Performance evaluation of different coolants used in car radiator: A Finite Element Analysis

Rohit Kumar Namdeo[1], Prof K.K. Jain[2]
[1] *Research Scholar, department of mechanical Engg. SRIT, Jabalpur (M.P)*
[2]*Professor, department of mechanical Engg. SRIT, Jabalpur (M.P)*

Abstract- **In automobile industry uninterrupted increased the need of high performance, best economy, optimum design of engine. Radiator is used like a cooling component of engine, and mostly water is used as coolant. In liquid-cooled system, heat is detached via coolant mixing in the radiator. The coolant is flow through pumps and the heat is carried away via radiator. Optimization of design and size of radiator is necessary for the efficient cooling rate.**

The design optimization has limited due to certain reasons thus the efficiency can be improve by testing different coolents instead of water. Thus in this work a car radiator has been optimized having there thermal performance using different coolant. For the based fluid, a mixture of water and water with Al2O3 and CuO particles of concentration 0.3% were added to the base fluid and then evaluate the heat transfer characteristics of the fluid.

This objective of the present paper is "to evaluate the performance of the heat transfer characteristics of water/anti-freezing based fluid as a coolant for car radiator".

For the based fluid, a mixture of water and water with Al2O3 and CuO particles of concentration 0.3% were added to the base fluid and then evaluate the heat transfer characteristics of the fluid.

Index Terms- **radiator, heat transfer rate, CFD, FEA approach etc.**

1. INTRODUCTION

1.1 General

In an automobile, fuel and air deliver power inside the engine through ignition. Just a segment of the aggregate generated power really supplies the automobile with power - the rest is squandered as fumes and warmth. On the off chance that this abundance warm isn't expelled, the engine temperature turns out to be too high which brings about overheating and viscosity breakdown of the lubricating oil, metal debilitating of the overheated engine parts, and worry between engine parts bringing about faster wear, in addition to other things.

As the coolant flows through the tubes of the radiator, warm is exchanged through the balances and tube dividers to the air by conduction and convection

1.2 HEAT TRANSFER THEORY

Heat transfer is the thermal energy in transit caused by a temperature difference. Heat transfer can occur basically in three different ways, namely – Conduction, Convection and Radiation. It can occur either alone or in combination depending on the object under consideration. When the object under study is stationary and there is a temperature gradient in it, heat transfer through conduction takes place. Similarly, the heat transfer which will occur between a moving fluid and a stationary object is significantly convection. Although in reality, convection doesn't exist alone and some amount of heat transfer takes place through radiation.

Conduction

''Conduction is the transfer of energy from high-energy particles of a substance to the adjacent low-energy particles as a result of interactions between the particles. In solids, conduction is the result of the vibrations of molecules and the energy transport by free electrons. The amount of energy transferred depends on the internal temperature difference in the volume, cross section area and thermal conductivity of the material. The heat transfer rate can be described by

$$Q_{cond} = kA\frac{dT}{dx} \quad \ldots\ldots\ldots\ldots \quad (1.1)$$

Where Q_{cond} is the rate of heat transfer, k is the thermal conductivity, A is the cross section area, is the temperature difference between the layers and is the distance between them.

Convection

''Convection is the energy transfer between a solid surface and an adjacent fluid that is in motion; it is the combined effect of conduction and fluid motion. Convection can be natural or forced. Natural convection is a form of conduction between the volume and the stationary fluid and occurs because of the density differences due to temperature change in the fluid. Natural convection can be described by

$Q_{conv} = hA_s(T - T_{00})$ ………… (1.2)

Where $Q_{conv}$the heat transfer rate, h is the convection heat transfer coefficient, As is the surface area, T is the volume temperature and T_{00} is the fluid temperature.

Radiation

The emissivity is a measure of how close the material is to an ideal surface in terms of a maximum radiation rate. The net heat transferred by radiation can be described by

$Q_{rad} = \varepsilon\sigma A_s(T^4 - {T_{00}}^4)$ ………… (1.3)

Where Q_{rad} is the net heat transfer rate, ε is the emissivity, σ is the Stefan-Boltzmann constant, As is the surface area, T is the volume temperature and T_{00} is the surrounding air temperature.

1.3 The Cooling systems

When gasoline is combusted in an engine only 30 % of the chemical energy in the fuel is converted to useful work. The remaining energy is transformed to heat which must be removed from the engine in order to prevent the engine parts from overheating. To expand the heat dismissal from the engine a cooling system is used keeping in mind the end goal to exchange produced heat to the encompassing air. The cooling system in a cutting edge auto fundamentally comprises of three noteworthy subsystems, isolated by the distinction in cooling fluid, which is straightforwardly or in a roundabout way associated with the engine (Figure 1.1). These subsystems redirect around 50 % of the created heat in the engine and exchange it to the particular cooling fluid

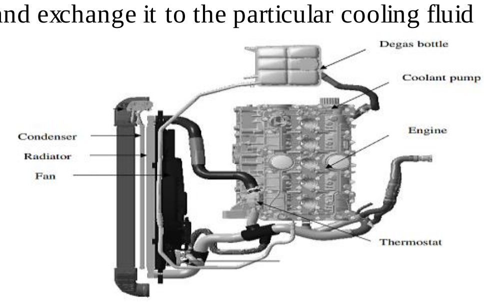

Figure 1.1 Cooling System

Radiator

The radiator is a component used to transfer heat from the coolant to the ambient air. The coolant flows in tubes from side to side, and the air flows in the transverse direction forced by the vehicle speed and under some circumstances by the fan. To increase the heat transfer, flat metal pieces known as fins are attached to the tubes. This increases the area where heat transfer can take place. Depending on gearbox selection, two different configurations of the radiator exists.

