ICMIEE20-127

Numerical Analysis on Heat Transfer with Nanofluid in an Automotive Radiator

Anzaman Hossen *, *Nazmus Sakib*
Department of Mechanical Engineering, Khulna University of Engineering & Technology, Khulna-9203, BANGLADESH

ABSTRACT

The present numerical analysis simulated heat transfer with nanofluid (Al_2O_3) passing through a two-dimensional radiator of turbulent flow using computational fluid dynamics (CFD) for single phase approaches. To validate the numerical results, the procedure involved to investigate the efficiency of water based Al_2O_3 nanofluids as coolant in a radiator of Tata Indica/Indigo. Particle concentration levels ranging between 1 vol% to 5 vol.% have been used as working fluids for investigating the current study. The advantages over using water were evaluated. Variations of outlet temperature with different mass flow and various nano-particle concentration level were obtained. Better heat transfer enhancement was found for higher nano-particle concentration levels. Nusselt number and pressure drop at various particle concentration levels of nanofluid in the radiator were compared. Local temperature and pressure with respect to distance from the radiator inlet have also been observed. Results have shown that temperature, pressure and Nusselt number decreases with the radiator length from the inlet. However, local pressure, temperature and Nusselt number also decreases with increasing of nano-particle concentration level. The current numerical investigation was validated through comparing of simulations with those mentioned in the literatures.

Keywords: Nanofluid, Automotive radiator, Convection, Turbulent flow, Heat transfer

1.Introduction

Radiator is a cooling and heating device used in automobile or aeroplane made of several thin tubes in which circulating water is cooled by its surrounding air. In other words radiators are one kind of heat exchangers which are used to transfer thermal energy from one environment to another for both cooling and heating purposes. Usually radiators are used to function in automobiles, buildings and electronics devices. It always remains as a source of heat to its surrounding, although radiator can be used for the purpose of heating to its surrounding environment or for cooling coolant supplied through it, as for engine cooling. Automotive radiators are usually mounted at the front section of the vehicle where they get in touch with air flow from the forward movement of the vehicle. It accomplishes heat from engine coolant comes from engine that passing around it. For a typical radiator, Heat transfer occurs between hot coolant and outdoor air around the radiator. Typically, water is used as a coolant but nanofluid have been used considerably for higher efficiency.

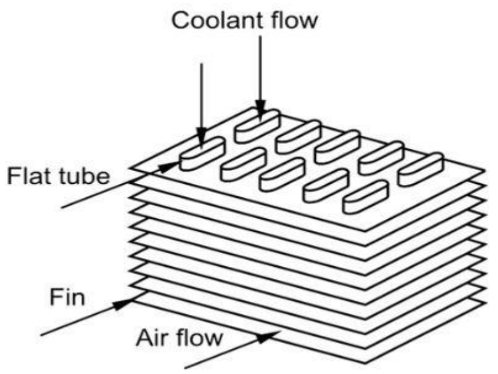

Fig.1: Configuration of an automobile radiator. [1]

Previous in 1970's, the first-generation automobiles used brass or copper radiator because they were cheap and obtainable at that era. During the most recent three decades, various hypothetical and experimental analysis of heat transfer through car radiator have been researched. Nowadays nanofluids have been used as coolant instead of water to achieve better heat transfer performance.

Tasgaonkar G.S. and Chavan D.K [2] brought in to have circular core of radiator where all regulars are in either rectangular or square shape molded which have many following inconveniences; fan convey wind current fit as a fiddle so that its air distribution isn't uniform over the whole center core less at corners and just about zero at focus along center heading to axial direction. Different plan information was performed by CFD investigation. Anyway, this model was having a few restrictions like flexion of tube which enhance loss of head.

Komalangan, Navid B. and Nariman B. [3] investigated on numerical study of water based CuO nanofluid in automotive Suburban diesel engine radiator. Nanoparticles size of 20nm with up to 2% volume concentration under turbulent flow were used in that experiment. To investigate local heat transfer coefficient and convection heat transfer coefficient, heat transfer between nanofluid and surrounding air flow was determined first.

