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Research Article

Performance investigation of Automobile Radiator operated with Nanofluids Based Coolant

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Abstract

Traditionally forced convection heat transfer in a Automobile radiator is performed to cool circulating fluid which consisted of water or a mixture of water and anti-freezing materials like ethylene glycol (EG). In this paper, the heat transfer performance of binary mixture EG+ water (50 %) volume concentration. Furthermore, different amounts of Al_2O_3 nano particle have been added into these base fluids and its effects on the heat transfer performance of the Automobile radiator have been determined experimentally. Air Reynolds number has been changed in the range of 84391-91290 and the fluid inlet temperature has been constant for all the experiments and mass flow rate of the coolant flowing through the radiator. The results demonstrate that nanofluids clearly enhance heat transfer compared to their own base fluid. In the best conditions, the heat transfer enhancement of about 70% compared to the base fluids has been recorded.

Keywords: *Nanofluids, Automobile Radiator, Heat Transfer Enhancement*

1. Introduction

The radiator is an important accessory of vehicle engine. Normally, it is used as a cooling system of the engine and generally water is the heat transfer medium .For this liquid-cooled system, the waste heat is removed via the circulating coolant surrounding the devices or entering the cooling channels in devices. The coolant is propelled by pumps and the heat is carried away mainly by heat exchangers. Continuous technological development in automotive industries has increased the demand for high efficiency engines. A high efficiency engine is not only based on its performance but also for better fuel economy and less emission. Reducing a vehicle weight by optimizing design and size of a radiator is a necessity for making the world green. Addition of fins is one of the approaches to increase the cooling rate of the radiator. It provides greater heat transfer area and enhances the air convective heat transfer coefficient. However, traditional approach of increasing the cooling rate by using fins and micro-channel has already reached to their limit. Optimal mass characteristics for a heat pipe radiator assembly for space application were investigated by Vlassov et al. Their results showed that under certain combinations of input parameters, the assembly with acetone HP can be more weight effective than the one with ammonia, in spite of the liquid transport factor criterion indicates an opposite trend. In addition, heat transfer fluids at air and fluid side such as water, ethylene glycol and mixture of ethylene glycol +water (50:50) combination exhibit very low thermal conductivity. As a result there is a need for new and innovative heat transfer fluids for improving heat transfer rate in an automobile radiator. Nanofluids seem to be potential replacement of conventional coolants in engine cooling system. Recently there have been considerable research findings highlighting superior heat transfer performances of nanofluids. Yu. Et. al. reported that about 15-40% of heat transfer enhancement can be achieved by using various types of nanofluids. With these superior characteristics, the size and weight of an automotive car radiator can be reduced without affecting its heat transfer performance. This translates into a better aerodynamic feature for design of an automotive car frontal area. Coefficient of drag can be minimized and fuel consumption efficiency can be improved.

Nanofluids have attracted attention as a new generation of heat transfer fluids in building in automotive cooling applications, because of their excellent thermal performance. Recently, there have been considerable research findings highlighting superior heat transfer performances of nanofluids.

Therefore, this study attempts to investigate the heat transfer characteristics of an automobile radiator using mixture of ethylene glycol + water (50:50) combination based Al_2O_3 nanofluids as coolants. Thermal performance of an automobile radiator operated with nanofluids is compared with a radiator using conventional coolants. The effect of volume fraction of the Al_2O_3 nanoparticles with base fluids on the thermal performance and potential size reduction of a radiator were also carried out. Al_2O_3 nanoparticles were chosen in this study.

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2. Nanofluid in enhancing thermal conductivity

Eastman et al reported that the thermal conductivity of ethylene glycol nanofluids containing 0.3% volume fraction of copper particles can be enhanced up to 40% compared to that of ethylene glycol basefluid. Hwang et al found that thermal conductivity of the nanofluids depends on the volume fraction of particles and thermal conductivity of basefluid and particles. Lee et al. measured the thermal conductivity of low volume concentration of aqueous alumina (Al_2O_3) nanofluids produced by two-step method. Authors inferred that the thermal conductivity of aqueous nanofluids increases linearly with the addition of alumina particles. Thermal conductivity of zinc dioxide ethylene glycol (ZnO+EG) based nanofluids was investigated by Yu et al .They obtained about 26.5% enhancement of thermal conductivity by adding 5% volume fraction of zinc dioxide nanoparticles in ethylene glycol. Present study concluded that size of nanoparticles and viscosity of the nanofluids played a vital role in thermal conductivity enhancement ratio of them.