2 LITERATURE REVIEW

The various researchers have been study the cooling performance of radiators some of them are:

"Experimental investigation of heat transfer potential of Al2O3/ Water-Mono Ethylene Glycol nanofluids as a car radiator coolant", Dattatraya G. Subhedar, Bharat M. Ramani, Akhilesh Gupta, 2018, Case Studies in Thermal Engineering 11 (2018) 26–34

In this examination, the heat transfer potential of Al_2O_3/Water-Mono Ethylene Glycol nano-fluids is explored tentatively as a coolant for auto radiators. The base liquid was the blend of water and mono ethylene glycol with 50:50 extents by volume. The stable nano-fluids got by ultra-sonication are utilized as a part of all trials. In this study nanoparticle volume fraction, coolant flow rate, inlet temperature used in the ranges of 0.2–0.8%, 4–9 l per minute and 65–85 °C.

The results show that the heat transfer performance of radiator is enhanced by using nano-fluids compared to conventional coolant. Nano-fluid with lowest 0.2% volume fraction 30% rise in heat transfer is observed.

"Thermos-physical properties and heat transfer characteristics of water/anti-freezing and Al_2O_3/CuO based nanofluid as a coolant for car radiator" Alhassan Salami Tijani, Ahmad Suhail bin Sudirman, 2018, International Journal of Heat and Mass Transfer 118 (2018) 48–57

In recent times conventional heat transfer fluids such as water and engine oil are widely used in the automobile radiator.This investigation means to assess the execution of the heat transfer qualities of water/hostile to solidifying based nanofluid as a coolant for auto radiator. For the based liquid, a blend of water and Ethylene Glycol were utilized with grouping of half for every one of the liquid. Al_2O_3 and CuO nano particles of fixation 0.05%, 0.15% and 0.3% were added to the base liquid and after that assess the heat transfer qualities of the nanofluid .The mass flow rate of nanofluids in the flat tube was kept constant. The heat transfer models are simulated using ANSYS fluent solver. The performance of the heat transfer characteristics were evaluated based on certain parameters which are the heat transfer coefficient, thermal conductivity, Nusselt number, and rate of heat transfer of the nanofluids. It was found that the nanofluid that exhibited the highest heat transfer performance was the CuO nanofluid. The heat transfer coefficient was recorded at 36384.41 W/m^2 K, the thermal conductivity was 1.241 W/m K, Nusselt number was 208.71 and the rate of heat transfer was at 28.45 W. The Al_2O_3 nanofluid had a heat transfer coefficient of 31005.9 W/m2 K, thermal conductivity of 1.287 W/m K, Nusselt number was 173.19 and the rate of heat transfer was at 28.25 W.

"Full vehicle CFD investigations on the influence of front-end configuration on radiator performance and cooling drag", Chunhui Zhang, Mesbah Uddin, Clay Robinson, Lee Foster, 2017, Applied Thermal Engineering (2017)

This paper presents computational examinations to explore underhood air stream highlights related with radiator execution and cooling drag. Moreover, examination of the effect of the front grille opening size and underhood aloof streamlined gadgets on the cooling drag and radiator execution are introduced in view of full vehicle CFD simulations carried out using a model of Hyundai Veloster.

It is demonstrated in this study that by properly manipulating the cooling air flow pattern, simultaneous improvement of radiator performance and total vehicle drag can be achieved.

3 MODELLING AND SIMULATION

There are a few methods for acquiring the numerical formulation of a heat conduction issue, for example, the finite distinction technique, the finite element strategy, the limit element technique, and the energy adjust (or control volume) strategy. The flow of thermal energy from issue possessing one region in space to issue involving an alternate region in space is known as heat transfer. Heat transfer can occur by three main methods: conduction, convection, and radiation. The fluid flow and heat transfer are effective and complex parameters in radiator flattened tube. CFD simulation depends upon many factors. Geometry modeling and its boundary condition, grid generation, choice of fluent parameters are significantly affect the simulation process.

Ansys Fluent 15.0 is a fluid analysis software of Ansys workbench platform. Ansys combines the cad modeling, complex mesh generation, algorithm solution and post processing facility.

Assumptions

The mathematical model is based on following assumptions:

- The process is steady-state,
- Fluid flow is considered as laminar and incompressible
- The thermo-physical properties of the coolants were constant throughout the flow.
- The energy equation is used to calculate temperature distribution.

Model Description

A three dimensional Radiator was generated using Ansys workbench geometry modular. The aluminum material of fins attached on the tube. The model was generated using the Auto CADD software. The geometry is shown in figure 3.1.

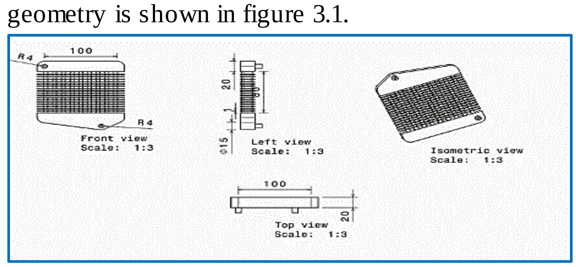

Figure 3.1 Geometry of Radiator

Meshing

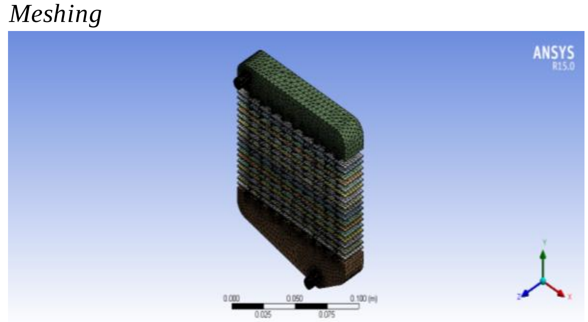

Figure 3.2 Mesh Model

A Tetrahedrons method is used for the meshing. A local minimum size of mesh element is 9.0635e-5 m. Total number of 233300 nodes and 215120 elements are generated during the meshing process. The mesh model shown in figure 3.2.

