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An Experimental CFD Analysis of Heat Transfer Enhancement in Radiator Tube using Hybrid Nanofluid

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Abstract

Radiators are heat exchangers used for the purpose of cooling and heating by transferring thermal energy from the coolant fluid to the environment. In some recent decades, nanofluid, nanomaterial (size less than 100nm) in the base fluid.A comparative experimental investigation for thermal performance analysis of different nanofluid combinations flowing in a radiator is presented. The cooling performance of the radiator was investigated using ANSYS and compared with normal cooling fluid. A 3d computational domain was considered for the analysis. A two-phase equation with the k-ε turbulence model was selected. A discrete phase model based on the Lagrangian–Eulerian approach is used, in which Nano particles are considered as a discrete phase. Along with this a continuity, momentum and energy conservation equations are solved. The base computational domain is selected as a circular tube, which is meshed unstructured manner with a smooth inflation layer near the wall. The nanofluid concentration is increased from 0.05 to 0.15. The Inlet fluid temperature is kept constant at 90°C in the region. In this research work, the comparison of heat transfer enhancement, overall heat transfer coefficients for different nanofluid combinations and compared with the coolant. Performance of the radiator subjected to a flow of coolants like hybrid nanofluid is compared with water as a coolant. The nanofluid Al_2O_3 with a constant inlet temperature of 90°C is used for the case study. The nanofluid is varied with volume concentration from 0.05 to 0.15 % of volume concentration of nanofluid. The Reynolds' number changes from 260 to 780. It has been found that as % of VC of nanofluid increases, heat transfer increases. Also, the enhancement in heat transfer is observed with an increment in Reynolds' number. The highest drop in fluid temperature was 42.51°C at a volume concentration of 0.15 per cent at 780 Reynolds' Number.

Major Findings: *The major findings of the research work are to evaluate the heat transfer enhancement and overall heat transfer coefficients for various combinations of nanofluids, as well as a comparison with the coolant. The radiator's performance when exposed to coolant flow, such as that of a hybrid nanofluid, is contrasted with that of water. For the case study, a nanofluid Al_2O_3 with a constant inlet temperature of 90°C is utilised. A range of volume concentrations of the nanofluid is used, ranging from 0.05 to 0.15 per cent. From 260, the Reynolds' number rises to 780. It has been discovered that heat transfer rises with the percentage of VC in the nanofluid. Additionally, as Reynold's number increases, heat transport is seen to improve. At 780 Reynolds' Number, the maximum fluid temperature drop was 42.51°C at a volume concentration of 0.15 per cent.*

