CFD Analysis of Nanoparticles With Antifreeze Coolants In Automobile Radiator

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Abstract- *Convectional heat transfer fluids such as water, mineral oil and ethylene glycol play an important role in many industrial sectors including power generation, chemical production, air-conditioning, transportation and microelectronics. Although various techniques have been applied to enhance their heat transfer capabilities, their performance is often limited by their low thermal conductivities which obstruct the performance enhancement and compactness of heat exchangers. With the rising demand of modern technology for process intensification and device miniaturization, there was a need to develop new types of fluids that are more effective in terms of heat exchanger performance. To achieve this, this has been recently proposed to disperse small amounts of nanometer-sized (10-50 nm) solid particles (nanoparticles) in base fluids (antifreeze coolants), resulting in what is commonly known as nanofluids.*

This project helps to achieve the higher heat transfer rate with high-thermal conductive nanofluids and base fluids (antifreeze coolants) by using CFD software.

I. INTRODUCTION

Energy is one of the main resources for society nowadays. Climate change, fossil fuel reservoirs depletion and the growth of worldwide energy demand have been the motivators for the looking of more efficient ways of energy generation, storage and consumption.

Thermal processes play a major role in energy generation from both convectional fuels and renewable resources. Thermal cycles, involving different heat transfer processes, are essential to transform energy, eventually converted into electricity in power plants from fossil and nuclear fuels, biomass or thermal solar energy. Nevertheless, cooling processes of components involved in energy generation are also susceptible of an improve in its efficiency.
Given the importance of increasing the efficiency of heat transfer processes, several approaches have been investigated over the past years to enhance heat transfer such as vibration techniques, application of electric and magnetic fields or surface modification, among others. However, particle addition to working fluids has been explored for several years and has become more and more relevant since Choi et al. suggested the use of nanoparticle dispersions, nanofluids, for heat transfer applications, taking advantage of the enhanced thermal conductivity of solids compared to the poor thermophysical properties of common working fluids.

Although early attempts with bigger solid particle additives were carried out prior to Choi et al. serious issues due to poor stability and deposits of the particles were solved using nanosized additives instead. The nanoparticles used are ultrafine; therefore, nanofluids appear to behave more like a single-phase fluid than a solid–liquid mixture. The commonly used materials for nanoparticles are metals (Al, Cu, Ag, Au, Fe), nonmetals (graphite, carbon nanotubes), oxides ceramics (Al_2O_3, CuO, TiO_2, SiO_2), carbides (SiC), nitrides (AiN, SiN), layered (Al+ Al_2O_3, Cu+C), PCM and functionalized nanoparticles. The base fluid is usually a conductive fluid, such as water (or other coolants), oil (and other lubricants), polymer solutions, bio-fluids and other common fluids, such as paraffin. Investigations have shown that nanofluids possess enhanced thermophysical properties such as thermal conductivity, thermal diffusivity, viscosity and convective heat transfer coefficients compared to those of base fluids like oil or water. Owing to their enhanced thermophysical properties, nanofluids have numerous industrial, engineering and bio-medical applications such as heat transfer applications: industrial cooling, smart fluids; nanofluid coolant: vehicle cooling, electronics cooling; medical applications: magnetic drug targeting and nanocryosurgery.
In recent years, heat transfer has received many engineering applications such as heat exchanger, piping system, solar collectors and electric conductors. Some of these applications depend on natural convection for heat transfer mechanism, while others depend on forced convection for heat removal in the systems. However, it is quite evident that appropriate convective heat transfer fluids are necessary. The use of nanofluids as coolants would allow for smaller sized and better positioning of the radiators. Owing to the fact that there would be less fluid due to the higher efficiency, coolant pumps could be shrunk and truck engines could be operated at higher temperatures allowing for more horsepower while still

meeting stringent emission standards. Future engines designed using nanofluids cooling properties will run at more optimal temperatures allowing for increased power output. With a nanofluid engine, components would be smaller and weight less allowing for less fuel consumption, saving consumers money and resulting in fewer emissions for a cleaner environment.