Thermo physical property of Coolant used

The Thermo-physical properties of coolant used for the study are as *(A.S. Tijani, A.S.b. Sudirman)*

Table 3.1 Thermo-physical property of coolant used for the study

Material	Density (kg/m^3)	Specific Heat Capacity (J/kg K)	Thermal Conductivity (W/mK)	Viscosity (kg/ms)
Water	1027	3570	0.415	0.00076
Water + Al_2O_3	1896.6	1975.971	1.287	0.0019
Water + CuO	2655.6	1461.41	1.241	0.0019

4 SIMULATION RESULTS

The simulation has been carried out on the basis of CFD analysis using Ansys Fluent. The results can be subdivided in two different sections i.e. when fluid velocity constant and fluid inlet temperature varies and second is when the fluid inlet temperature is constant and fluid inlet velocity varies.

4.1 Results having constant fluid velocity (i.e. 0.5 m/s) and varying the fluid inlet temperature.

For comparing the results on the basis of fluid inlet temperature the fluid inlet temperature varies from 345K to 375K with a 10K incremental temperature. Figure 4.1 to 4.4 shows the temperature difference in inlet and outlet temperature obtained for water, figure 4.5 to 4.8 shows the temperature difference in inlet and outlet temperature obtained for water+Al_2O_3 and the temperature difference in inlet and outlet temperature obtained for water+CuO fluid respectively.

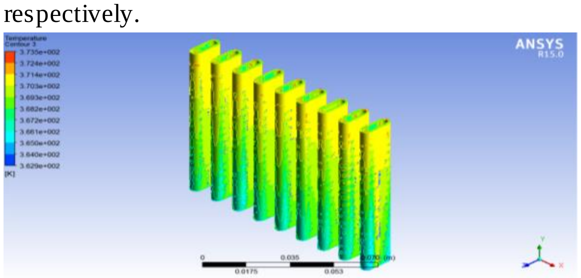

Figure 4.1 Temperature difference obtained having inlet temperature 375 K for Water as a Coolant

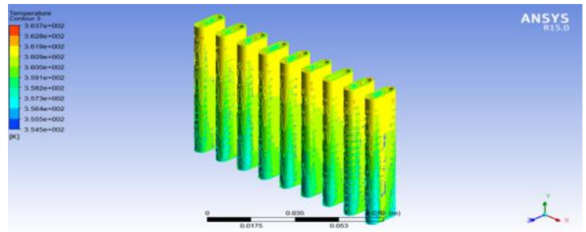

Figure 4.2 Temperature difference obtained having inlet temperature 365 K for Water as a Coolant

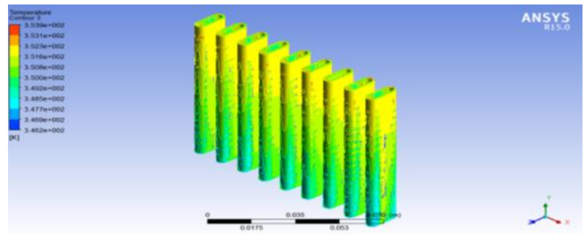

Figure 4.3 Temperature difference obtained having inlet temperature 355 K for Water as a Coolant

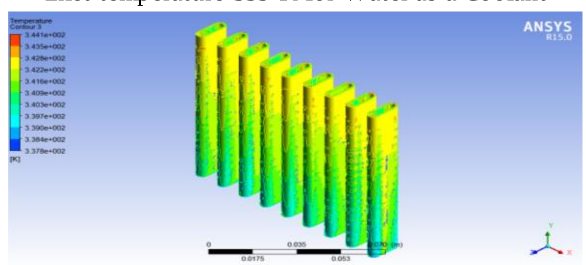

Figure 4.4 Temperature difference obtained having inlet temperature 345 K for Water as a Coolant

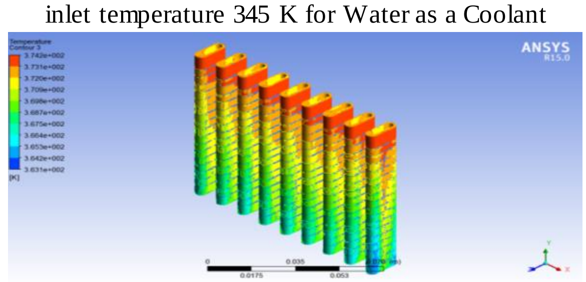

Figure 4.5 Temperature difference obtained having inlet temperature 375 K for Water+Al_2O_3 as a Coolant

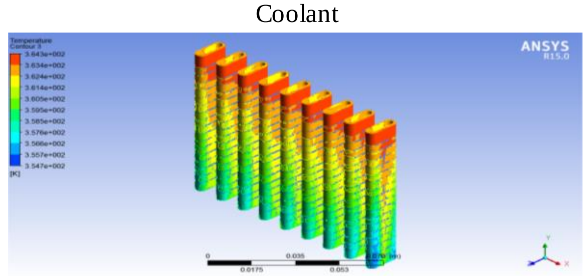

Figure 4.6 Temperature difference obtained having inlet temperature 365 K for Water+Al_2O_3 as a Coolant

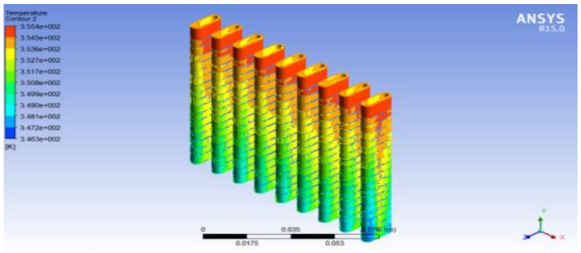

Figure 4.7 Temperature difference obtained having inlet temperature 355 K for Water+Al_2O_3 as a Coolant