Keywords: *CFD, Heat Transfer, Hybrid Nanofluid, Nanofluid, Radiator*

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1.0 Introduction

In recent years, a lot of academics have focused on improving heat transfer. Numerous variables, including their size and shape, the volume concentration of particles in the base fluid, the mass flow rate of air, *etc.*, affect the amplification of heat transfer[1,2]. Compared to single nanofluids in the base fluid, hybrid nanofluids are more efficient. A hybrid nanofluid is a mixture of one or more nanofluids in a base fluid, such as water, ethylene glycol, *etc*. Hybrid nanofluid's ability to enhance heat transmission is dependent on its preparation technique, particle size in nanometers, and other factors[3,4].The use of nanofluid to improve heat transmission in forced convection is the subject of this study. Tijani and bin Sudirmanlooked[5] and Oliveira[6] at the Al_2O_3/water-mono ethylene glycol nanofluid used as coolant in automobile radiators. The base fluid is a proportionate amount of water and monoethylene glycol mixture. The study used a temperature range of 65 to 850 degrees Celsius, a coolant flow rate that varied between 4 and 9 l/min, and a volume fraction that varied between 0.2-0.8%. The outcome indicates that with a 0.2% volume fraction of nanofluid, heat transmission increased by 30%. Naraki *et al.*[7] and Leong *et al.*[8] investigated the use of Al_2O nanofluid to improve heat transmission in automobile radiators. In a car radiator with two distinct wire coil insert geometries, the volume concentrations of 0.08%, 0.5%, and 1% were examined. The findings demonstrate that the tube insert's heat transfer enhancement is greater than that of using plain ethylene glycol as the foundation fluid. In a car radiator, Ali *et al.*[9] and Peyghambarzadeh *et al.*[10] investigated the thermophysical and heat transport properties of an Al_2O_3/CuO nanofluid using water as the base fluid. The base fluid was supplemented with 0.05%, 0.15%, and 0.3% concentrations of Al_2O_3 and CuO nanoparticles for the investigation. There was a 5% boost in thermal performance. The impact of titanium dioxide (TiO_2) and aluminium oxide (Al_2O_3) nanoparticles in a base fluid that contained 50:50% water and EG was experimentally investigated by Said *et al.*[11] and Delavari and Hashemabadi[12]. The findings demonstrate that employing Al_2O_3 at a volume fraction of 0.3% can improve thermal performance by a maximum of 24.21%. Elsaid[13] and Devireddy *et al.*[14] investigated the use of Al_2O_3/water nanofluid to enhance radiator cooling performance. In the fully turbulent regime, the nanofluid concentration ranged from 0.1 to 1%. The results indicate that at 1 vol.% of nanofluid, heat transmission is enhanced by 45%. In a flat tube radiator, Elsebay *et al.*[15] and Contreras *et al.*[16] investigated the Al_2O_3 and CuO nanofluid. According to the results, the CuO nanofluid increases heat transfer enhancement by 38% and Al_2O_3 by 45%. In the case of Reynolds number 1750 and volume percentage 0.07 per cent, the friction coefficient increased by 271 and the pressure drop for Al_2O_3/Water increased by 267%. The friction coefficient and pressure drop for the CuO/water nanofluid increased by 266% and 226%, respectively. The performance parameter of the car radiator with louvred fins was investigated by Ramalingam *et al.*[17] and Jadar *et al.*[18], utilising nanofluids. The Al_2O_3 hybrid nanofluids used as radiator coolants contain an equal proportion of water-based Fe_2O_3, CuO, TiO_2, Ag, and Cu. With a penalty in pumping power, the results indicate an improvement in efficacy, heat transfer rate of 0.8% and 3%, and pressure decrease of 6% and 5.6%, respectively. Peyghambarzadeh *et al.*[19] and Hassani *et al.*[20] investigated how fexOy nanofluid affected the volumetric behaviour of the fluid and the enhancement of heat transmission. According to the results, the heat transfer coefficients for magnetic (Fe_3O_4) and non-magnetic (Fe_2O_3) materials were enhanced by 11% and 15%, respectively. Under the laminar flow regime of the CuO/water nanofluid in the radiator, Xie *et al.*[21] and Madhesh and Kalaiselvam[22] investigate experimentally how heat transmission is enhanced in the radiator. The range of the nanofluid concentration is 0 to 0.4 vol.%. The total improvement in heat transmission is 6% for 0.15 vol.% and 8% for 0.4 vol.% with CuO nanofluid. 94.11 is the highest value of the overall heat transfer coefficient. Using copper nanofluid, Pastoriza-Gallego *et al.*[23] examined the radiator's performance. For Re number 6000, adding 2% of copper nanoparticles to ethylene glycol increased the heat transfer enhancement by 45.2%. 2% copper nanoparticles were added. The air frontal area is reduced by 18.7% overall when the coolant and air have Reynolds numbers of 5000 and 6000, respectively. The effect of a diluted nanofluid on the enhancement of heat transfer in an automobile radiator is experimentally analysed. Iron oxide (Fe_2O_3) and copper oxide (CuO) nanoparticles with concentrations of 0.15, 0.4, and 0.65 vol.% are utilised in the experiment. The range of Reynolds' number was 50–1000. The findings indicate that when the inlet liquid flow increases, so does the overall heat transfer coefficient.

