol mixture (50:50), including thermal conductivity, density, viscosity, and specific heat. They found that the thermal conductivity improved with an increase in temperature due to an increase in Brownian motion of particles. An increase in the volume concentration of nanoparticles resulted in higher thermal conductivity, viscosity, and density, but a lower specific heat of the nanofluid. The lower specific heat of the nanofluid was attributed to the lower specific heat of the added particles compared to the base fluid.

MATHEMATICS MODELLING

Using computer-aided design (CAD) software, construct a 3D model of the radiator tube with the angle bend. Make sure the radiator tube's exact physical dimensions and properties are represented in the model. Heat transmission is enhanced by the presence of low-concentration particles in the fluid passing through the radiator tube. By encouraging turbulence and raising the fluid's effective Thermal conductivity, these particles raise the convective Heat Transfer Coefficient. The radiator dissipates heat more effectively as a result.

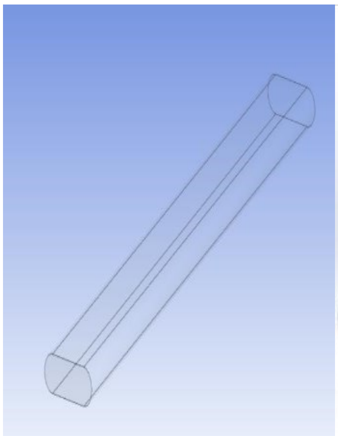

Fig. 1. Angular bend tube (2D)

Fig. 2. Angular bend tube (3D)

Thermal conductivity C of nanofluids was calculated using (1) equation given below:

$$K_{nf}/k_f = 1 + 64.7\emptyset^{0.7460} (d_f/d_s)^{0.3690} (k_s/k_f)^{0.7476} \quad Pr^{0.9955} Re_b^{1.2321} \tag{1}$$

Velocity of Aluminum oxide and Copper oxide has been calculated by using Equation:

$$U_{nf}/u_f = 1/ (1-34.87(d_s/d_f)^{-0.3} \emptyset^{1.03} \tag{2}$$

Density of nanofluids was calculated as:

$$\rho_{nf} = (1-\emptyset)\, \rho f + \emptyset_{\rho_S} \tag{3}$$

Specific heat of Aluminum oxide and Copper oxide has been calculated by flowing equation:

$$(C_p)_{nf} \quad =((1-\emptyset) (\rho Cp) + \emptyset(\rho Cp)_s \ )/ \rho nf \tag{4}$$

Hydraulic diameter of flat tube was calculated as :

$$D_h = (4 \text{ x } [(\pi/4)]d^2 + (D-d) \text{ x } d]) /(\pi \text{ x } d + 2\text{x}(D-d)) \tag{5}$$

Where, ‘D’ and ‘d’ are the major and minor diameters of the flat tube, respectively. Heat transfer rate from nanofluid was calculated as,

$$Q = m_{nf} \times c_{p.\ nf} \times (t_{in} - t_{out}) \tag{6}$$

The average heat transfer coefficient of nanofluid in flat tube was calculated as

$$h_{exp} = (m_{nf} \text{ x} c_{p(nf)} \text{x} (t_{in} + t_{out})) / ((A_S \text{ x } (t_{in} + t_{out})_{LM} \ ) \tag{7}$$

The bulk mean temperature (Tb) of nanofluid is given

$$T_b = (t_{in} + t_{out})/2 \tag{8}$$

Table 1. Boundary Conditions for nanofluids

Set No.	**Fluid**	**Velocity**	**Inlet Temp. (°C)**	**Mass flow Rate Kg/s**	**Hydraulic diameter**
1	Nanofluid (Al203/water)	2m/s	100 – 140	15.1759	0.07m
	Nanofluid (Cu2O/Water)	2m/s	100 – 140	15.1759	0.07m

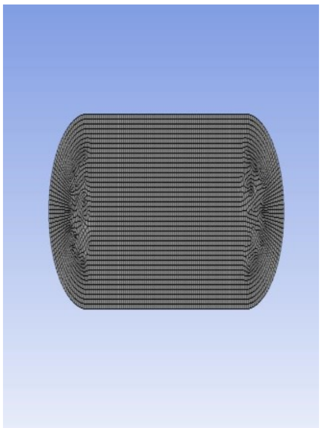

Fig 3. Meshing of angular bend tube 1

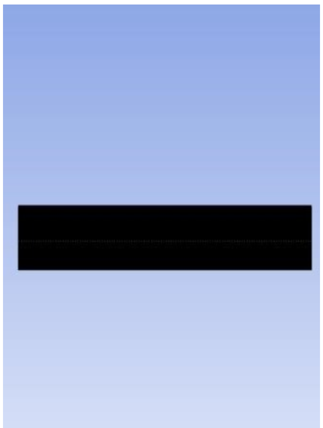

Fig 4. Meshing of angular bend tube 2.