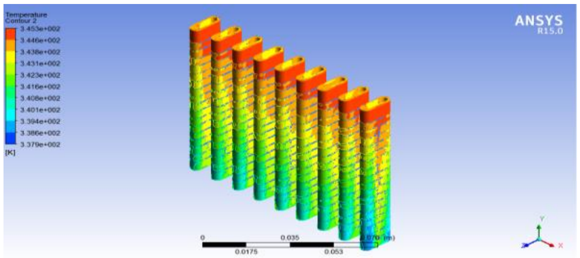

Figure 4.8 Temperature difference obtained having inlet temperature 345 K for Water+Al_2O_3 as a Coolant

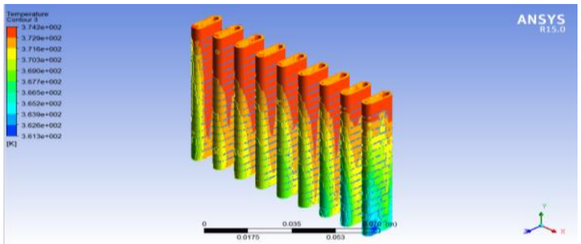

Figure 4.9 Temperature difference obtained having inlet temperature 345 K for Water+CuO as a Coolant

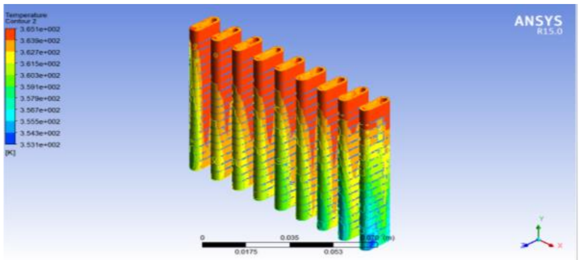

Figure 4.10 Temperature difference obtained having inlet temperature 365 K for Water+ CuO as a Coolant

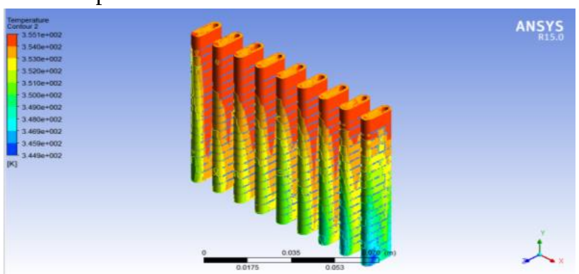

Figure 4.11 Temperature difference obtained having inlet temperature 355 K for Water+CuO as a Coolant

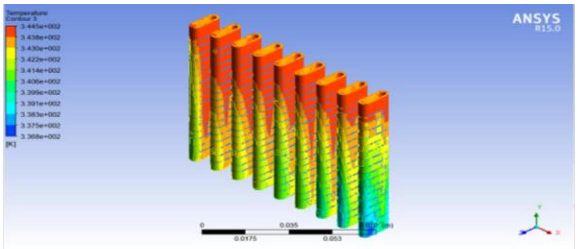

Figure 4.12 Temperature difference obtained having inlet temperature 345 K for Water+ CuO as a Coolant

Table 4.1 Temperature (Max and Min) obtained with varying inlet temperature at constant inlet velocity 0.5 m/s

Material	375 K Inlet Temp		365 K Inlet Temp		355 K Inlet Temp		345 K Inlet Temp	
	Max Temp	Min Temp	Max Temp	Min Temp	Max Temp	Min Temp	Max Temp	Min Temp
Water	373.5	362.9	363.7	354.5	353.9	346.2	344.1	337.8
Water + Al_2O_3	374.2	363.1	364.3	354.7	355.4	346.3	345.3	337.9
Water + CuO	374.2	361.3	365.1	353.1	355	344.9	344.5	336.5

Table 4.2 Temperature Difference obtained with varying inlet temperature at constant inlet velocity 0.5 m/s

Material	Temp Difference Achieved (375 K Inlet Temp)	Temp Difference Achieved (365 K Inlet Temp)	Temp Difference Achieved (355 K Inlet Temp)	Temp Difference Achieved (345 K Inlet Temp)
Water	10.6	9.2	7.7	6.3
Water + Al_2O_3	11.1	9.6	9.1	7.4
Water + CuO	12.9	12	10.1	8

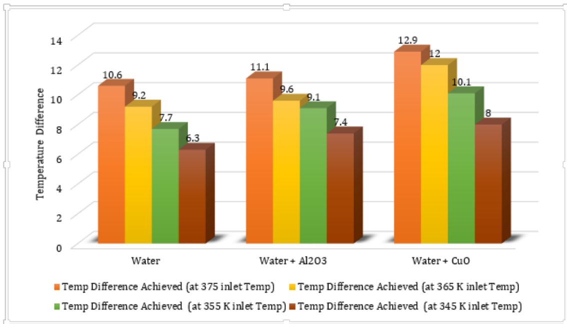

Figure 4.13 Temperature Difference obtained with varying inlet temperature at constant inlet velocity 0.5 m/s

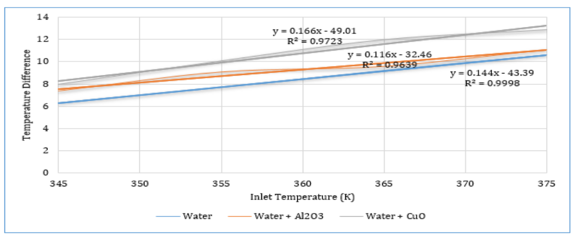

Figure 4.14 Temperature Difference variation trends with respect to inlet temperature for all the 3 fluids

Table 4.1 and 4.2 shows the Maximum and Minimum temperature obtained and the temperature difference obtained with varying inlet temperature at constant velocity. Figure 4.13 and 4.14 shows the comparison in between all the three fluids with respect to inlet temperature variations and trends obtained in temperature difference for the same respectively.

It is obvious from the figure 4.13 that the maximum temperature difference at all inlet temperature can be obtained using Water + CuO fluid as coolant. Water + Al_2O_3 shows the better performance compare then using Water as a coolant.