Vajjha, Das and Namburu [4] investigated heat transfer efficiency of Al_2O_3 and CuO nanoparticles under laminar flow in the flat tubes of an automotive radiator. It was shown that the convective heat transfer coefficient along the flat tubes with the various concentration level of nanofluid flow had significance advancement over water and ethylene base fluid.

Vahid Delavari and Sayed Hassan Hashemabadi [5] investigated on numerical analysis for both water and ethylene glycol based Al_2O_3 nanofluid in an automotive

* Corresponding author. Tel.: +88-01521301927
E-mail address: nzamanhossen.riad@gmail.com

radiator. They considered only a flat tube to simulate the whole radiator. Though Eulerian-Eulerian approach is more acceptable but they used mixture model to avoid the lack of large computer memory and high-performance CPU. They compared the Nusselt number between pure ethylene glycol and pure water.[4]

Maiga [6] used fluent code to investigate numerical results of convective heat transfer using nanofluid through a uniformly heated tube for both laminar and turbulent flow. They investigated both water–Al_2O_3 and ethylene glycol–Al_2O_3 nanofluid flows and found that for both laminar and turbulent flows, Heat transfer rate and shear stress were increasing with nanoparticle level.

Rinu Sathyan [7] investigated two-dimensional straight circular tube radiator (Tata Indigo/Indica) numerically. The author used 25% ethylene glycol and 75% water as radiator coolant to investigate heat transfer and fluid flow characteristics through CFD and found better heat transfer enhancement than water as a coolant. He also investigated for both circular and helical tubes for the radiator and found helical tube is more efficient.

In this study Rinu sathyan's two-dimensional (Tata Indigo/Indica) radiator has been used with Al_2O_3 nano fluid as a coolant under turbulent flow. Cooling performances of nanofluid coolants were compared with water coolants. Variation of outlet temp-erature of the radiator with different mass flow rate at various volume level of particle was carried out. Variation of local temperature and pressure with distance of the radiator tube was also shown. Finally, Surface Nusselt number and pressure drop with different mass flow rate at various particle concentration levels of nanofluids were investigated.

2. Thermo-physical properties of nanofluid

Here, density (ρ_{nf}) of Al_2O_3-water nanofluid is calculated based on empirical Eq. (1) which was proposed by Cho and Pak [8] as-

$$\rho_{nf} = (1-\emptyset)\rho_{bf} + \emptyset\rho_p \qquad (1)$$

Where $\emptyset$ is the volume concentration level of nanoparticle and ρ_{bf} is base-fluid's density and ρ_p is nanoparticle's density.

Xuan and Roetze [9] proposed a correlation Eq. (2) for specific heat of nanofluid.

$$C_{p,nf} = \frac{(1-\emptyset)\rho_{bf}C_{p,bf} + \emptyset\rho_p C_{p,p}}{(1-\emptyset)\rho_{bf} + \emptyset\rho_p} \qquad (2)$$

Where ρ_p is the density of nanoparticle itself, ρ_{bf} is the density of base fluid. Similarly, $C_{p,p}$ is the specific heat of nanoparticle and $C_{p,bf}$ is base-fluid's specific heat. Therefore, thermal conductivity (K_{nf}) and viscosity (μ_{nf}) for nanofluid can be calculated based on two semi-empirical Eq. (3) proposed by Hamilton and Crosser [10] equation -

$$K_{nf} = \frac{K_p + (n-1)K_{bf} - \varphi(n-1)(K_{bf} - K_p)}{K_p + (n-1)K_{bf} - \varphi(n-1)(K_{bf} - K_p)} \times K_{bf} \qquad (3)$$

Where K_p is are the thermal conductivity of nanoparticle and K_{bf} is the thermal conductivity of base fluid. Finally, n is the shape factor for the effect of the shape of the particles and for spherical nano-particle n= 3

According to Brinkman [11], μ be calculated by Eq. (4)

$$\mu_{nf} = \frac{1}{(1-\emptyset)^{2.5}} \times \mu_{bf} \qquad (4)$$

Where μ_{bf} is expressed as dynamic viscosity for base fluid.

3. Solution methodology

Computational fluid dynamic is a set of numerical methods to obtain approximate solution of problems with heat transfer and flow of fluid.