Singh et al., researchers at Argonne National Laboratory assessing the applications of nanofluids for transportation, determined that the use of high-thermal conductive nanofluids in radiators can lead to a reduction in the frontal area of the radiator by up to 10 %. This new aerodynamic automotive design which minimises the aerodynamics drag not only leads to fuel saving of up to 5 % but also reduces emissions as well. The use of nanofluid also leads to a reduction of friction and wear, reducing parasitic losses, operation of components such as pumps and compressors and hence more than 6 % fuel savings.

It can be concluded that the use of nanofluids will enhance the efficiency and economic performance of car engines, as well as greatly influence the structural design of automotives, such as smaller and lighter engine radiators cooled by a nanofluids which can be placed elsewhere in the vehicle as opposed to the front of the car. By reducing the size and repositioning the radiator, a reduction in weight and wind resistance could enable greater fuel efficiency and subsequently lower exhaust emissions.

II. LITERATURE REVIEW

Yiding Cao et al. They introduce application of heat pipe in automobile industry. In this application heat pipe is introduced in the automotive radiator to enhance heat transfer. The use of heat pipe increases the automobile radiator efficiency and reduces cooling fan power consumption. Heat pipes are wickless heat pipes and basically two- phase closed thermosyphons. The working fluids inside the heat pipe are different than the engine coolant. The effectiveness of heat pipe are hundred times higher than the copper. The gravity is used to assist the return fluid. Air is evocated from container and container is sealed. Heat was applied to the evaporator section, which causes the liquid to vaporize. The vapor then flows from the hotter section due to the higher vapor pressure to the colder section of the heat pipe, where it was condensed. The liquid condensate then returns to the evaporator section from the condenser section under the assistance of gravity.

Efeovbokhan et al. The cooling properties of a locally formulated coolant (sample c) its boiling characterized and specific heat capacity were investigated along with common coolant water (as sample A) and a commercial coolant (sample B). The results off investigation showed that sample C gave the best performance compared to other two samples A and B. The boiling point of sample B is higher than sample A and C is higher than B. This means that the possibility of a boil-out of sample C from the radiator is little compared to samples A and B. Also, for the same quantity of coolant more heat would be required to raise sample C to its boiling point than for samples A and B. The better cooling is achieved using sample C.

Oliet et al. Studied different factors which influences the radiator performance. It includes air, fin density, coolant flow and air inlet temperature. The radiator performance depends upon air and coolant mass flow rate. When air and coolant flow rates increases the efficiency of radiator also increases. When inlet air temperature increases the cooling capacity decreases. Smaller fin spacing and greater louver fin angle have higher heat transfer. Fin density may be increased till it blocks the air flow and heat transfer rate reduced.

Jama et al. The air flow distribution and non-uniformity across the radiator of full size Australian made ford falcon was tested in industrial wind tunnel. The cooling air intake of the vehicle were shielded by a quarter, one half and three quarter and fully blocked. The best method to shield front end is to employ horizontal method. This shielding method produces the more uniform cooling airflow distribution compared to other methods. Non uniformity index increased significantly as the front end air intake area was shielded. It is reduced the cooling capacity of the vehicle. These shielding methods also produced higher average velocity across the radiator which is analogous to better cooling.

Sadik Kakac, et al In his literature survey showed that nanofluids significantly improve the heat transfer capability of conventional heat transfer fluids such as oil or water by suspending nanoparticles in these base liquids. The understanding of the fundamentals of heat transfer and wall friction is prime importance for developing nanofluids for a wide range of heat transfer application. He concluded that although there are recent developments in the study of heat transfer with nanofluids, more experimental results and the theoretical understanding of the mechanisms of the particle movements are needed to understand heat transfer and fluid flow behavior of nanofluids.

D. Chintakayala et al. In the present study a Nano fluid is used as a coolant in a radiator model and radiator model is modeled in CATIA modeling software and is meshed using a pre-processing software GAMBIT. It is analyzed and presented by using a Computational Fluid Dynamics (CFD) environment software FLUENT. In results velocity distribution graphs shown that the radiator design have to be optimized to eliminate water stagnation. To account for the variation of the inlet conditions with time as in practical cases, transient analysis can be done.