It can be observed that the temperature difference is higher while increasing the coolant inlet temperature. There is close relation in between temperature difference and fluid inlet temperature as maximum value of R^2 can be obtained and the curve varies linearly.

4.2 Results having constant fluid inlet temperature (i.e. 375 ˚K) and varying the fluid inlet velocity.

For comparing the results on the basis of fluid inlet velocity the fluid inlet velocities varies from 0.1 m/s to 0.4 m/s with a 0.1m/s incremental velocity. Figure 4.15 to 4.18 shows the temperature difference obtained for water while varying the inlet velocity, figure 4.19 to 4.22 shows the temperature difference in inlet and outlet temperature obtained for water+Al_2O_3 while varying the inlet velocity and the temperature difference in inlet and outlet temperature obtained for water+CuO while varying the inlet velocity of fluid respectively.

Table 4.3 and 4.4 shows the Maximum and Minimum temperature obtained and the temperature difference obtained with varying inlet velocity at constant inlet temperature 375K. Figure 4.23 and 4.24 shows the comparison in between all the three fluids with respect to inlet velocity variations and trends obtained in temperature difference for the same respectively.

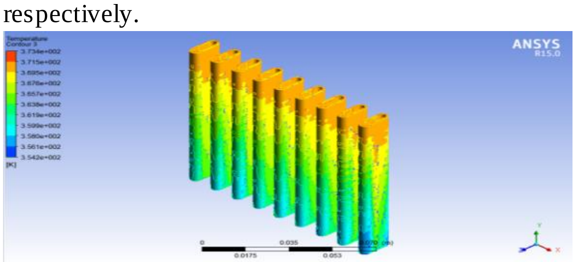

Figure 4.15 Temperature difference obtained having inlet velocity 0.1m/s for Water as a Coolant

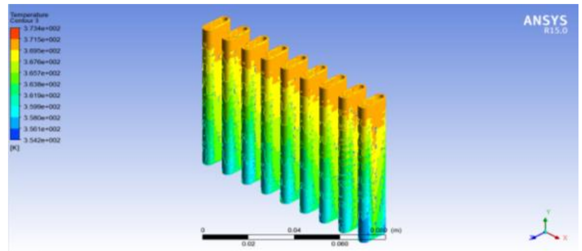

Figure 4.16 Temperature difference obtained having inlet velocity 0.2m/s for Water as a Coolant

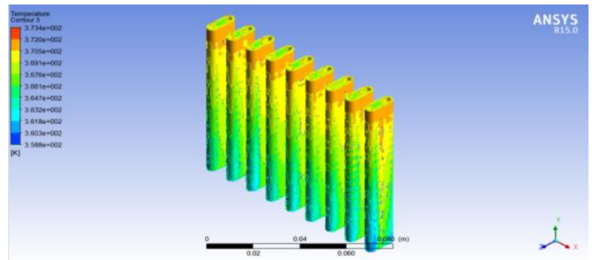

Figure 4.17 Temperature difference obtained having inlet velocity 0.3 m/s for Water as a Coolant

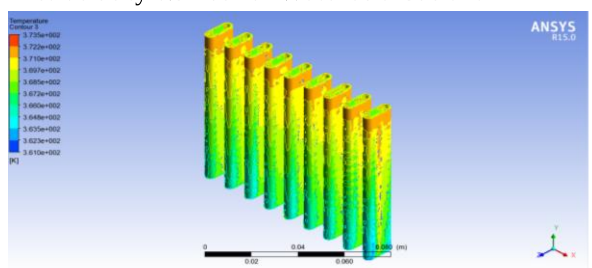

Figure 4.18 Temperature difference obtained having inlet velocity 0.4 m/s for Water as a Coolant

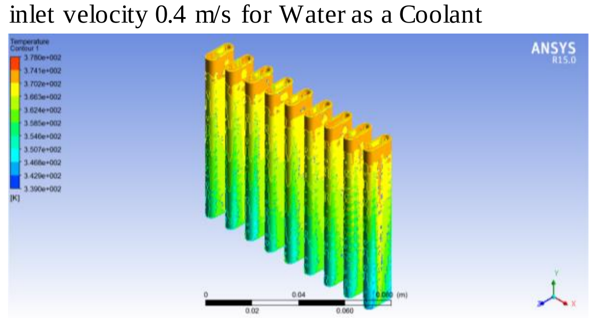

Figure 4.19 Temperature difference obtained having inlet velocity 0.1 m/s for Water + Al_2O_3 as a Coolant

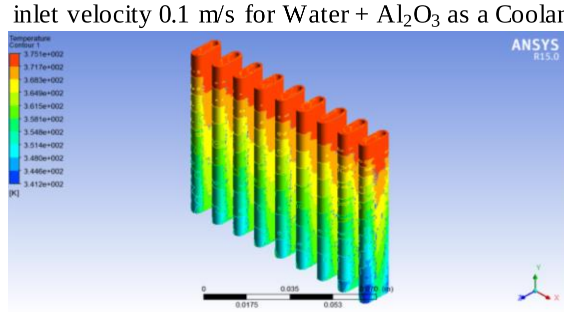

Figure 4.20 Temperature difference obtained having inlet velocity 0.2 m/s for Water + Al_2O_3 as a Coolant

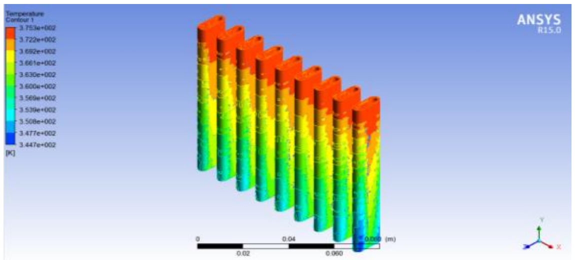

Figure 4.21 Temperature difference obtained having inlet velocity 0.3 m/s for Water + Al_2O_3 as a Coolant