RESULT AND DISCUSSION

In this investigation, the counter flow configuration of radiator tube has been taken into consideration and different materials and fluids for inner angular tube have been selected. Three different sets of boundary conditions e.g.- inlet temperature, hydraulic diameter, mass glow rate for aluminium oxide and copper oxide have been introduced for CFD method of angular tube. The output results of angular radiator tube according to the inlet boundary conditions have been studied to determine the heat transfer performance based on Reynolds number.

The rate of heat transfer determines the heat transfer performance in the radiator tube. It has been evaluated by using following equation:

$$Q = m_{nf} \times c_p.nf \times (t_{in} - t_{out})$$

Table 2. Heat transfer at 100° C inlet temp.

Re	Ti(°C)	To(°C)	M	Cp	Q(watt)
9000	100	76.0927	0.039	4.182	3023.573
12000	100	79.5745	0.053	4.182	4305.386
15000	100	81.9407	0.066	4.182	4567.955
18000	100	83.6063	0.079	4.182	4837.758
21000	100	84.8575	0.093	4.182	5106.872

Table 3. Heat transfer at 120° C inlet temp.

Re	Ti(°C)	To(°C)	M	Cp	Q(watt)
9000	120	90.1159	0.039	4.182	4913.307
12000	120	94.4681	0.053	4.182	5704.637
15000	120	97.4258	0.066	4.182	6280.937
18000	120	99.5079	0.079	4.182	6824.695
21000	120	101.072	0.093	4.182	7420.913

Table 4. Heat transfer at 140°C inlet temp

Re	Ti(°C)	To(°C)	M	Cp	Q(watt)
9000	140	104.1391	0.039	4.182	5895.9
12000	140	109.3618	0.053	4.182	6845.5
15000	140	112.911	0.066	4.182	7537.1
18000	140	115.409	0.079	4.182	8124.1
21000	140	117.286	0.093	4.182	8905.0

It was observed that the heat transfer characteristics of the water increased with the trends of Reynolds number. By increasing the Reynolds value, the rate of heat transfer increased because of the increasing Reynolds value the flow of the water changes. The rate of heat transfer easily identifies by the graph which is given below:

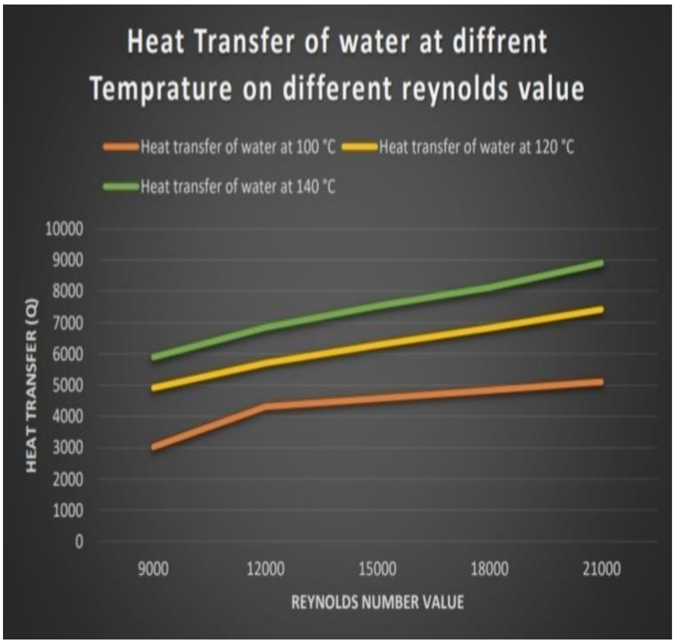

Fig.5. Heat Transfer of water at different temperature on different Reynolds number

Similarly, the rate of heat transfer of car radiator tube studied by using aluminium oxide nanofluid and evaluated the all results which are given below:

Table 5. Heat transfer at 100°C inlet temperature

Re	Ti(°C)	To(°C)	M	Cp	Q(watt)
9000	100	75.1015	0.039	4.17556	4093.614
12000	100	78.6953	0.053	4.17556	4760.153
15000	100	81.5248	0.066	4.17556	5140.44
18000	100	82.5921	0.079	4.17556	5797.515
21000	100	83.8261	0.093	4.17556	6341.133

Table 6. Heat transfer of Al2O3 at 120°C inlet temperature

Re	Ti(°C)	To(°C)	M	Cp	Q(watt)
9000	120	89.9772	0.039	4.17556	4889.166
12000	120	94.1923	0.053	4.17556	5711.417
15000	120	96.2015	0.066	4.17556	6558.621
18000	120	98.2402	0.079	4.17556	7177.960
21000	120	99.7827	0.093	4.17556	7851.019

Table 7. Heat transfer of Al2O3 at 140 °C inlet temperature

Re	Ti(°C)	To(°C)	M	Cp	Q(watt)
9000	140	103.577	0.039	4.17556	5931.345
12000	140	108.772	0.053	4.17556	6910.813
15000	140	112.286	0.066	4.17556	7637.607498
18000	140	113.888	0.079	4.17556	8613.562
21000	140	115.739	0.093	4.17556	9421.215

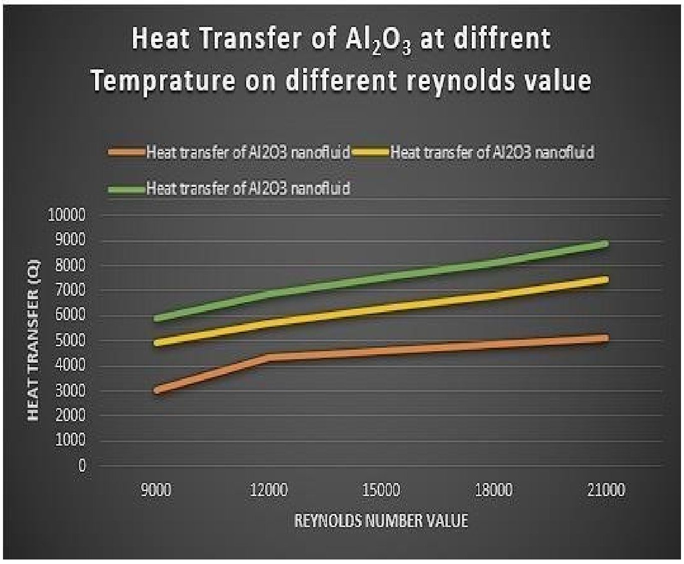

Fig. 6. Heat transfer of Al2O3 nanofluids at different inlet temperatures

And following given tables provide the data of heat transfer radiator tubes by using copper oxide nanofluids:

Table 8. Heat transfer of CuO at 100 °C inlet temperature

Re	Ti(°C)	To(°C)	M	Cp	Q(watt)
9000	100	68.6437	0.039	2.91808	4740.308
12000	100	72.3454	0.053	2.91808	5955.325
15000	100	75.1318	0.066	2.91808	6959.915
18000	100	77.1869	0.079	2.91808	7928.12
21000	100	79.1398	0.093	2.91808	8882.632

Table 9. Heat transfer of CuO at 120 °C inlet temperature

Re	Ti(°C)	To(°C)	M	Cp	Q(watt)
9000	120	68.6839	0.039	2.91808	5840.03
12000	120	72.617	0.053	2.91808	7328.16
15000	120	75.5776	0.066	2.91808	8555.45
18000	120	77.7611	0.079	2.91808	9737.25
21000	120	79.446	0.093	2.91808	11005.6

Table 10. Heat transfer of CuO at 140 °C inlet temperature

Re	Ti(°C)	To(°C)	M	Cp	Q(watt)
9000	140	79.0207	0.039	2.91808	6939.75
12000	140	83.7405	0.053	2.91808	8701
15000	140	87.2931	0.066	2.91808	10151
18000	140	89.9133	0.079	2.91808	11546.4
21000	140	91.9352	0.093	2.91808	13043.9