A. Sing Nano fluid is the suspensions of nano particle in base fluid. Nano fluid are the unique feature which is different from conventional liquid solid mixture in which nm or µm sized particle are added in the base fluid to enhance the heat transfer rate. Most system/process whose performance is affected by the heat transfer disepetation nanao fluid provides very important role in such case. It is evident that the effects of viscosity and thermal conductivity should be considered together.

D. Sandhya The performance of ethylene glycol and water based TiO_2 nano fluid as an automobile radiator coolant is determined experimentally. The preparation of nanofluid is as 40% ethylene glycol and 60% water with volume concentration of 0.1%, 0.3%, and 0.5% of TiO_2 nano powder. The degree of heat transfer enhancement is depends on quantity of nanoparticle added in the base fluid. At the concentration of 0.5%, the heat transfer enhancement of 35% compared to base fluid was observed. The increase in flow rate of working fluid enhance the heat transfer coefficient for both water and nanofluid considerably the variation of fluid inlet temperature to the radiator slightly influence the heat transfer rate. Brownian motion of nanoparticles may one of the major factor in heat transfer enhancement.

S. Heris They study the effect of water ethylene glycol mixture base nanofluid in a car radiator. Significant enhancements in heat transfer rate are observed using this mixture. The highest Nu number enhancement up to 55% was obtained in 0.8 % volume concentration of CuO and water ethylene glycol mixture. As increase in inlet temperature the Nu number is increased..

III. HEAT TRANSFER ENHANCEMENT METHODS

Heat transfer enhancement methods are generally classified into three categories:

- Active method
- Passive method
- Compound method

Active Method : Active heat transfer enhancement methods require external power input, it is done using the mechanical aids.

Passive Method : While in passive method of heat transfer enhancement does not require any external power input. One of the ways in passive method to enhance heat transfer is to increase the effective surface area and resistance time of the heat transfer fluid.

Compound method : When both active technique and passive technique are used simultaneously for increasing heat transfer of any devices, which is greater than by using any one method at a time, then this term is known as the compound method. Uses both external power sources and geometry design changes.

Methods of heat transfer enhancement in radiator:

There are several different approaches that can be used to optimize heat transfer performance of smaller radiator design. These are 1) Changing the fin design 2) Increasing the core depth 3) Changing the tube type 4) Changing the flow arrangement 5) Changing the fin material 6) Increasing the surface area to coolant ratio 7) Changing the different types of fluid and mixture concentration.

Among the methods mentioned above any one method can be used to enhance the heat transfer rate and then to minimize the radiator size. The selection of method is done as per the application requirement and utilizing range. The changing fin design and increase the number of fins can reached at certain level and there is certain limitation on number of new fins. So its need to look in something new technology which can wide scope of heat transfer enhancement process. Among all it is convenient to use the last method that is changing the different types of fluid and mixture concentration. It does not require to any geometrical change in radiator fin design. The use of nanofluid is one of them.

Preparation methods of nanofluids:

The preparation methods of nanofluids are clearly shown in figure 1.

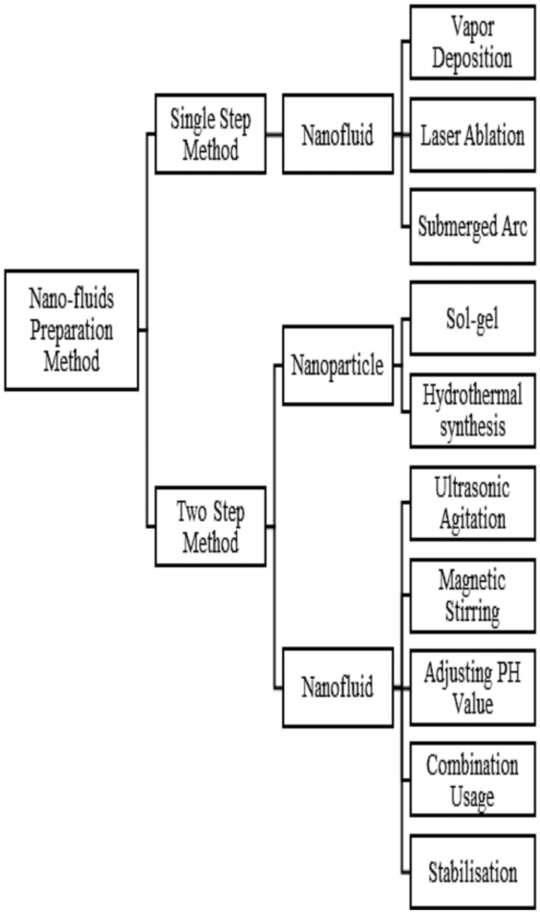

Figure 1 Preparation method of Nanofluids

Modelling Equations:

According to Newton"s law of cooling heat transfer coefficient and corresponding Nu number can be calculated as

$$Q = h\ A\ \Delta T = h\ A_s\ (T_b - T_s)$$

Where,

A_s is the surface area of the tube,
T_b is the bulk temperature,
$T_b = (T_{in} + T_{out}) / 2$

T_{in} and T_{out} are inlet and outlet temperatures respectively and T_s is the tube wall temperature which is the mean value by two surface thermocouples as

$$T_s = (T_1 + \ldots\ldots.. + T_n) / n$$

And heat transfer rate calculated by

$Q = m^* C\ \Delta T = m^* C\ (T_{in} - T_{out})$ m^* is mass flow rate which is determined as

$$m^* = \rho\ V^*$$

$$hexp = m^* C\ (T_{in} - T_{out}) / A_s\ (T_b - T_s)$$

and the Nusselt number can be calculated as
$Nu = hexp\ D_h / k$
D_h is the hydraulic diameter
$D_h = 4\times$ Area / perimeter.
Reynolds number (R_e) is determined as
$_{ReD} = \rho nf\ D_h\ u / \mu nf$

IV. METHODOLOGY

Generic Steps To Solving Problem in Fluent:

Like solving any problem analytically, you need to define (1) your solution domain, (2) the physical model, (3) boundary conditions and (4) the physical properties. You then solve the problem and present the results. In numerical methods, the main difference is an extra step called mesh generation. This is the step that divides the complex model into small elements that become solvable in an otherwise too complex situation. Below describes the processes in terminology slightly more attune to the software.

- **Build Geometry** Construct a two or three dimensional representation of the object to be modeled and tested using the work plane coordinates system within ANSYS.
- **Define Material Properties** Now that the part exists, define a library of the necessary materials that compose the object (or project) being modeled. This includes thermal and mechanical properties.
- **Generate Mesh** At this point ANSYS understands the makeup of the part. Now define how the Modeled system should be broken down into finite pieces. The figure 2 shows the geometry of meshing in ANSYS fluent.

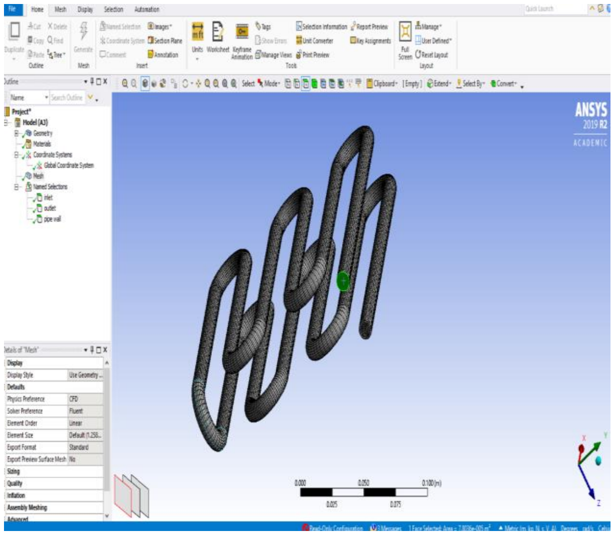

Figure 2 Generated Mesh of Radiator Geometry

- **Define Boundary Conditions** Once the system is fully designed, the last task is to burden the system with constraints, such as physical loadings or boundary conditions. Figure 3 shows the setup initialization in Ansys workbench for defining the boundary conditions.
- **Obtain Solution** This is actually a step, because ANSYS needs to understand within what state (steady state, transient… etc.) the problem must be solved.
- **Present the Results** After the solution has been obtained, there are many ways to present ANSYS" results, choose from many options such as tables, graphs, and contour plots.