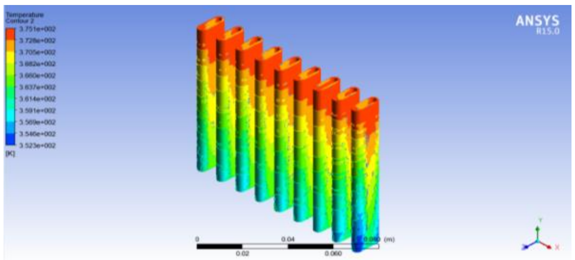

Figure 4.22 Temperature difference obtained having inlet velocity 0.4 m/s for Water + Al_2O_3 as a Coolant

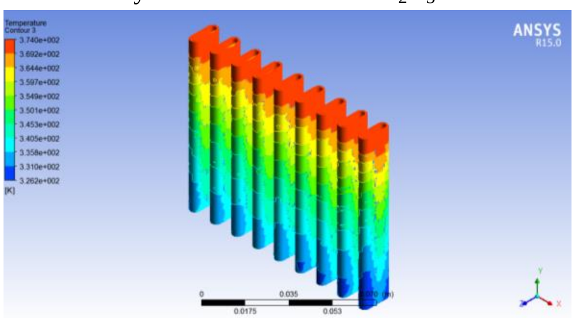

Figure 4.23 Temperature difference obtained having inlet velocity 0.1 m/s for Water + CuO as a Coolant

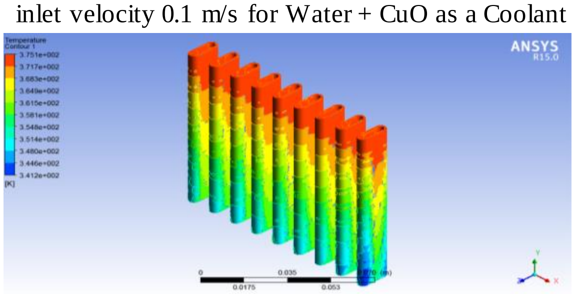

Figure 4.24 Temperature difference obtained having inlet velocity 0.2 m/s for Water + CuO as a Coolant

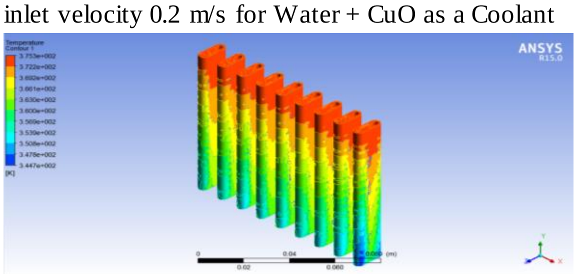

Figure 4.25 Temperature difference obtained having inlet velocity 0.3 m/s for Water + CuO as a Coolant

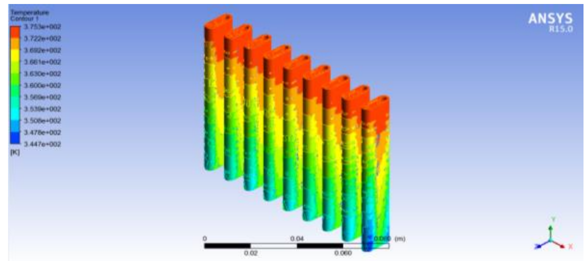

Figure 4.26 Temperature difference obtained having inlet velocity 0.4 m/s for Water + CuO as a Coolant

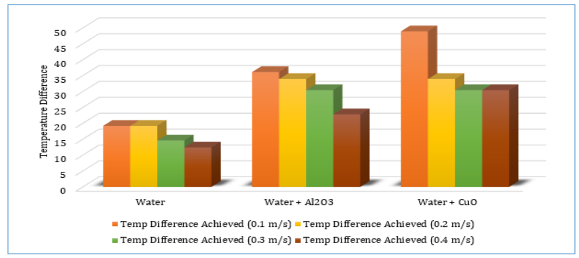

Figure 4.27 Temperature Difference obtained with varying inlet velocity at constant inlet temperature 375 K

Table 4.3 Temperature (Max and Min) obtained with varying coolant inlet velocity at constant inlet temperature (375 K)

Material	Inlet Velocity at 0.1m/s		Inlet Velocity at 0.2 m/s		Inlet Velocity at 0.3 m/s		Inlet Velocity at 0.4 m/s	
	Max Temp	Min Temp	Max Temp	Min Temp	Max Temp	Min Temp	Max Temp	Min Temp
Water	373.4	354.2	373.4	354.2	373.4	358.8	373.4	361
Water + Al2O3	375.1	339	375.1	341.2	375.1	344.7	375.1	352.3
Water + CuO	375.1	326.2	375.1	341.2	375.1	344.7	375.1	344.7

Table 4.4 Temperature Difference obtained with varying inlet velocity at constant inlet temperature (375 K)

Material	Temp Difference Achieved (0.1 m/s)	Temp Difference Achieved (0.2 m/s)	Temp Difference Achieved (0.3 m/s)	Temp Difference Achieved (0.4 m/s)
Water	19.2	19.2	14.6	12.4
Water + Al2O3	36.1	33.9	30.4	22.8
Water + CuO	48.9	33.9	30.4	30.4

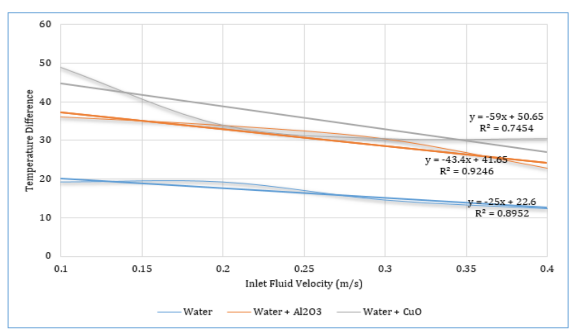

Figure 4.28 Temperature Difference variation trends with respect to inlet fluid velocity for all the 3 fluids

Table 4.3 and 4.4 shows the Maximum and Minimum temperature obtained and the temperature difference obtained with varying inlet fluid velocity at constant inlet fluid temperature respectively.