Mintsa et al investigated the effect of temperature, particle size and volume fraction on thermal conductivity of water based nanofluids of copper oxide and alumina. Authors suggested that thermal characteristics can be enhanced with increase of particles' volume fraction, temperature and particle size. Authors found that the smaller the particle size, the greater the effective thermal conductivity of the nanofluids at the same volume fraction. Contact surface area of particles with fluid and Brownian motion can be increased when smaller particles are used in the same volume fraction. This consequently increased thermal conductivity of nanofluids.

3. Nanofluid in enhancing forced convective heat transfer

Namburu et al numerically analyzed turbulent flow and heat transfer to three types of nanofluids namely copper oxide (CuO), alumina (Al_2O_3) and silicon dioxide (SiO_2) in ethylene glycol and water, flowing through a circular tube under constant heat flux. Results revealed that nanofluids containing smaller diameter of nanoparticles produce higher viscosity and Nusselt number. Nusselt numbers are also increased at higher volume fraction of particles. It is observed that at a constant heat flux (50 W/cm^2) with a constant Reynolds number (20,000), heat transfer coefficient of 6% CuO nanofluid has increased 1.35 times than that of the base fluid. At the same particle volume fraction, CuO nanofluid produced higher heat transfer coefficient compared to that of other types of nanofluids.

Ding et al found that convective heat transfer coefficient of nanofluids has the highest magnitude at the entrance length of a tube. It starts decreasing with axial distance and eventually accomplish at a constant value in the fully developed region. At a given flow and particle concentration, aqueous carbon nanoparticles offer highest improvement. Zeinali et al experimentally investigated convective heat transfer to alumina water (Al_2O_3/water) nanofluids in laminar flow inside a circular tube with constant wall temperature under different concentrations of nanoparticles. They obtained augmentation of heat transfer coefficient of nanofluid with increase of nanoparticle concentration. They also obtained greater heat transfer coefficient of nanofluid in comparison to that of distilled water base fluid at a constant Peclet number. Authors have reported that the heat transfer augmentation results are much higher in experimental observation than that of predicted results. Yu et al conducted heat transfer experiments of nanofluids containing 170-nm silicon carbide particles at 3.7% volume concentration. The results showed that heat transfer coefficients of nanofluids are 50-60% greater than those of base fluids at a constant Reynolds number.

Kim et al investigated effect of nanofluids on the performances of convective heat transfer coefficient of a circular straight tube having laminar and turbulent flow with constant heat flux. Authors have found that the convective heat transfer coefficient of alumina nanofluids improved in comparison to base fluid by 15% and 20% in laminar and turbulent flow, respectively. This showed that the thermal boundary layer played a dominant role in laminar flow while thermal conductivity played a dominant role in turbulent flow. However, no improvement in convection heat transfer coefficient was noticed for amorphous particle nanofluids.

4. Experimental test rig and procedure

4.1 Experimental test rig

The below figure 1 shows schematic diagram of experimental set up which consists of closed loop circuit. The experimental test rig includes reservoir and heating element, magnetic drive pump, Rotameter, radiator fan(speed control DC motor) and Automobile radiator. Magnetic drive pump gives the flows 16-18 LPM; the flow rate of the test section is regulated by two globe valve which is appropriate adjustable to the recycle line as shown in fig 1. The working fluid fills 30% of the storage tank whose total volume is 35 lit. The total volume of the circulating liquid is constant in all the experiments. The circuit include 0.30m diameter pipeline which is made of the steel pipe. A Rotameter is used to measure the flow through the test section. The specification of the Rotameter is 100-1000 LPH and measurement of 1/2" BSP(M).

For heating the working fluid an electric heater of capacity 2000 watt and controller were used to maintain the temperature 50-80^oC. Two K type thermocouples were implemented on the flow line to record the radiator inlet and outlet temperature. Two thermocouples K types is installed in the radiator to measure the wall temperature of the radiator.

4.2 Experimental Procedure

The analysis on radiator specification and condition of the fluids shown in table 1 and 2 .How ever nano particle volume fraction air Reynolds number and mass flow rate of the coolant flowing though radiator were varied in order