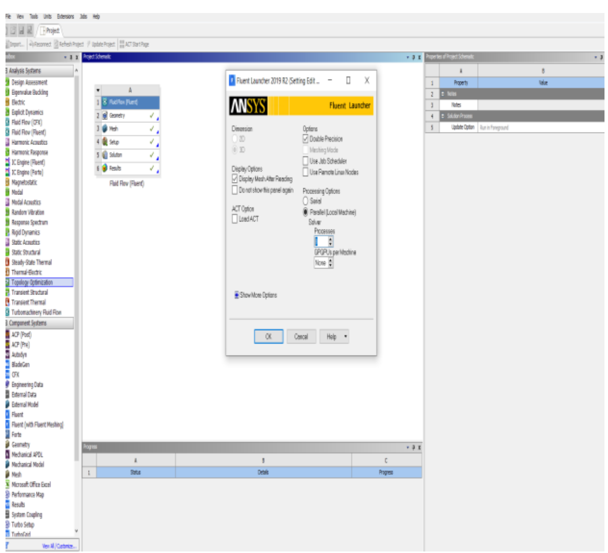

Figure 3 Defining Boundary Conditions in Setup

Specifications of radiator:

The specifications of radiator component used in the ANSYS Fluent was given in the Table 1.

Table 1 Specifications of radiator

Details	Dimensions (mm)
Length	644
Width	30
Height	360
Tube length	584
Tube inner diameter	7
Tube outer diameter	9

Tube material : Aluminium
Coolant Fluid : A Mixture Of Ethylene Glycol and nanofluids

Boundary conditions:

The main boundary condition include, a mass flow rate inlet boundary condition where used in the inlet nozzles. The cylindrical shaped geometries are the wall. At the outlet, the pressure outlet (atmospheric pressure) boundary condition was used. And all other portions are considered as the wall boundary with convective heat transfer surfaces.

- **Inlet :**
  - Select inlet and change type to mass flow inlet
  - Enter the mass-flow rate
  - Enter the value of inlet gauge pressure = 1.5e5 Pa
  - Provide the inlet temperature = 353K
  - Change the option under Direction Specification to "Normal to boundary"
- **Outlet :**
  - Select the outlet and change type to "Pressure-outlet"
  - Enter the value for outlet gauge pressure = 0 Pa
  - Change the option under Direction Specification to "Normal to boundary"
- **Wall :**
  - Select wall and change type to "Wall"
  - Select the material for the wall: Aluminium
  - Choose convection as the heat transfer mechanism employed in wall. Enter the value for heat transfer coefficient as 80 W/m²K.
  - Enter wall thickness as 1mm
  - Enter the free stream temperature on wall

V. CONTOUR PLOTS

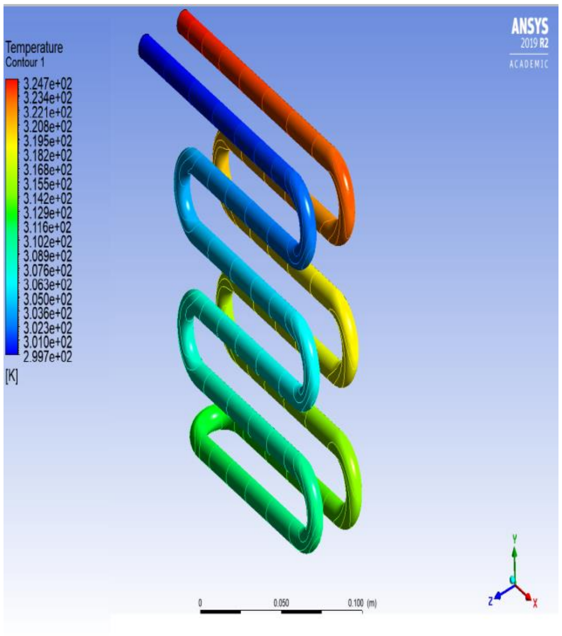

Figure 4 Temperature Contour for nanofluids with ethylene glycol

The figure 4 shows temperature profile for the various points of the radiator geometry. The temperature of the inlet fluid was about 80˚C (ie. 353K) and the aoylet fluid temperature was about ambient temperature (ie.,30˚C). The material of the radiator aluminium also enhance the heat transfer capacity as stated in the material properties of aluminium.