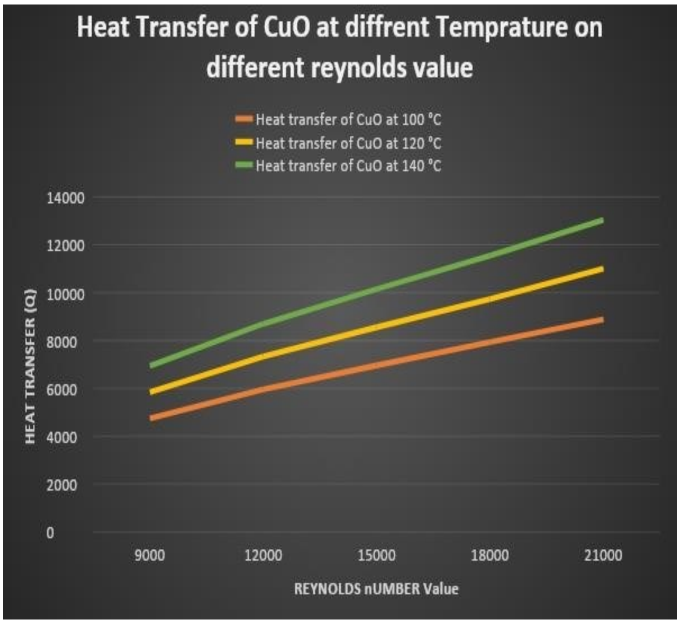

Fig. 7. Heat transfer of CuO at different inlet temperature

In following graphs, the rate of heat transfer shows of water, aluminium oxide and copper oxide nanofluids and compare the heat transfer of all fluids.

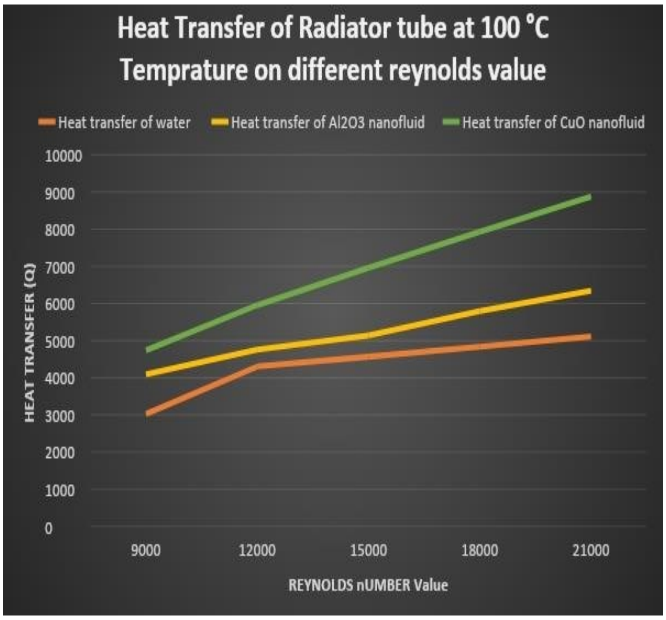

Fig. 8. Graph of heat transfer of water, aluminium oxide and copper oxide nanofluids at 100 °C temperature

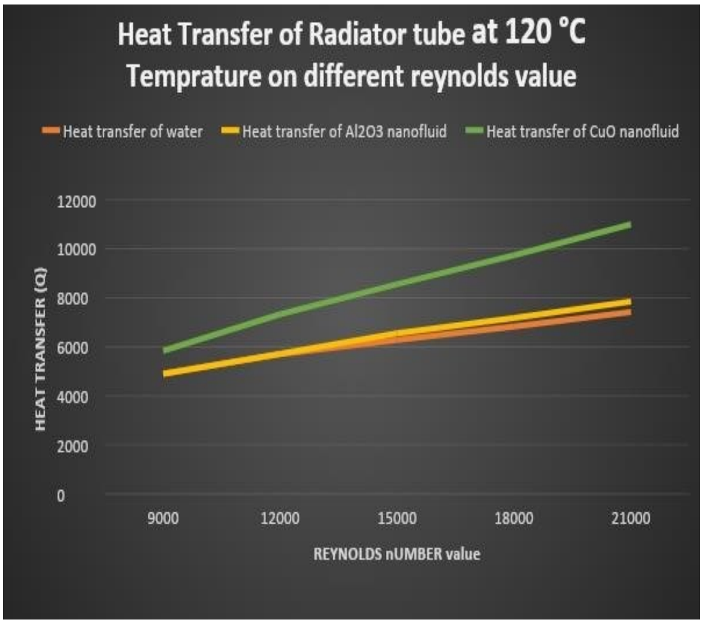

Fig. 9. heat transfer of water, aluminium oxide and copper oxide at 120 °C temperature