The effectiveness of copper nanofluides based on ethylene glycol in vehicle cooling systems. It was found that for Reynolds' number 5000, a 3.8% increase in heat transfer occurs at 2% copper particle addition. An experimental investigation of the copper-titanium nanofluid in a tubular heat exchanger is conducted. The highest convective heat transfer coefficient was 48.4% at a volume concentration of 0.7% for the nanofluid. The heat transfer enhancement of aluminium oxide (Al_2O_3), copper oxide (CuO), and titanium dioxide (TiO_2) in car radiators was investigated. The findings indicate that the heat transfer rate of CuO nanofluid is higher than that of TiO_2 and Al_2O_3. The temperature of the nanofluid rises as the magnetic field intensity does using a ZnO/water nanofluid in an automobile radiator. The ZnO nanoparticle volumetric concentration in the base fluid ranged from 0.01% to 0.3%, which is equivalent to a Reynolds number between 17500 and 27600. At 0.2% nanofluid concentration, a 46% increase in heat transmission was observed. Additionally, the heat transfer improvement decreases as the nanofluid concentration (0.3%) increases further. The cooling efficiency of car radiators was affected by TiO_2 nanofluid in water and ethylene glycol as the base fluid. Heat transmission rose to 35% at a concentration of 0.5% TiO_2 in a base fluid of 40:60% EG/Water. Additionally, it has been noted that the Brownian motion of nanoparticles is a crucial element in improving heat transmission. It was studied the impact of TiO_2 and SiO_2 nanoparticles in automobile radiators. A 16.4% increase in Nusselt number for TiO_2-W and a 17.85% increase for SiO_2-W were observed for the Reynolds number range of 250–1,750. The TiO_2 nanofluid is experimentally investigated using a double pipe heat exchanger. The TiO_2 volume content ranged from 0.0004% to 0.02%, and the Reynolds number ranged from 4000 to 15,000. The heat transfer coefficient and friction factor are improved by 10.73% and 8.73%, respectively, for a volume concentration of 0.02%. The impact of a TiO_2-SiO_2 hybrid nanofluid in studied an EG-water mixture as the base fluid. The range of the volume concentration was 0.5% to 3%. The outcome demonstrates a 21% increase in heat transmission at a 3% nanofluid concentration. The impact of varying Silicon carbide (SiC) nanofluid sizes on improving heat transfer in an automobile radiator. The outcome demonstrates that heat transfer enhancement rises as nanoparticle size decreases. Furthermore, compared to 110 nm-SiC nanoparticles, the increase in thermal conductivity for 24 nm-SiC is 23% greater. As the temperature of the incoming fluid rises, the viscosity decreases. At 3% of 24 nm SiC nanoparticles, the heat transfer enhancement increases by the maximum of 28%. The performance of Al-MWCNT nanofluid in car radiators with conventional and composite fins is experimentally assessed. Compared to the basic fluid, the overall increase in heat transmission was determined to be 45%. Heat transfer is improved by up to 20% when MWCNT fins are used. In an automotive radiator, the experimental effects of an $H_2O/(CH_2OH)_2$ nanofluid based on Co_3O_4 and Al_2O_3. Three EG/water ratios at 0:100%, 10:90%, and 20:80% were tested with nanofluid concentrations of 0.02, 0.05, 0.1, and 0.2%. The friction factor is raised by 16%, and the maximum heat transfer augmentation of 31.8% takes place. The carbon nanotube-water nanofluid affected the car radiator's thermal performance. We found that the FCNT-water nanofluid enhanced heat transmission by 90.76% for the range of nanoparticle concentrations of 1% by volume. An experimental evaluation of the heat transmission properties of MWCNT/water in an automobile radiator was conducted. The MWCNT nanoparticle concentration ranges from 0.05 to 0.16%wt, while the fluid mass flow rate ranges from 30 to 70g/s. At 30°C, a maximum enhancement of 54% is achieved at 0.16%wt. Using nanofluid, Hussein *et al.*[24] and Chougule and Sahu[25] quantitatively examine the heat transfer properties of automobile radiators. The range of the Reynolds number is 100–2000. Carbon nanotubes, boron nitride nanotubes, and nanoparticle concentrations can vary by up to 1% in volume. For carbon and boron nitride nanotubes, the average heat transmission is improved by 11% and 7.7%, respectively[26,27].