VI. RESULT AND DISCUSSION

Thermophysical properties of ethylene glycol and nanoparticles:

The below table 2 shows about the thermophysical properties of ethylene glycol and nanoparticles.

Table 2 Thermophysical properties of ethylene glycol and nanoparticles

Material	ρ (kg/m3)	cp (J/kgK)	k (W/mK)	β ×10−5 (k−1)	σ (S/m)
Ethylene–glycol	1114	2415	0.252	57	5.5×10^{-6}
Copper oxide (CuO)	6510	540	18	0.85	5.96×10^{7}
Alumina (Al_2O_3)	3970	765	40	0.85	3.5×10^{7}
Titania (TiO_2)	4250	686.2	8.9538	0.9	2.38×10^{6}

As mixing the three different nanoparticles with the base fluid of Ethylene Glycol and water in the inlet fluid of radiator and the thermal efficiency and the heat transfer coefficients are analysed with their respective volume concentration percent.

The below figure 5and 6 shows the temperature profile and velocity profile for different nanofluids such as Copper Oxide (CuO), Alumina (Al_2O_3), Titania (TiO_2) with the base fluid of Ethylene Glycol.

Temperature Profile:

In the figure 5 the (CuO – EG) mixture has the highest heat transfer rate as compared to the (Al_2O_3 – EG) and (TiO_2 – EG) mixtures and also (CuO – EG) has the least velocity profile around the radiator tubes than the other two mixtures. It is observed that the temperature gradually decreases from a maximum value near the plate surface to zero far away from the plate satisfying the free stream conditions. Figure 5 shows that CuO–EG nanofluid thermal boundary layer thickness is greater than that the other two nanofluid as expected. This is in accordance with the earlier observation, since the CuO–EG nanofluid tends to absorb more heat from the plate surface owing to its close proximity to the hot surface. The constant collision of the nanoparticles in the base fluid which is associated with Brownian motion as well as the thermophoresis effect has the summative effect of increasing the fluid temperature; thus, as shown in Fig. 5, increasing the nanoparticle volume fraction φ increases the fluid temperature. In Fig. 6, it is noted that an increase in *Ha* leads to an increase in the temperature and, as a result, the thermal boundary layer thickness increases. This is as expected, since the presence of the magnetic field results in joule heating.

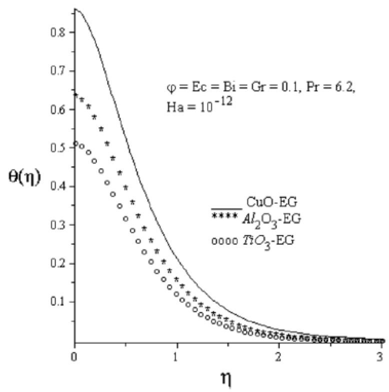

Figure 5 Temperature profile for different nanofluids

Velocity Profile:

It is noted that for all the pertinent parameters, the velocity is maximum at the moving plate surface but decreases gradually to zero at the free stream far away from the plate surface, thus satisfying the boundary conditions.