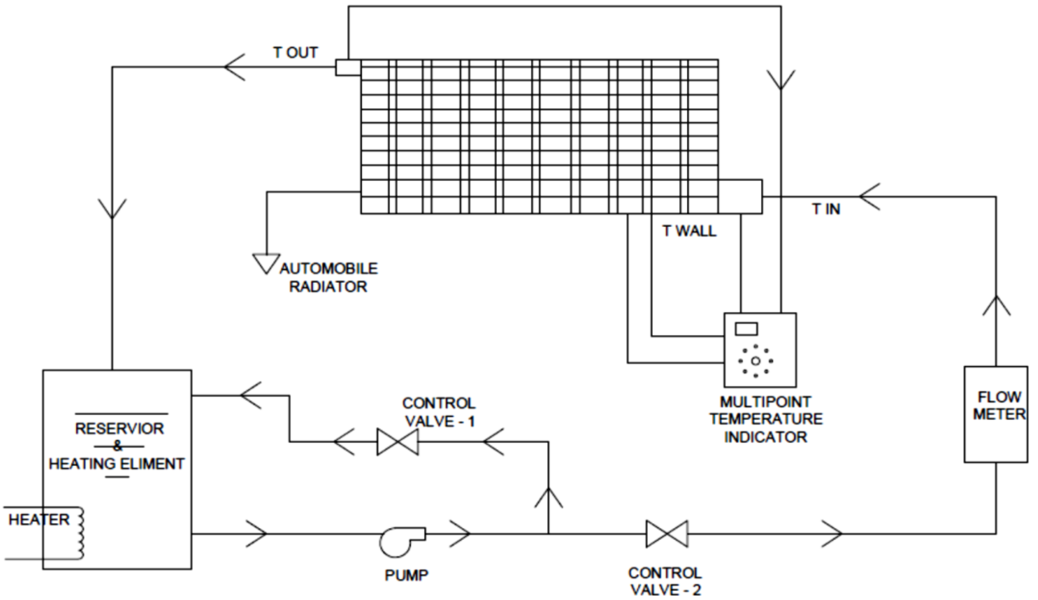

Figure 1 Schematic of experimental set up

to determine the thermal performance of the radiator using nanofluids. The procedure of each analysis is explained below.

Influence of the volume fraction of Al_2O_3 nanoparticles on the thermal performance of an automobile radiator. In the study air Reynolds number and mass flow rate of the coolant were kept fixed at 84391 and 0.08 kg/s. However the concentration of Al_2O_3 nanoparticles were increased from 0 to 1% . Total heat transfer ,overall heat transfer coefficient and effectiveness of the radiator were determined.

Table 1 Radiator specification

Sr.no.	Description	Air	Coolant
1	Fluid inlet temperature	20-40 (Assume T_a=24)	50-80 (Assume Ta= 60)
2	Core width	0.35 m	
3	Core height	0.35 m	
4	Core depth	0.016 m	
4	tubes	0.7 cm x 30 cm	
5	Fin thickness	0.01 cm	
6	Hydraulic Diameter	0.0007 m	
7	Fine types	Ruffled	
8	Tubes arrangement	Staggered	

Table 2 Thermo physical Properties of base Fluid and nanoparticles

Sr.no	Properties	Al_20_3	Mixture of water +ethylene glycols
1	Density (Kg/m^3)	3950	1064
2	Specific heat (J/kg K)	873.336	3370
3	Thermal conductivity	31.922	0.363
4	Viscosity ($N/^{sm2}$)	-	4.65 x 10^{-5}

Influence of the air Reynolds number on the thermal performance of automobile radiator .Air Reynolds number was varied from 84391 to 91290 while mass flow rate of the coolant was kept fixed to 0.08 kg/s. The analysis also included a comparison of the thermal performance of radiator with nanofluid s at different volume fractions. This part focused on effectiveness .overall heat transfer coefficient based on the air side and total heat transfer of an automobile radiator.

Comparison of the coolant pressure drop and pumping power. In this study coolant flow rate was fixed at 0.000083 m^3/s and air Reynolds number is 91290 but the volume fraction of Al_2O_3 nanoparticles was varied. It focused on the effects of volume fraction of Al_2O_3 nanoparticles on the coolant pressure drop and pumping power

5. Mathematical formulation of mixture of water +ethylene glycol based Al_20_3 nanofluids in an automobile radiator

Mathematical correlation shown in this section is taken from the references (V. Vasu *et al*, 2008) & (W.M. Kays et al, 1984; D.G. Charyulu *et al*, 1999). In this paper a comparison is made between the heat transfer performance of radiator by operating with mixture of ethylene glycol+water and nanofluid coolants. It highlighted not only the influence of nanofluids but also volume fraction of Al_2O_3 nanoparticles to the heat transfer rate of a radiator. Described equations are being incorporated to aid the comparison.