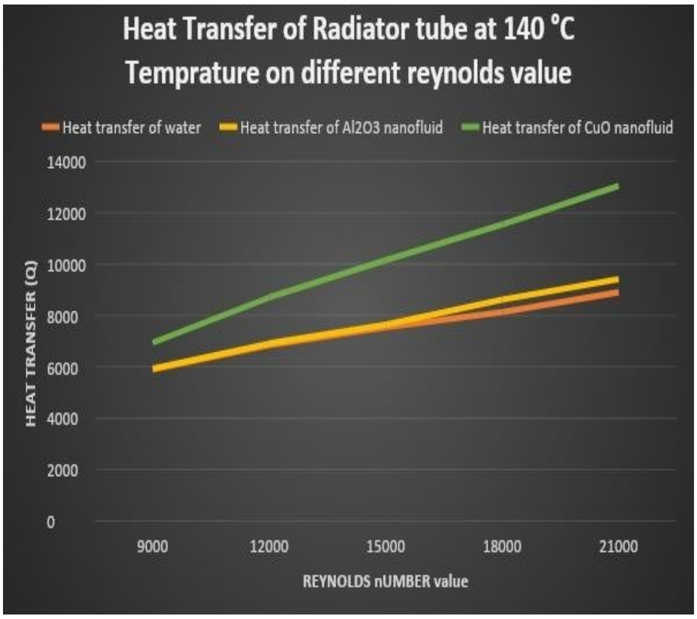

Fig. 10. Graph of heat transfer of water, aluminium oxide and copper oxide nanofluids at 140 °C temperature

Reynold's number ;

Reynolds's Number is a dimensionless parameter which is defined as the ratio of inertia forces to the viscous forces. As the flow configuration in pipes mainly depends on flow velocity, surface geometry, surface roughness, type of fluid among other characteristics, Reynolds number is used to determine the flow configuration whether the flow is laminar or turbulent. If the Reynolds number is less than 2400, the flow is said to be laminar and if the Reynolds number is greater than 4000, the flow is said to be turbulent.

Reynolds number for hot fluid and cold fluid has been calculated by using the following equation:

$$Re = VD\rho/\mu \text{ or } VD/v$$

Table 11: The Reynolds number for different fluids

Sr No.	Fluid	Reynolds's No.(Re)
1.	Water	9000-21000
2.	Al_2O_3	9000-21000
3.	CuO	9000-21000

In this study, the heat transfer evaluated on the basis of vary of Reynolds number from 9000-21000.

Nusselt Number;

Nusselt Number is a dimensionless quantity which signifies the improvement of heat transfer through a fluid layer as a result of convection related to conduction across the same fluid layer. It helps to determine the heat transfer coefficient in the Heat Exchanger.

The following correlation is used to determine the Nusselt No. for aluminum and copper oxide fluid:

$$Nu= 0.023 Re0.8 Pr0.4$$

The following table shows the results of Nusselt No. for hot and cold fluid:

Table 12. Nusselt Number for different fluids

	Fluid	Nusselt No.
1	Al_2O_3	0.122
	Water	0.108
2	CuO	1.112
	Water	1.009

CONCLUSION

This numerical study on heat transfer performance of Radiator Tube with angular bend has been conducted by doing the simulation of the angular flat tube with different sets of boundary conditions. Aluminium oxide and copper oxide have been considered as nanofluids respectively. Aluminium have been selected as a material for tube of the Car Radiator. The inlet temperatures of nanofluids are taken as 100 °C, 120°C and 140 °C. Different parameters have been analyzed to measure the heat transfer performance of the Car Radiator Tube. The following outcomes of the investigation have been observed:

- The thermal conductivity and viscosity of the nanofluid are increased once the nanoparticles are dispersed in distilled water, and this enhancement grows as particle concentrations rise.
- The density and viscosity increased with increasing the particle concentration, while they both decreased with increase in temperature.
- The deviation between viscosity of nanofluids and base fluid reduced with increase in temperature.
- Nusselt No. increases with the increment of Reynold's No.
- The heat transfer rate increased with increase in fluid inlet temperature, particle concentration and Reynolds number.
- Thermal conductivity, other factors such as fluid inlet temperature, Reynolds number and fluid velocity also affect heat transfer rate.

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