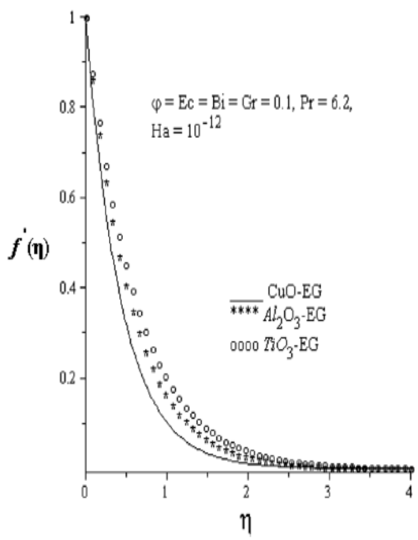

Figure 6 Velocity profile for different nanofluids

As shown in Fig. 6 the momentum boundary thickness for CuO–EG nanofluid is thinner compared to the other nanofluids. This is due to the fact that CuO is more susceptible to the influence of the magnetic field than the rest of the nanoparticles used. Consequently, CuO–EG nanofluid tends to flow closer to the convectively heated plate surface. As expected from theory and as illustrated in above figure, increasing the magnetic parameter *Ha* slackens the fluid velocity due to the Lorentz force which results in resistance to the transport phenomena. This retarding force can control the nanofluids velocity which is useful in numerous industrial, engineering and bio-medical applications such as heat transfer applications: industrial cooling, smart fluids; nanofluid coolant: vehicle cooling, electronics cooling; medical applications: magnetic drug targeting and nanocryosurgery.

Thermophysical properties of water and copper oxide:

The below table 3 shows about the thermophysical properties of water and (CuO) nanoparticle.

Table 3 Thermophysical properties of Water and Copper Oxide

Material	ρ (kg/m3)	Cp (J/kgK)	k (W/mK)	β ×10−5 (k−1)	σ (S/m)
Copper oxide (CuO)	6510	540	18	0.85	5.96 × 10^7
Water (H_2O)	1000	4.1796	0.022	21.60	0.0723

The values from the above table is used with the mixture of Copper Oxide water as the base fluid. Which gives the graphical composition of temperature profile by varying the volume fraction of the nanofluid (CuO) by ϕ = 0.05%, 0.10%, 0.20% respectively

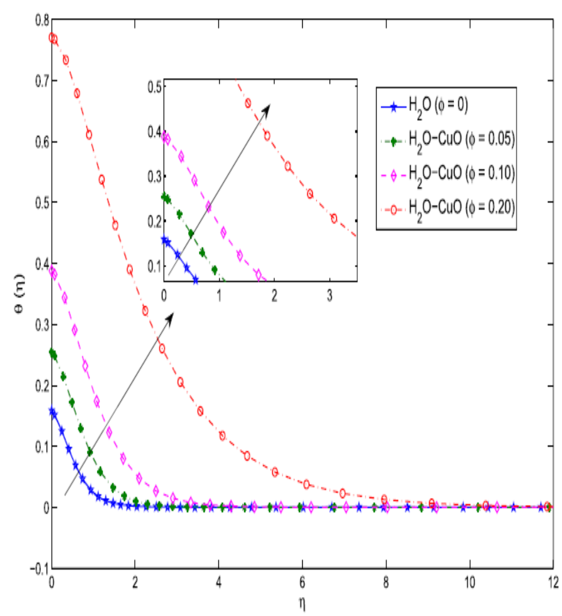

Figure 7 Temperature profile with varying values of nanoparticle volume fraction ϕ

VII. CONCLUSION

In this paper, we investigate the heat transfer rate enhancement using water based nanofluids with application to automotive radiators. Three different type's viz. copper-oxide (CuO), Alumina ($Al_2 O_3$) and Titanium (TiO_2) nanoparticles are taken into consideration in this study with Ethylene Glycol. Copper-Oxide with Ethylene Glycol gives the maximum heat transfer rate so that efficiency of the radiator can be improved. But the cost of the ethylene glycol and nanofluids are too expensive so there was a need of alternate method to improve the life and efficiency of the radiator economically.

To achieve the alternate solution the study was carried out by analytical method with ANSYS fluent software by using Copper – Oxide with water which gives higher heat transfer rate when larger the concentration of CuO nanoparticles. The velocity of nanofluid decreases with increasing magnetic field strength (Ha) and concentration factor (ϕ) of nanoparticles.

Moreover, water based nanofluids with copper oxide nano-particles have a much higher heat transfer rate than Al_2O_3-water and TiO_2-water nanofluids. Nanofluids based on copper oxide nanoparticles have slow velocity than the other two nanofluids. This is due to the copper oxide nanoparticles which enhance the viscosity of the CuO-water nanofluid over the other two nanofluids. It allows the nanofluid to take more time on the heated surface and thus absorbs more heat from surface in comparison to other two nanofluids.

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