The characteristics of nanoparticles and base fluid used in this study are summarized in Table 2. The necessary thermo physical properties in this paper are density, viscosity, specific heat and thermal conductivity. In this paper, density (ρ_{nf}) and special heat capacity (C_{pnf}) of Al_2O_3/water nanofluid have been calculated based one empirical correlations proposed by Pak and Xuan as follows:

$$\rho_{nf} = (1-\varphi)\rho_{bf} + \varphi\rho_p \quad (1)$$

$$C_{nf} = \frac{\varphi\rho_p + (1-\varphi)\rho_{bf}c_{bf}}{\rho_{nf}} \quad (2)$$

Where f is nanoparticle volume concentration and ρ_p, ρ_{bf} and $C_{p,p}$, C_{bf} are the densities and the specific heats of the nanoparticles and base fluid, respectively.

Also, thermal conductivity (k_{nf}) and viscosity (μ_{nf}) for nanofluid have been estimated based on two semi-empirical equations presented by M. Eftekhar in 2013 on the basis of a wide variety of experimental date available in the literature as following equations

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

$$\mu_{nf} = \mu_{bf} \times \frac{1}{(1-\varphi)^2} \quad (4)$$

5.1 Heat transfer modeling

The rate of heat transferred between nanofluid coolant and airflow in the radiator can be written as follows:

$$Q = m_{nf}\, C_{nf}(T_{nfo} - T_{nfi}) = m_a\, C_{pa}(T_{ao} - T_{ai}) \quad (5)$$

where nf and ai denote the relevant parameters of nanofluid coolant and airflow

The mass flow rates are calculated based on the pump for mixture of water & ethylene glycol (50% volume concentration) +nanofluid and the speed and frontal area for the air as follows:

$$m_{nf} = \rho_{nf} V_{nf} A_{tube} \quad (6)$$

$$m_a = \rho_a v_a A_{fr} \quad (7)$$

The Effectiveness of the radiator is given below

$$Effectivness\ of\ the\ fin = \frac{Actual\ Heat\ transfer}{maximum\ Heat\ Transfer} \quad (8)$$

$$\varepsilon = \frac{m_{nf}\ C_{nf}\ (T_{nfo} - T_{nfi})}{m_a\, C_{pa}(T_{nfo} - T_{ai})} \quad (9)$$

$$C_{min} = m_a \times C_{pa} \quad (10)$$

Total heat transfer in the radiator is given below

$$Q_t = \varepsilon\, C_{min}(T_{nf} - T_{ai}) \quad (11)$$

Overall Heat Transfer coefficient based on the air side can be express below

$$U = \frac{Q_t}{A_{fr}\,(T_{nfi} - T_{ai})} \quad (12)$$

Air Heat transfer coefficient can be expressed as follows

$$h_a = \frac{J_a\ \ G_a C_{pa}}{pr_a^{\frac{2}{3}}} \quad (13)$$

Where

$$J_a = \frac{0.174}{Re_a^{0.383}} \quad (14)$$

$$G_a = \frac{Re_a\, \mu_a}{D_{ha}} \quad (15)$$

5.2 Pressure drop modeling

Pressure drop is given by

$$\Delta P_{nf} = \frac{2 \times G_{nf}^2 \times f_{nf} \times H}{\rho_{nf} \times D_{hnf}} \times (\mu_{nf}/\mu_{bf})^{0.25} \quad (16)$$

$$G_{nf} = \frac{Re_{nf} \times \mu_{nf}}{D_{nf}} \quad (17)$$

Pumping Power is given by

$$P = V_{nf} \times \Delta P_{nf} \quad (18)$$

6. Results and discussions

6.1. Influence of volume fraction of Al2O3 particles to thermal performance of an automobile radiator at constant air Reynolds number and constant mass flow rate

In the present paper thermal performance of the Automobile radiator at constant air Reynolds number (84391) and constant mass flow rate (0.08 Kg/s) have been carried out. With increase in the volume fraction of Al_2O_3 particles dynamic viscosity of nanofluid has been increased. Dynamic viscosity in this study was calculated using the correlation developed by Tsai and chein as show in equation 4. This parameter influence mass Flow rate of the nanofluid in automobile radiator. The relationship shown in fig 2 where overall heat transfer coefficient based on the air side increase in the volume concentration of Al_2O_3 particles in the base fluid. An overall heat transfer coefficient 711 w/m^{2}k can be achieved for 1% Al_2O_3+ mixture of EG/water (50% volume concentration) nanofluid compared 428 w/m^{2}k for based fluid.