1.1 Literature Summary

The experimental and software validation of heat transfer enhancement utilising nanofluid is the focus of the research literature review mentioned above. where the primary factors for each investigation are the concentration of various nanofluid kinds. However, hybrid nanofluid and radiator geometry changes receive less research attention. The current study examines the influence of nanofluid in a basic tube with variations in Reynolds' number and nanofluid %. Many researchers have been working to improve heat transfer in recent years. Many factors influence the amplification of heat

transfer, such as their size and shape, the mass flow rate of air, the volume concentration of particles in the base fluid, *etc.* Hybrid nanofluids are more effective than single nanofluids in base fluids. A hybrid nanofluid is a combination of one or more nanofluids in a base fluid, like ethylene glycol, water, *etc.* The method of creation, the size of the particles in nanometers, and other variables all affect how well a hybrid nanofluid transmits heat. This work focuses on the application of nanofluids to enhance heat transfer in forced convection.

1.2 Objectives of the Research Work

The objectives of the research work are described as follows:

(i) To study the existing literature on heat transfer enhancement in radiator tubes using hybrid nanofluid
(ii) To prepare the nanofluid as the main key aspect for analysing the heat transfer enhancement of nanofluids
(iii) To obtain optimal process parameters for heat transfer enhancement in the radiator tube using a hybrid nanofluid

2.0 Nanofluid

Nanomaterials are particles of size less than 100 nm. Different nanomaterials are used as additives due to their high heat transfer characteristics. Reddy and Rao[28] and Hamid[29] introduced the concept of Nanofluids, adding the nanometer-sized (size less than 100nm) solid particles in base fluid such as water, EG, *etc.* The enhancement in heat transfer is mainly due to the good thermal properties of the nanomaterial. The thermal properties of nanomaterials depend on particle size, type of particle and method by which it is prepared. This application of nanomaterials depends on its shape and size in nanometers, the material from which they are synthesised, the synthesis of nanofluid, method stability of nanofluid, various fluid and thermal properties of nanomaterials like viscosity, conductivity, *etc.*

2.1 Types of Nanofluid

Pure metal particles such as Al, Cu, Au, Fe, Zn, *etc.*
Metal oxides: oxides of metal make these nanoparticles. Such as Al_2O_3, CuO, SiO_2, Fe_3O_4,
Carbide materials, such as TiC, SiC, *etc.*
Carbon allotropes: These materials are single or multi-walled carbon nanotubes, graphite, *etc.*
Nitride ceramiscs: such as SiN, AIN, *etc.*
These materials are individually or in combination with two or more suspended in a base fluid such as water, EG, oil, *etc.*

2.2 Preparation of Nanofluid

Preparation of nanofluid is the main key aspect for the heat transfer enhancement of nanofluids. There are various methods for the synthesis of Nanofluids, such as gas condensation, chemical precipitation or mechanical attrition techniques. The nanoparticles are synthesised using two main methods, *i.e.*, the one-step method and the two-step method. For the stability of nanofluides, the following three methods are used[30]. Preparation of nanofluid is the main key aspect for the heat transfer. Khan and Dil[31] prepared TiO_2 nanofluid using a two-step process. For the stability of the nanofluid, the ultrasonic technique is used. Saidur *et al.*[32] reported the Al_2O_3 nanoparticle by a two-step method in which the powder of Al_2O_3 nanoparticles is mixed in the Base fluid, and to avoid agitation of particles ultrasonic stir is used. Sundar *et al.*[33] used a step method for the preparation of the nanofluid. For the stability of nanoparticles, an ultrasonic apparatus is used[34]. prepared multi-walled carbon nanotubes nanofluid using a two-step method, *i.e.*, a high-pressure homogenization process. Asirvatham *et al.*[35] prepared the copper oxide nanoparticles using a two-step method. The nanofluid is stabilised using pH control and Sodium Dodecyl Sulfonate surfactant. Naiman *et al.*[36] synthesised ZnO (Zinc Oxide) particles by a two-step method. The pH is made acidic to a value of 2.2, and constant stirring is performed for 2 h. The ultrasonic vibrations are used to stabilise the fluid with nanoparticles. The surfactant, SHMP (Sodium Hexa Meta Phosphate) ratio of 1:5 is used for the stability of the nanofluid. Rafieian *et al.*[37] have used the CuO/water and Fe_2O_3/water nanofluids prepared by a two-step method. For stability of nanofluid adequate quantity of HCl and NaOH solutions is required to maintain pH of at pH =10.1 for CuO and pH =11.1 for Fe_2O_3 nanoparticles. Dehghandokht *et al.*[38] synthesised Al_2O_3 and titanium oxide TiO_2 nanofluid using a two-step method. For the stability of nanofluid, Polyvinylpyrrolidone (PVP) and Arabic Gum (AG), these two surfactants are used. A