3.1 Geometry model

The geometry was generated by Solidworks 2019. After generating geometry in Solidworks, it was inputted in the ANSYS 16.2 software and simulation was performed. The dimensions and geometry are followed below in the table 1 and fig.2 respectively.

Table 1: Dimensions of the radiator. [7]

Part details	Dimension(mm)
Length	694
Width	30
Height	360
Tube length	584
Inner tube diameter	7
Outer tube diameter	8

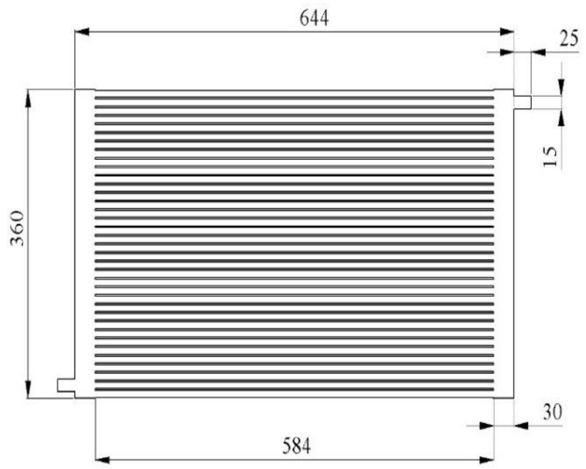

Fig.2: Geometry used in the current numerical study

Fig.2 shows geometry and dimensions of the model

3.2 Governing equations

The coolant inside the radiator can be taken as income-pressible. The governing equations are assumed to be steady state for incompressible fluid. The compression work and the viscous dissipation can be neglected for the coolants flow in the radiator. The density of the water-and ethylene glycol-based nanofluids is almost constant under pressure. The gravity force was also neglected. Under these circumstances, the following conservation equations have been solved numerically under two-dimensional flow field through computational fluid dynamics using finite volume method on ANSYS 16.2

Continuity equation
$(\nabla.V) = 0$

Momentum equation
$\rho_{nf}(\nabla.V)\ V = -\ \nabla P + \mu_{nf}\nabla^2 V$

Energy equation
$\rho_{nf}C_{pnf}(\nabla.V)T = K_{nf}\nabla^2 T$

3.3 Boundary conditions

Numerical simulations were performed in a turbulent flow with different mass flow rates of 500kg/h, 1000kg/h, 1500kg/h, 2000kg/h, 2500Kg/h and inlet temperature of 368 K. As aluminum oxide particles have higher thermal conductivity, used as a coolant and concentration range for nanoparticles were 1%, 3% and 5%. The boundary conditions as previously mentioned were the following:

-inlet: various mass flow rate, inlet temperature of 368K and gauge pressure = 1.5e5 Pa;
-wall: aluminum material,
Ambient temperature T_o = 300 K,
No slip condition, 1mm thick,
Heat transfer coefficient h_o = 10 W/m^{2}k;
-outlet: outlet gauge pressure = 0 Pa was considered.

Good convergence was the primary priority throughout the simulations. The solution time increases if the convergence criteria is made strict. As the model was two dimensional it didn't take too much time to converge with 10^{-6} residual. Also, high resolution advection scheme and double precision solver were used.

3.4 Model validation

"Analysis of Automobile Radiator Using Computational Fluid Dynamics" by Rinu Sathyan[7] which was analyzed through ANSYS. The setup run through present software for validation. For model validation, Rinu Sathyan's model were carried out in mass flow range from 500 Kg/h to 2500 Kg/h with mixture of ethylene glycol & water. Through comparison of outlet temperatures of the radiator with the results reported by Rinu Sathyan, current numerical solutions have been investigated. It is noted from Fig. 3 that the current results are in acceptable condition comparing with the results presented by Rinu Sathyan.