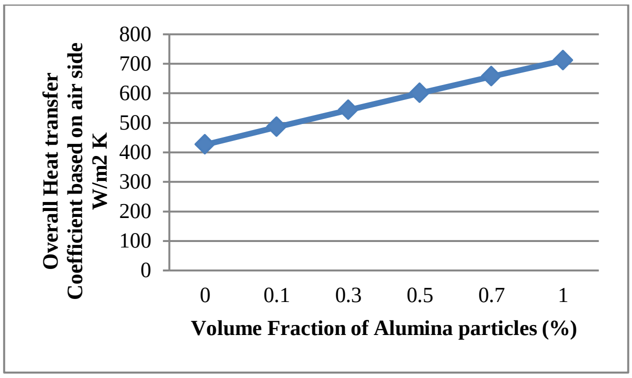

Fig 2 Effect of Al_2O_3 particles to the overall heat transfer coefficient based on air side at constant air Reynolds number and constant mass flow rate .

It showed that it increased overall heat transfer coefficient based on air side up to 66% from above figure at constant air Reynolds number (84391) and constant mass flow rate (0.08 kg/s) This study also found that heat transfer rate is increased exponentially as the volume fraction of copper particles are increased as shown in Fig. 5. This improvement is calculated using Eq. (11).

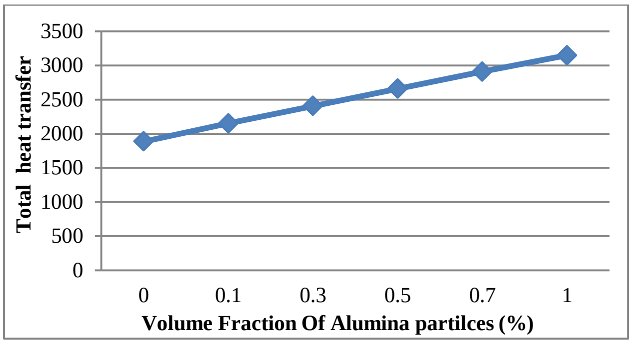

Fig 3 Effect of Al_2O_3 particles to total heat transfer at constant air Reynolds number and constant mass flow rate.

With increase volume concentration of Al_2O_3 nanoparticles in the base Fluid at constant air Reynolds number and constant mass Flow rate. It increased Effectiveness of the radiator. It increased effectiveness of the radiator. It shown in below figure 4.

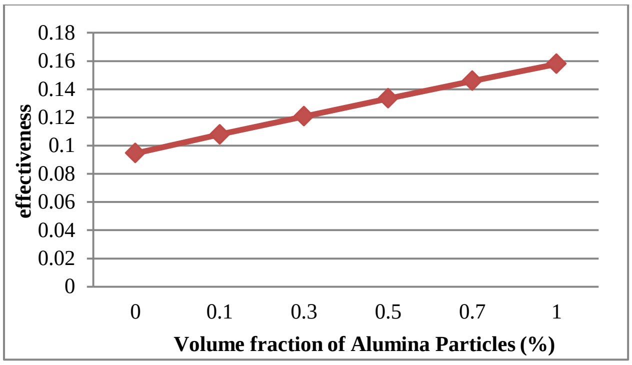

Figure 4 Effect of Al_2O_3 particles to effectiveness at constant air Reynolds number and constant mass flow rate

6.2 Influence of air Reynolds number on thermal performance of a radiator

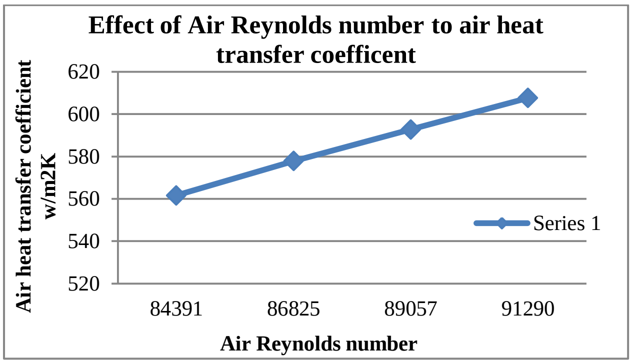

Figure 5 Effect of air Reynolds number to air heat transfer coefficient

The effect of air Reynolds number on the thermal performance of a radiator is discussed in this section. The coolant mass flow rate is kept constant (0.03 kg/s) since a coolant's Reynolds number, Nusselt and Prandtl numbers did not experience any change Only air Reynolds number and fraction of Al_2O_3 nanoparticles were varied in this section. With the increase of air Reynolds numbers, the air heat transfer coefficient was increased as shown in Fig. 5

Nanofluids with higher Al_2O_3 volume fraction generates higher overall heat transfer coefficient than that of a base fluid. Same scenario happened for heat transfer rate where it is proportional to air Reynolds number as shown in Fig. 6. About 70% of heat transfer improvement can be achieved with addition of 1% Al_2O_3 particles at 91290 and 39343 Reynolds number for air and coolant respectively. Based on the overall heat transfer coefficient and heat transfer rate improvement, percentage reduction of air frontal area can be estimated, at these Reynolds numbers.