magnetic stirrer stirs the solution, and sonic vibrations are used for uniform mixing of the nanofluid. Leong *et al.*[39] have used a step method for the synthesis of TiO_2 nanoparticles. The fluid is kept under sonic vibration for 8 h. To minimise the surface tension, oleic acid and C-TAB (Cetyl-Trimethyl Ammonium Bromide) surfactant are used. Srinivasu *et al.*[40] have prepared a nanofluid by a two-step method. Graphene is dispersed in a base fluid, whereas the modified polyol method is used for the synthesis of Silver nanofluid. For stability of the nanofluid, a 400-bar pressure homogeniser was used for 1 h. Nieh *et al.*[41] Synthesised nanofluid using a planetary ball mill and magnetic stirrer, used for proper mixing of nanofluid. The ultrasound technique is used to obtain a stable nanofluid solution. Peyghambarzadeh *et al.*[42] synthesised MWCNT by chemical vapour deposition Method. An ultrasonic bath sonicator is used for the stability of the fluid. Peyghambarzadeh *et al.*[43] employed gamma alumina nanoparticles in water by a two-step method. No any surfactant or stabiliser was added to the nanofluid for stabilisation of the nanofluid. Vajjha *et al.*[44] prepared a copper/titania hybrid nanofluid by a two-step method. The mixture of nanofluid stabilised by the ultrasonic method. Authors employed Magnetite nanoparticles (Fe_3O_4) using a coprecipitation method Authors prepared a homogenous solution of TiO_2 and SiO_2 nanofluid using a step method and a mechanical stirrer. The solution is subjected to ultrasonic vibration to avoid agglomerations of nanoparticles. The authors synthesised the CNT nanocoolants by the Functionalisation (FCNT) and Surface Treatment (SCNT) method. The ultrasonic bath was used to stabilise the nanofluid, whereas the ammonium hydroxide was used to neutralise the nanofluid. Totani *et al.*[45] prepared a nanofluid by a two-step method. TiO_2 volume concentration varied from 0.0004% to 0.02% in the base fluid with 60% water and 40% EG. For stability of nanofluid, the surfactant oleic acid and C-TAB (Cetyl Trimethyl Ammonium Bromide) of 0.5 ml were added to the base fluid, and a mechanical stirrer was used for uniform mixing of nanofluid Authors prepared a nanofluid TiO_2-SiO_2 hybrid nanofluid using a step and sonication method. The use of a magnetic stirrer and an ultrasonic bath is used to stabilise the nanofluid. Vithayasai *et al.*[46] synthesised the nanofluid using a two-step method and sonication. For stabilised nanofluid, sonic vibrations are used for several hours. For the better stabilisation of nanofluid, a zero potential above 30 mV is desirable. The different methods of preparation of nanofluid is shown in Table 1.

Table 1. Summary of Method of Preparation of nanofluid

S. No.	Nanoparticle	Base Fluid	Method of Preparation
1	TiO_2[14]	W-EG	Two-step
2	Co_3O_4- Al_2O_3[31]	DW-EG	Two-step
3	Graphene[16]	W-EG	Two-step
4	FMWCNT[18]	W-EG	Vapour deposition method
5	Al_2O_3[19]	water	Two-step
6	CuO[21]	W-EG	Two-step
7	copper-titanium[22]	water	Two-step
8	Fe_2O_3 & Fe_3O_4[23]	EG	Coprecipitation method
9	TiO_2- SiO_2[24]	Pure water	Two-step
10	CNT[25]	Pure water	(FCNT) and the (SCNT) method
11	TiO_2[28]	W-EG	Two-step
12	TiO_2[29]	W-EG	Two-step