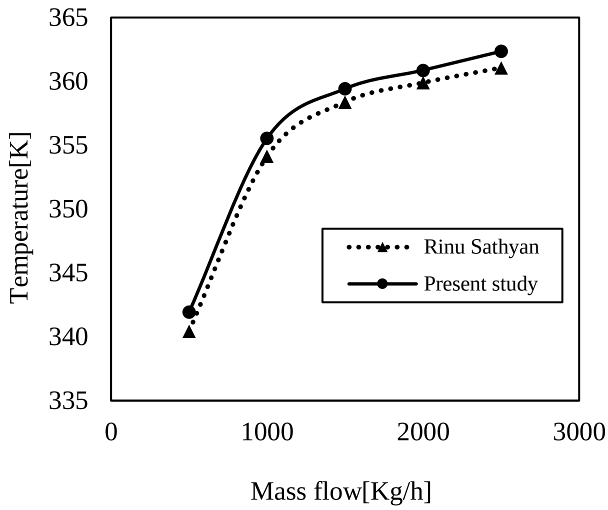

Fig.3: Numerical results for water and ethylene glycol mixture in comparison with the results reported by Rinu Sathyan.

4. Results and discussion

As Rinu Sathyan investigated the outlet temperatures and temperature contours using ethylene glycol and water mixture for both straight and helical tube radiator, in this present study only straight tube radiator was used with different volume concentration of Al_2O_3 nanofluids. In this present analysis water based Al_2O_3 nanofluids was used as a coolant instead of water or water-ethylene glycol mixture to get better heat transfer performances.

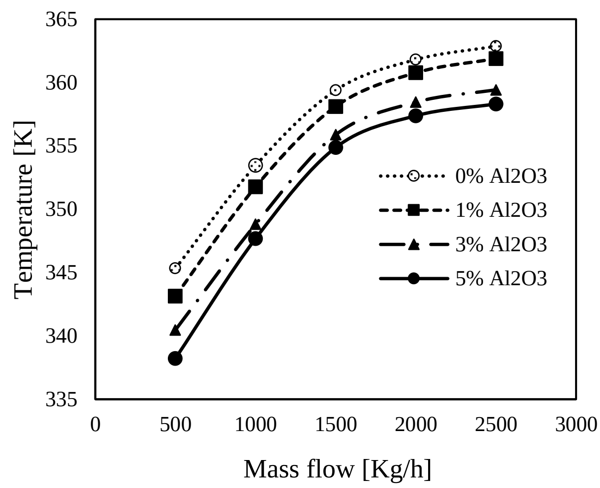

Fig.4: Variation of outlet temperature of the radiator with different mass flow.

Fig.4 shows the effect of mass flow at the outlet temperature of the radiator. The outlet temperature increases with increasing mass flow at the inlet. As the convection heat transfer coefficient and ambient temperature around the radiator is constant, temperature increases with increasing of coolants amount. Also, it can be seen that temperature at the outlet for nanofluids remain signify-cantly lower than the temperature of base fluid. Therefore, for a given mass flow, outlet temperature decreases with an increase in the nanoparticle concentration level.

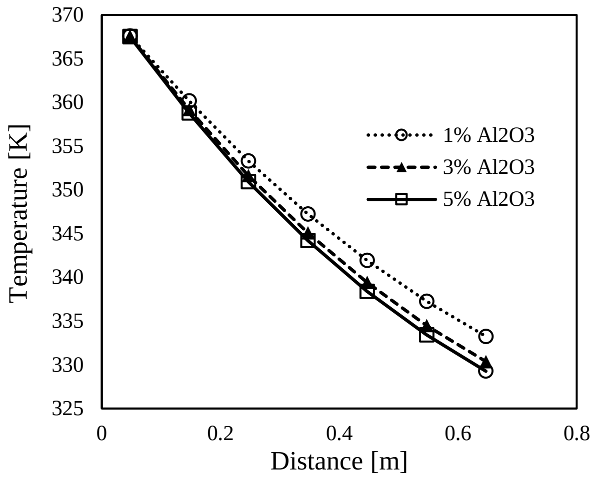

Fig.5: Variation of temperature with distance of the radiator tube for various volume concentration of Al_2O_3

Fig.5 shows variation of average temperature with various sections of the radiator tube. It is shown that temperature decreases with increasing of distance from the radiator inlet because of higher heat transfer. Greater the distances traveled by coolants, greater the convective heat transfer. Hence temperature is decreased. From fig.5 it is also shown that temperature decreases with the increase of volume fraction of nanofluids at a given radiator section. But for larger volume fraction such as 5% Al_2O_3, temperature decrement is lower than that for lower volume centration level of nanofluids.