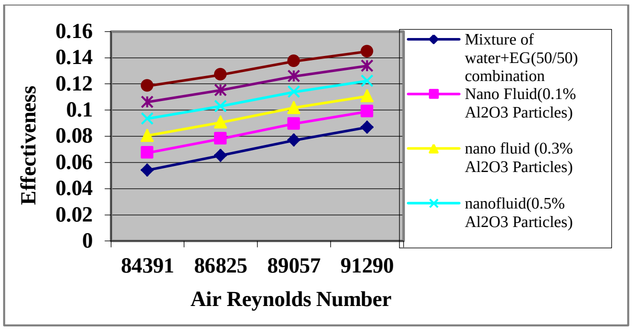

Figure 6.Effect of Air Reynolds number and Al_2O_3 volume fraction to Overall Heat Transfer Coefficient Based on Air Side.

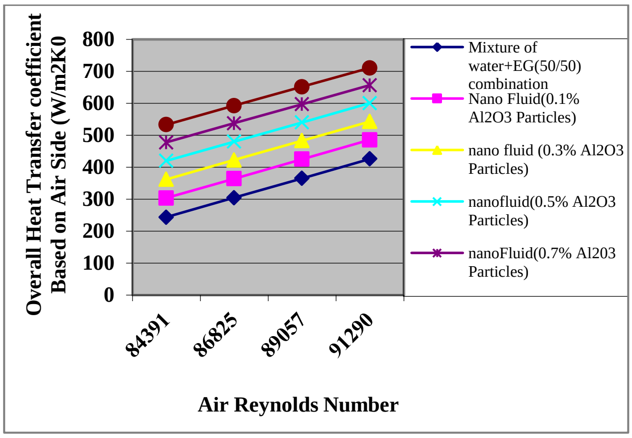

Figure 7 Effect of Air Reynolds number and Al_2O_3 volume fraction to total heat transfer

Although results indicated that higher air Reynolds number leads to better heat dissipation process, design of the radiator must ensure the engine operation at optimum temperature. Driving conditions or its speed and engine load must be considered. For instance, car's engine needs to operate at higher load when driving up hill and at the same time air Reynolds number is low due to lower air velocity. Hence, there is possibility for engine to get overheated at this condition. However when driving downhill, an engine only requires operating at lower load and at the same time high air Reynolds number is observed. Eventually engine might be overcooled. Therefore, these aspects must take into consideration when designing automobile radiator.

If we increase the volume concentration of the Al_2O_3 particles in the base fluids with 1%. It increases the effectiveness of the radiator .The Below figure 7 shows that with increase in volume concentration of Al_2O_3 particles and air Reynolds number the effectiveness is gradually increases.

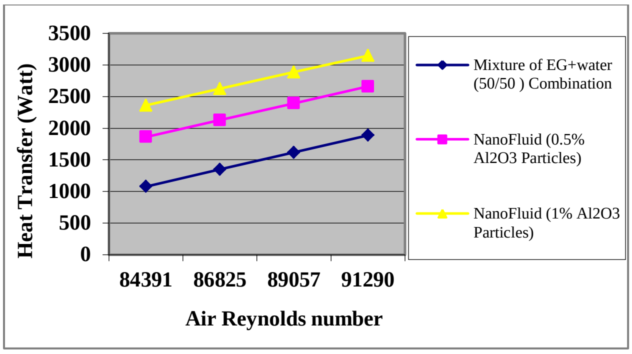

Figure 8 Effect of Air Reynolds number and Al_2O_3 volume fraction to effectiveness

6.3. Comparison of coolant pressure drop and Increment in thermal Conductivity.

In this section analyzed comparison of the coolant pressure drop and pumping power. In this study coolant flow rate was fixed at 0.000083 m^3/s and air Reynolds number is 91290 but the volume fraction of Al_2O_3 nanoparticles was varied. It focused on the effects of volume fraction of Al_2O_3 nanoparticles on the coolant pressure drop and pumping power. It was observed that with increase in the volume fraction of Al2O3 Particles in nanofluid pumping power and pressure drop increased .the results show that pressure drop of 3059.142 N/m^2 by adding 1 % Al_2O_3 particles compared to pressure drop 2979.009 N/m^2 for a based fluid