1.3 Geometric Modelling

The mathematical and computational methods used to construct, depict, and modify an object's shape and form, usually in two or three dimensions, are referred to as geometric modelling. A grid of volumetric pixels, or voxels, is used in voxel-based models to represent things. Details about the substance present there are contained in each voxel. A vital component of many contemporary applications, such as engineering design, entertainment, and scientific visualisation, is geometric modelling. NURBS, voxel, and parametric modelling are some of the powerful approaches that make it possible to create extremely detailed and versatile models, but issues with computing cost, precision, and complexity still need to be addressed. Geometric modelling is both a technical and artistic discipline since the choice of modelling technique frequently involves a trade-off between accuracy, flexibility, and efficiency. In order to do a CFD analysis on the radiator, a geometric model of the system must be created. After creating a model of the radiator tube

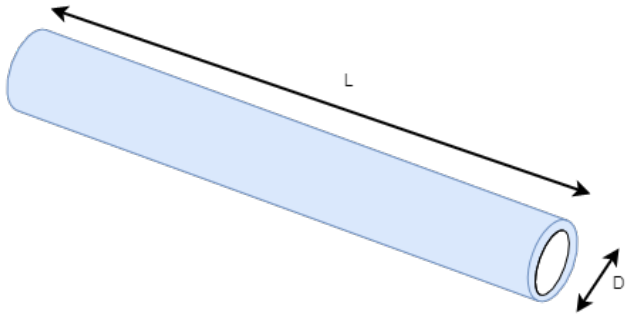


Figure 1. Schematic diagram of the circular pipe.

Table 2. Properties of Al_2O_3

Name of property	Value
Cp. Specific Heat (KJ/kg°C)	525
K Thermal Conductivity (W/mK)	17.65
μ Dynamic Viscosity (Pa.s)	1.70E-05
ρ Density (kg/m^3)	3970

in ANSYS 20, it is utilised in the CFD ANSYS program. In this research work, the heat transfer augmentation is studied in a plain pipe using different types of fluid velocity. Diameter of the pipe (D) and the Length of the pipe (L) are 6.4 mm and 310 mm. The pipe is made of aluminium material. The properties of Al_2O_3 nanofluid are given in Table 2.

2.4 Meshing

A key component of radiator simulation efficiency and accuracy is meshing. To capture the minute details of fluid movement and heat transmission within radiators, proper element selection, refinement techniques, and mesh density are crucial. Radiator meshing can be made better in several important areas, such as boundary layer resolution, dynamic mesh deformation handling, and local mesh refinement at heat transfer interfaces. The meshing is done as per the requirements in the problem. A finer mesh was applied to the main portion of the geometric