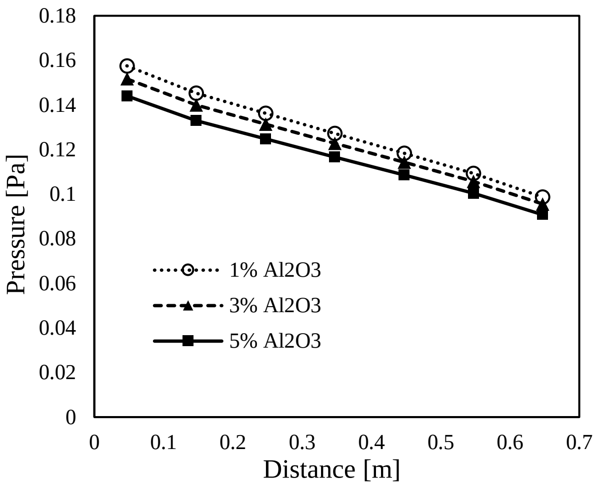

Fig.6: Variation of pressure with distance of the radiator tube for various volume concentration levels of Al_2O_3

Fig.6 shows variation of local pressure for various section of the radiator tube. Pressure decreases with increasing of distance from inlet of the radiator. It should be noted that only tube sections of the radiator have been considered rather than inlet and outlet tank of the radiator. At inlet and outlet tank, average pressure would be greater than that at tube sections. It can also be shown that pressure decreases with increasing of concentration level of Al_2O_3 because of greater viscosity and density.

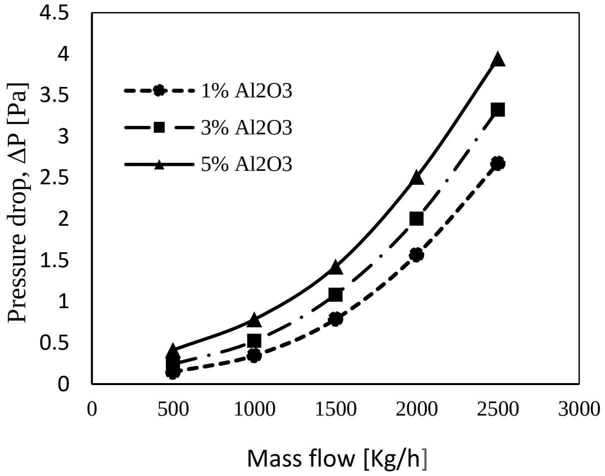

Fig.7: Variation of pressure drop with different mass flow for various particle concentration levels of Al_2O_3

Pressure drop variation with different mass flow is shown in fig.7. Pressure drop increases with the increase of mass flow at the inlet. At higher mass flow rate, pressure drop is higher than that at lower mass flow rate. It is also shown that pressure drop is increased with increasing of percentage levels of Al_2O_3 particles. Since density as well as viscosity depend on the particle concentration level, friction factor is increased. Thus, nanofluid requires higher pumping power.

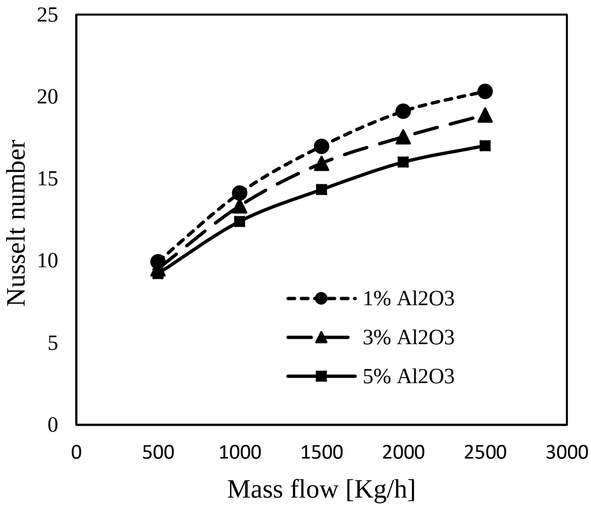

Fig.8: Characteristics of surface Nusselt number for different mass flow at various volume concentration levels of Al_2O_3

Fig.8 shows the heat transfer enhancement investigation due to use of nanofluids as a coolant in the automobile radiator. Surface Nusselt number is decreased at wall due to increment of Al_2O_3 particles. It is also shown from fig.8 that Nusselt number increases with increasing of mass flow. At lower mass flow, Nusselt numbers are not changing significant-ly with increasing of particle concentration levels of Al_2O_3.