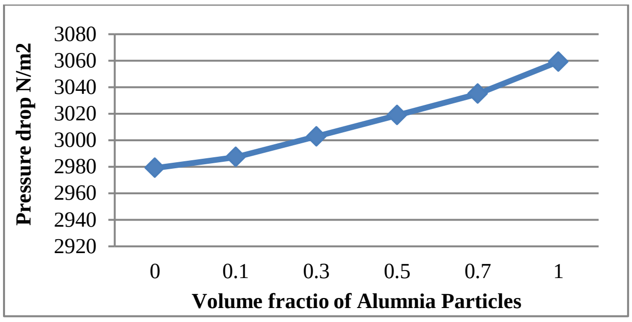

Figure 9 Influence of Al_2O_3 volume fraction to coolant pressure drop at fixed coolant volumetric flow rate

Due to this extra pressure drop, a higher coolant pumping power is needed. The pumping power is calculated using Eq. (18). Calculated results indicate that about 3% increase in pumping power is observed at 1% addition of Al_2O_3 nanofluids compared to a basefluid. These trends are shown in Figs. 9 and 10. Increase in density increases pressure drop of flowing liquids. Adding particles in a base liquid increases density of the fluid and augments pressure drop at a low percentage as observed in the present study.

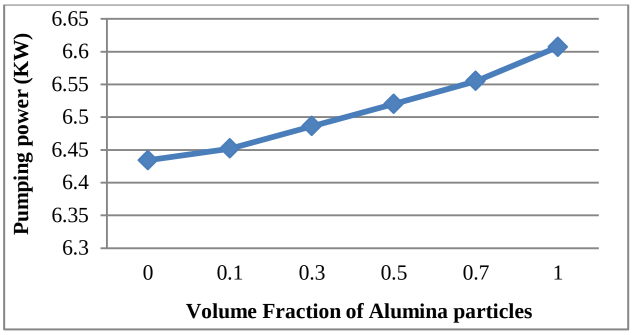

Figure10 Influence of Al_2O_3 volume fraction to pumping power at fixed coolant volumetric flow rate.

With increase in the concentration of the Al_2O_3 particle in the base fluid .It showed increment in the thermal conductivity. It has been seen that from the above figure 10 thermal conductivity of the mixture of EG+water (50/50) combination increases by adding the volume fraction of the Al_2O_3 particle in nanofluids. The percentage increase in thermal conductivity by adding the 1% volume fraction of Al_2O_3 particle in the base Fluid is 3.03%.

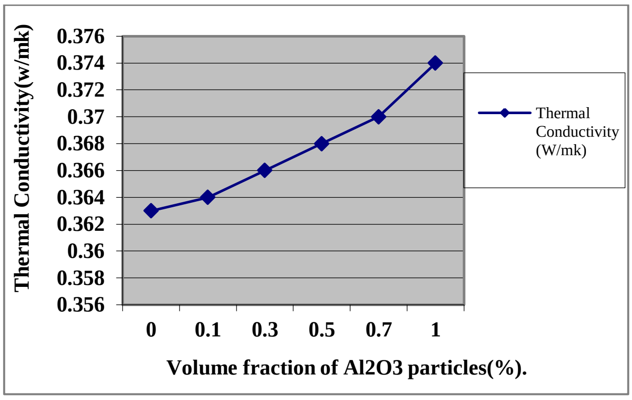

Figure 11 Volume Fraction of Al_2O_3 particles Vs Thermal Conductivity

Conclusions

Heat transfer rate and effectiveness is increased with increase in volume concentration of nanoparticles (ranging from 0% to 1%). About 3.8% and 54% heat transfer enhancement and effectiveness were achieved with addition of 1% Al_2O_3 particles at 84391 air Reynolds number and constant mass flow rate (0.08Kg/s) .

Thermal performance of a radiator using nanofluid or mixture ethylene glycol+water (50 Volume concentration) coolant is increased with air Reynolds Number. About 70 % increment in the total heat transfer and overall heat transfer coefficient based on the air side at constant mass flow rate (0.08 Kg/s) and variable air Reynolds number (84391-91290) About.

Additional 3% pumping power is needed for a radiator using nanofluid of 1% Al_2O_3 particles at 0.000083 m^3/s coolant volumetric flow rate compared to that of the same radiator using only pure ethylene glycol coolant.

Thermal Conductivity increased by 3.05 % with increase in the volume concentration of Al2O3 particles in Base Fluid.

References

D.P. Kulkarni, R.S. Vajjha, D.K. Das, D. Oliva, (2008), Application of aluminum oxide nanofluids in diesel electric generator as jacket water coolant, *Applied Thermal Engineering* 28 pp.14-15, pp.1774-1781.