Figure 4.27 and 4.28 shows the comparison in between all the three fluids with respect to inlet coolant velocity variations and trends obtained in temperature difference for the same respectively. It is obvious from the figure 4.28 that the maximum temperature difference at all fluid inlet velocity can be obtained using Water + CuO fluid as coolant. About 48.9 K temperature difference in between fluid inlet and outlet temperature can be achieved at 0.1 m/s inlet velocity. Water + Al_2O_3 shows the better performance compare then using Water as a coolant.

It can be observed that the temperature difference lowers while increasing the coolant inlet temperature. This is due to the fact that higher velocity lowers the surface contact time and reduces the heat transfer. There is close relation in between temperature difference and fluid inlet temperature as maximum value of R^2 can be obtained and the curve varies linearly.

4.3 Surface Heat Transfer Coefficient

The surface heat transfer coefficient for all the three fluid used as coolant at constant Temperature inlet 375K and constant inlet fluid velocity 0.1 m/s. Figure 4.29, 4.30 and 4.31 shows the Surface heat transfer for used coolant as Water, Water + Al_2O_3 and Water + CuO respectively.

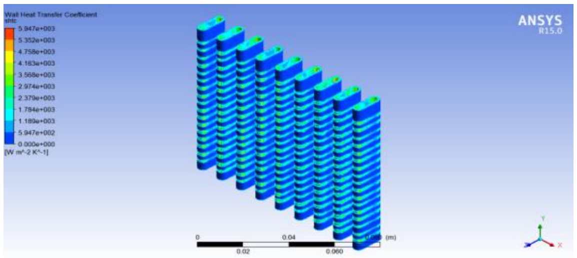

Figure 4.29 Surface Heat Transfer for Water

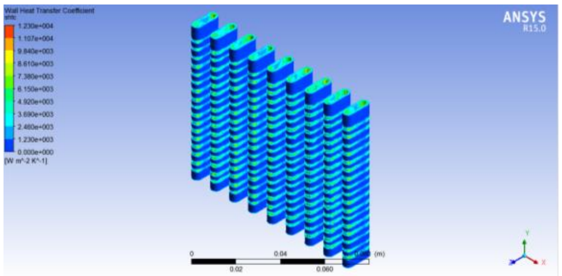

Figure 4.30 Surface Heat Transfer for Water + Al_2O_3

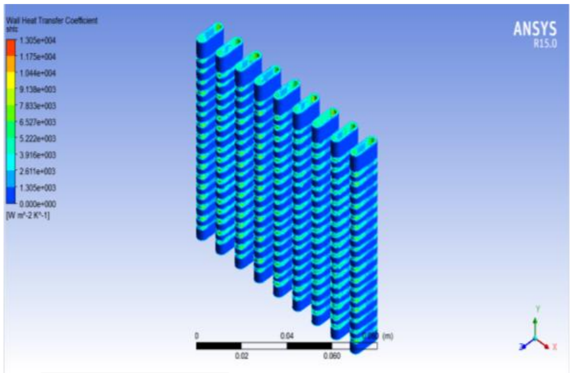

Figure 4.31 Surface Heat Transfer for Water CuO

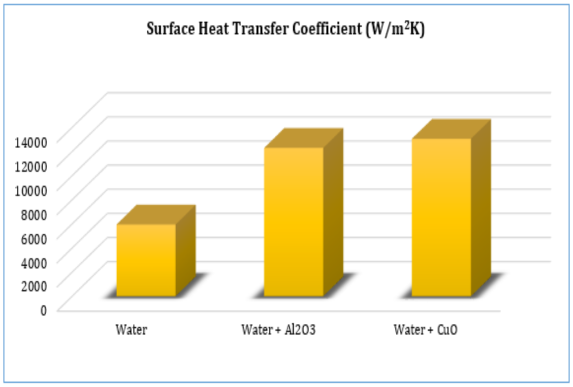

Figure 4.32 Comparison of Surface Heat Transfer for all the 3 Fluids

Table 4.5 Surface Heat Transfer Coefficient for all the 3 Fluids

Material	Surface Heat Transfer Coefficient (W/m^2K)
Water	5947.01
Water + Al_2O_3	12300.4
Water + CuO	13054.3

The lowest heat transfer coefficient was at 5947.01 W/m^2 K for the water as a coolant, while the highest was at 13054.3 W/m^2K for the Water + CuO as coolant, both were simulated at a velocity of 0.1 m/s.

Table 4.6 shows the variation in Prandtl, Reynolds and Nusselt Number for all the 3 Fluids. The highest Reynold's number was 698.84, which is shown in CuO contained fluid. The lowest Nusselt number was calculated at 499.1 by Al_2O_3 contained fluid. Comparing both Al_2O_3 and CuO and Water only fluid, the highest Nusselt number is for Water is 10.79 and the second highest is for CuO fluid were 6.49 and the lowest value is 5.66 for Al_2O_3 contained fluid.

Table 4.6 Prandtl, Reynolds and Nusselt Number for all the 3 Fluids

Material	Density (kg/m^3)	Viscosity (kg/ms)	Prandtl Number Pr	Reynolds Number Re	Nusselt Number Nu
Water	1027	0.00076	6.54	675.65	10.79
Water + Al_2O_3	1896.6	0.0019	2.92	499.10	5.66
Water + CuO	2655.6	0.0019	2.24	698.84	6.49

5 CONCLUSION

The heat transfer performance of both Al_2O_3 and CuO contained Water fluid were determined and compared against each other. Both fluids were also compared to the base fluid water to determine the best fluid to be used as coolant in the car radiator.

In this work the temperature has been selected as the main parameter to study heat transfer distribution across the surface of the radiator tube. The reason for selecting temperature contour is that, it describes the effect of thermal characteristics of each fluid on heat transfer enhancement. The heat from the high temperature of the coolant was transferred via convection and conduction to the walls of the flat tube and to the fins attached on the side of the flat tube walls.