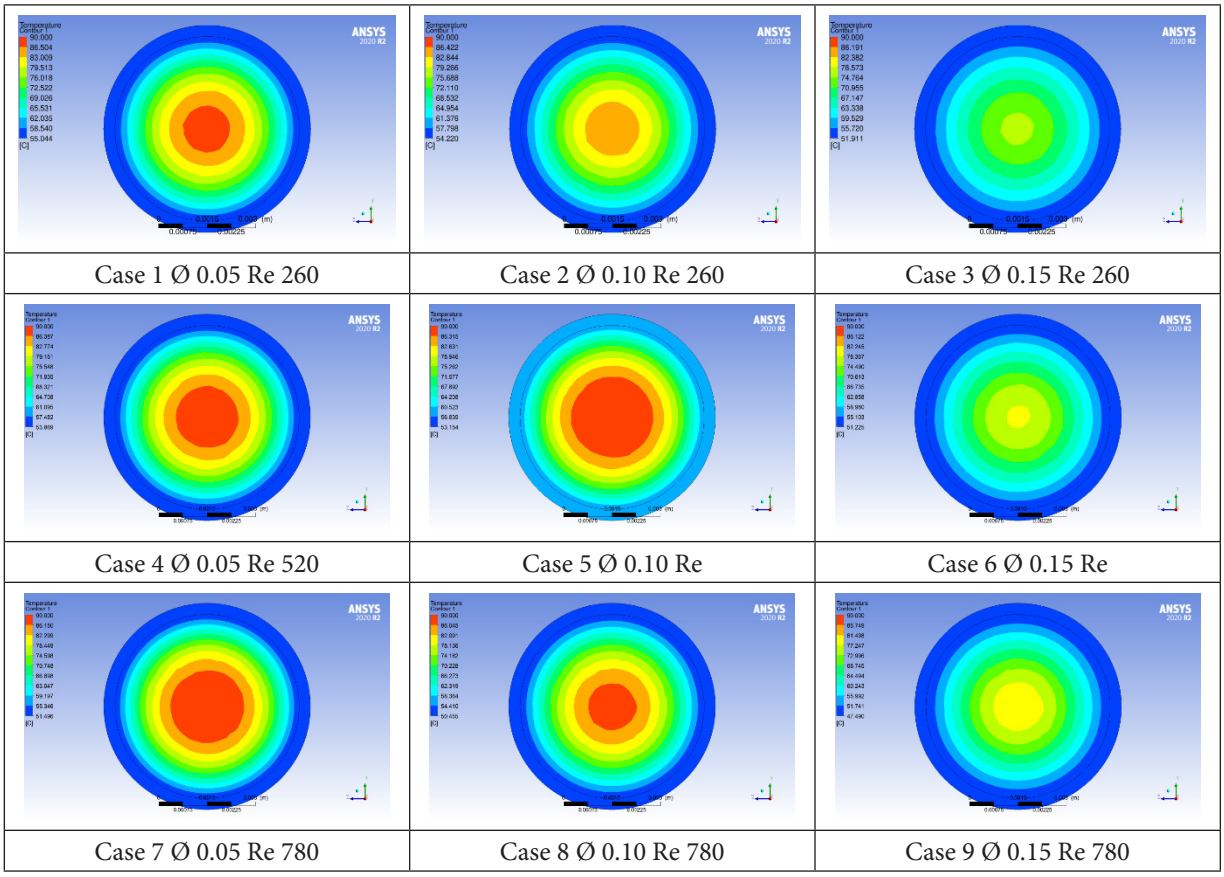


Figure 2. CFD analysis for different conditions.

model compared to the other areas of the geometry in order to minimise CPU time and computer load.

3.0 Results and Discussion

In the analysis, the diameter of the pipe is constant. The input heat load, *i.e.*, temperature of inlet fluid, is kept constant, *i.e.*, tin=90°C. The volume concentration changes from 0.5 to 1.5. The heat transfer enhancement is studied for three different Reynolds numbers.

3.1 Different Cases

For the experimentation, the different cases of nanofluid are tested in the radiator tube. For the Al_2O_3 nanofluid, the concentration of nanofluid changes from 0.05 to 0.15% of VC. Also, the Reynolds' numbers vary from 260, 520 and 780. The inlet fluid temperature remains constant for all cases at 90°C. The length of the tube (l) is 0.37 m. The CFD analysis for the different nanofluid concentration is shown in Figure 2.

4.0 Conclusions

Heat exchangers called radiators are used to heat and cool by releasing thermal energy into the surrounding air from coolant fluid. Nanomaterials (less than 100 nm in size) in the base fluid have been widely used in recent decades for both industrial and scientific applications. Radiators use a 60:40 weight per cent mixture of ethylene glycol and pure water as their fundamental fluid, which is also commonly used as a cooling fluid in the automotive sector. The effect of heat transfer augmentation was investigated in this suggested system by using various hybrid nano-fluid combinations in radiator pipes. A comparative experimental analysis of the thermal performance of various combinations of nanofluids flowing in a radiator is presented. ANSYS was used to examine the radiator's cooling performance and compare it to that of standard cooling fluid. The investigation took into account a 3d computational domain. A k-ɢ turbulence model with a two-phase equation was chosen. Nanoparticles are regarded as a discrete phase in a discrete phase model based on the Lagrangian–Eulerian method. Equations for momentum, energy, and continuity conservation are also resolved. A circular tube with an unstructured mesh and a smooth expansion layer close to the wall is chosen as the basic computational domain. The concentration of the nanofluid is raised from 0.05 to 0.15. In the area, the inlet fluid temperature is maintained at 90°C. From the above analysis following conclusions are made. The heat transfer enhancement increases with an increase in flow velocity. The increase in nanofluid concentration increases the heat transfer augmentation. The maximum fall in fluid temperature is 42.51°C at 0.15% volume concentration at 780 Reynolds's Number.

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