Vlassov, V. V., de Sousa, F. L. and Takahashi, W. K., (2006), Comprehensive optimization of a heat pipe radiator assembly filled with ammonia or acetone, *International Journal of Heat and Mass Transfer*, pp.4584-4595.

W. Yu, D.M. France, S.U.S. Choi, J.L. Routbort, (2007), Review and Assessment of Nanofluid Technology for Transportation and Other Applications, (No. ANL/ ESD/07-9). Energy System Division, *Argonne National Laboratory, Argonne.*

J.A. Eastman, S.U.S. Choi, S. Li, W. Yu, L.J. Thompson, (2001), Anomalously increased effective thermal conductivities of ethylene glycol-based nanofluids containing copper nanoparticles, *Applied Physics Letters,* pp.718-720.

Y. Hwang, J.K. Lee, C.H. Lee, Y.M. Jung, S.I. Cheong, C.G. Lee, (2007), Stability and thermal conductivity characteristics of nanofluids, *Thermochimica Act* 455, pp.70-74.

J.-H. Lee, K.S. Hwang, S.P. Jang, B.H. Lee, J.H. Kim, S.U.S. Choi, (2008), Effective viscosities and thermal conductivities of aqueous nanofluids containing low volume concentrations of Al_2O_3 nanoparticles, *International Journal of Heat and Mass Transfer*, pp. 2651-2656.

W. Yu, H. Xie, L. Chen, Y. Li, (2009), *Investigation of thermal conductivity and viscosity of ethylene glycol based* ZnO nanofluid, *Thermochimica Act* a 491, pp.92-96

H.A. Mintsa, G. Roy, C.T. Nguyen, D. Doucet, (2009), New temperature dependent thermal conductivity data for water-based nanofluids, *International Journal of Thermal Sciences* 48 , pp. 363-371

Navid Bozorgan, MostafaMafi and Nariman Bozorgan,(2012), Performance Evaluation of Al_2O_3/Water Nanofluid as Coolant in a Double-Tube Heat Exchanger Flowing under a Turbulent Flow Regime, *Hindawi Publishing Corporation Advances in Mechanical Engineering Volume 3*

P.K. Namburu, D.K. Das, K.M. Tanguturi, R.S. Vajjha, (2009), Numerical study of turbulent flow and heat transfer characteristics of nanofluids considering variable properties, *International Journal of Thermal Sciences*, Vol. 48, pp. 290-302

Y. Ding, H. Chen, Y. He, A. Lapkin, M. Yeganeh, L. Siller, (2007), forced convective heat transfer of nanofluids, *Advanced Powder Technology,* pp. 813-824

H.S. Zeinali, M. Nasr Esfahany, S.G. Etemad, (2007), Experimental investigation of convective heat transfer of Al_2O_3/water nanofluid in circular tube, *International Journal of Heat and Fluid Flow",* pp. 203-210

W. Yu, D.M. France, D.S. Smith, D. Singh, E.V. Timofeeva, J.L. Routbort, (2009), Heat transfer to a silicon carbide/water nanofluids, *International Journal of Heat and Mass Transfer,* pp.3606-3612

D. Kim, Y. Kwon, Y. Cho, C. Li, S. Cheong, Y. Hwang, (2009), Convective heat transfer characteristics of nanofluids under laminar and turbulent flow conditions, *Current Applied Physic*s, pp. 119-123

V. Vasu, K.R. Krishna, A.C.S. Kumar,(2008), Thermal design analysis of compact heat exchanger using nanofluids, *International Journal of Nonmanufacturing*, pp 271-287

W.M. Kays, A.L. London,(1984),Compact Heat Exchanger, third ed. McGraw-Hill, Inc., United States

D.G. Charyulu, G. Singh,J.K. Sharma, (1999), Performance evaluation of a radiator in a diesel engine case study, *Applied Thermal Engineering no.*19, pp. 625-639

Pak B.C., Cho Y.I., (1998), Hydrodynamic and heat transfer study of dispersed fluids with submicron metallic oxide particles, Experimental Heat transfer, Vol. 11, no.2, pp. 151-170

Xuan Y., Roetzel W., (2000), Conceptions of heat transfer correlation of nanofluids, *International Journal of Heat and Mass Transfer*, Vol. 43, no. 19, pp. 3701-3707

M. Eftekhar, A. Keshavarz A. Ghasemian, and J. Mahdavinia, (2013),The Impact of Nano-fluid Concentration Used as an Engine Coolant on the Warm-up Timing, *International Journal of Automotive Engineering*, Vol.3.