The following results have been obtained after the study

- The maximum temperature difference at all inlet temperature can be obtained using Water + CuO fluid as coolant. Water + Al_2O_3 shows the better performance compare then using Water as a coolant.
- It is observed that the temperature difference is higher while increasing the coolant inlet temperature.
- There is close relation in between temperature difference and fluid inlet temperature as maximum value of R^2 can be obtained and the curve varies linearly.
- The maximum temperature difference at all fluid inlet velocity can be obtained using Water + CuO fluid as coolant. About 48.9 K temperature difference in between fluid inlet and outlet temperature can be achieved at 0.1 m/s inlet velocity. Water + Al_2O_3 shows the better performance compare then using Water as a coolant.
- It is observed that the temperature difference lowers while increasing the coolant inlet temperature. There is close relation in between temperature difference and fluid inlet temperature as maximum value of R^2 can be obtained and the curve varies linearly.
- The lowest heat transfer coefficient was at 5947.01 W/m^2 K for the water as a coolant, while the highest was at 13054.3 W/m^{2}K for the Water + CuO as coolant, both were simulated at a velocity of 0.1 m/s.
- The highest Reynold's number was 698.84, which is shown in CuO contained fluid.
- The lowest Nusselt number was calculated at 499.1 by Al_2O_3 contained fluid. Comparing both Al_2O_3 and CuO and Water only fluid, the highest Nusselt number is for Water is 10.79 and the second highest is for CuO fluid were 6.49 and the lowest value is 5.66 for Al_2O_3 contained fluid.

The addition of Al2O3 and CuO particles to the water as coolant fluid of the car radiator enhanced the heat transfer performance, with an increase in the thermal conductivity, heat transfer coefficient and Nusselt number.

It can be concluded that CuO contained water fluid exhibited a higher heat transfer performance as compared to that of Al_2O_3 contained fluid and only water as coolant.

REFERENCES

[1] Alhassan Salami Tijani, Ahmad Suhail bin Sudirman, "Thermos-physical properties and heat transfer characteristics of water/anti-freezing and Al2O3/CuO based nanofluid as a coolant for car radiator" 2018, International Journal of Heat and Mass Transfer 118 (2018) 48–57

[2] Chunhui Zhang, Mesbah Uddin, Clay Robinson, Lee Foster, 2017 "Full vehicle CFD investigations on the influence of front-end configuration on radiator performance and cooling drag", , Applied Thermal Engineering (2017)

[3] C. Uma Maheswari, C. Suresh Reddy, C, Rajeshwara Reddy, A.T. Kiran Sai Naidu, C. Saradhi, A. Chenna kesavulu, "CFD Analysis of

Radiator", 2016, Invention Journal of Research Technology in Engineering & Management (IJRTEM)

[4] Dattatraya G. Subhedar, Bharat M. Ramani, Akhilesh Gupta, "Experimental investigation of heat transfer potential of Al2O3/ Water-Mono Ethylene Glycol nanofluids as a car radiator coolant", 2018, Case Studies in Thermal Engineering 11 (2018) 26–34

[5] Deepak Chintakayala, Rajamanickam C S, "CFD analysis of fluid flow and heat transfer of an automotive radiator with nano fluid", 2013, IEEE

[6] Devireddy Sandhya, M. Chandra Sekhara Reddy, Veeredhi Vasudeva Rao, "Improving the cooling performance of automobile radiator with ethylene glycol water based TiO2 nanofluids", 2014, International Communications in Heat and Mass Transfer

[7] Hardik V. Patel, Dattatraya G. Subhedar, Dr.Bharat Ramani, "Numerical Investigation of performance for Car Radiator Oval Tube", 2016, ICEMS 2016

[8] Jonn Are Myhren, Sture Holmberg, "Performance evaluation of ventilation radiators", 2013, Applied Thermal Engineering 51 (2013) 315-324

[9] K.Y. Leong, R. Saidur, S.N. Kazi, A.H. Mamun, "Performance investigation of an automotive car radiator operated with nanofluid-based coolants (nanofluid as a coolant in a radiator)", 2010, Applied Thermal Engineering 30 (2010) 2685-2692

[10] K. Goudarzi, H. Jamali, Heat transfer enhancement of AL2O3-EG nanofluid in a car radiator with wire coil inserts, Applied Thermal Engineering (2017)

[11] Kasuba Sainath, Suresh Akella, T. Kishen Kumar Reddy, "Experimental and computational analysis of radiator and evaporator", 2015, Materials Today: Proceedings 2 (2015) 2277 – 2290

[12] Miguel A. Campano, Juan J. Sendra, Samuel Domínguez, "Analysis of thermal emissions from radiators in classrooms in Mediterranean climates", 2011, International Conference on Green Buildings and Sustainable Cities.

[13] Rajashekhar Pendyala, Suhaib Umer Ilyas, Lian Rui Lima, Narahari Marneni, "CFD Analysis of Heat Transfer Performance of Nanofluids in Distributor Transformer", 2016, Procedia Engineering 148 (2016) 1162 – 1169

[14] Rinu Sathyan, "Analysis of Automobile Radiator Using Computational Fluid Dynamics", 2016, International Journal of Latest Technology in Engineering, Management & Applied Science (IJLTEMAS), Volume V, Issue VI, June 2016 | ISSN 2278-2540

[15] S.M. Peyghambarzadeh, S.H. Hashemabadi, M. Seifi Jamnani, S.M. Hoseini, "Improving the cooling performance of automobile radiator with Al2O3/water nanofluids", 2011, Applied Thermal Engineering 31 (2011) 1833-1838

[16] Yukio Matsushima, Toshio Takeuchi, Itsuhei Kohri, "Prediction method of engine compartment air flow using CFD analysis", 2000, JSAE Review 21 (2000) 197}203