5. Conclusions

The water based Al_2O_3 nanofluid convective heat transfer in turbulent flow along with an automobile radiator had been investigated numerically. Initially, the present model was validated for the coolant as mixture of water and ethylene glycol. Then the effects of particle concentration levels and the mass flow rate on the heat transfer performances of nanofluids were determined. The density and viscosity of nanofluids are increased with the addition of Al_2O_3 nanoparticle. It can be noted that relation between heat transfer coefficient and volume concentration level of nanofluid is proportional. Temperature at outlet decreases with the addition of nanofluid particles. Local temperature and pressure also decreased with the increase of length from the inlet. Pressure drop is increased at higher particle concentra-tion level of Al_2O_3, hence the requirement of pumping power also increased for much higher particle concentration level. Nano-particle concentration level should not be increased much higher because at higher particle concentration about 5%, pressure drop and pumping power is increased. The expense of the system is also increased although negligible increases in heat transfer performance can be obtained.

6. References

[1] G. Huminic, A. Huminic, Numerical analysis of laminar flow heat transfer of nanofluids in a flattened tube, International Communications in Heat and Mass Transfer (2013).

[2] Chavan D.K, Tasgaonkar, G.S. (2013), Study, Analysis and Design of automobile radiator (heat exchanger) proposed with cad drawings and geometrical model of the fan, International Journal of Mechanical and Production Engineering Research and Development (IJMPERD) ISSN 2249-6890.

[3] N. Bozorgan, K. Krishnakumar, N. Bozorga, Numerical study on application of CuO-Water nanofluid in automotive diesel engine radiator, Modern Mechanical Engineering Vol.2 No.4(2012), Article ID:24895

[4] R.S. Vajjha, D.K. Das, P.K. Namburu, Numerical study of fluid dynamic and heat transfer performance of Al2O3 and CuO nanofluids in the flat tubes of a radiator, International Journal of Heat and Fluid Flow 31 (2010) 613–621.

[5] V. Delavari, S. H. Hashemabadi, CFD simulation of heat transfer enhancement of Al_2O_3/water and Al_2O_3/ethylene glycol nanofluids in a car radiator, Applied Thermal Engineering, Volume 73, Issue 1, 5 December 2014, Pages 380-390.

[6] Maïga, Sidi & Palm, Samy & Nguyen, Cong & Roy, Gilles & Galanis, Nicolas. (2005), Heat transfer enhancement by using nanofluids in forced convection flows, International Journal of Heat and Fluid Flow.26.530-546.10.1016/j.ijheatfluidflow.2005.02.004.

[7] Rinu Sathyan, Analysis of automobile radiator using computational fluid dynamics, International Journal of Latest Technology in Engineering, Management & Applied Science (IJLTEMAS) Volume V, Issue VI, June 2016, ISSN 2278-2540.

[8] B.C. Pak, Y.I. Cho, Hydrodynamic and heat transfer study of dispersed fluids with submicron metallic oxide particles, Experimental Heat Transfer 11 (1998) 15.

[9] Xuan Y., Roetzel W., Conceptions of heat transfer correlation of nanofluids, International Journal of Heat and Mass Transfer, Vol. 43, No. 19, pp. 3701-3707,2000.

[10] Hamilton, R.L. and Crosser, Thermal conductivity of heterogeneous two component system, I and EC Fundamentals 1, 1962, pp. 187-191.

[11] H.C. Brinkman, The viscosity of concentrated suspensions and solution, The Journal of Chemical Physics 20 (1952) 571–581.

NOMENCLATURE

c_p : Specific heat, J/kg K
h : Heat transfer coefficient, W/m2K
m : Mass flow, kg/s
k : Thermal conductivity, W/m K
p : pressure, kPa
T : Temperature, K
To : Ambient temperature, K
Nu : Nusselt number
$\emptyset$: Volumetric concentration, %
ρ : Density, kg/m^3
μ : viscosity, Pa s