IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 11, Issue 3 Ver. V (May- Jun. 2014), PP 23-30
www.iosrjournals.org

Performance investigation of Automobile Radiator operated with Al_2O_3 based nanofluid

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Abstract : *In this study, effect of adding Al_2O_3 nanoparticle to base fluid (mixture of EG+Water) in Automobile radiator is investigated experimentally. Radiators are compact heat exchangers optimized and evaluated by considering different working conditions. The cooling system of a Automobile plays an important role in its performance, consists of two main parts, known as radiator and fan. Improving thermal efficiency of engine leads to increase the engine's performance, decline the fuel consumption and decrease the pollution emissions. For this purpose, an experimental setup was designed. Effects of fluid inlet temperature, the flow rate and nano particle volume fraction on heat transfer are considered. Results show that Nusselt number, total heat transfer, effectiveness and overall heat transfer coefficient increases with increase , nano particle volume fraction , air Reynolds number and mass flow rate of coolant flowing through radiator.*

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

Nomenclature

Afr= Frontal Area of the tube	D_{ha}= Hydraulics diameter of the tube
G= Mass Velocity in Kg/m^2s	T= Temperature in Deg C
H= Total water Flow length in m	μ = Dynamic viscosity N/sm^2
H= Heat transfer coefficient W/m^2K	f= fanning friction factor
J = Colburn factor dimensionless	**subscripts**
K= Thermal conductivity W/mK	bf= Base Fluid
Qt= total heat transfer W/m^2k	nf= nanofluid
m = Mass Flow rate Kg/s	ai= air inlet temperature
Δp= Pressure drop N/m^2	nfo=nanofluid outlet and nfi= nanofluid inlet

P= Pumping power Watt, Re= Reynolds number ε= effectiveness.

I. Introduction

In an automobile, fuel and air produce power within the engine through combustion. Only a portion of the total generated power actually supplied to the automobile with power, the rest is wasted in the form of exhaust and heat. If this excess heat is not removed, the engine temperature becomes too high which results in overheating and viscosity breakdown of the lubricating oil, metal weakening of the overheated engine parts, and stress between engine parts resulting in quicker wear, among the related moving posts . A cooling system is used to remove this excessive heat. Most automotive cooling systems consist of the following components: radiator, water pump, electric cooling fan, radiator pressure cap, and thermostat. Of these components, the radiator is the most prominent part of the system because it transfers heat. As coolant travels through the engine's cylinder block, it accumulates heat. Once the coolant temperature increases above a certain threshold value, the vehicle's thermostat triggers a valve which forces the coolant to flow through the radiator. As the coolant flows through the tubes of the radiator, heat is transferred through the fins and tube walls to the air by conduction and convection

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. [1] Optimal mass characteristics for a heat pipe radiator assembly for space application were investigated by Vlassov et al. [2]. 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., [3] 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.[9]

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.

II. Nanofluid in enhancing thermal conductivity and Nanofluid in enhancing forced Convective heat transfer

Eastman et al. [4] 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. [5] found that thermal conductivity of the nanofluids depends on the volume fraction of particles and thermal conductivity of basefluid and particles. Lee et al. [6] 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. [7]. 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. [8] 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.

Namburu et al. [10] 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. [11] 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. [12] 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. [13] 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.

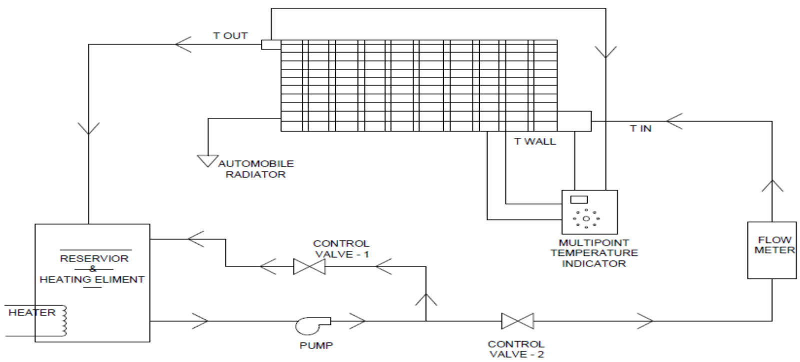
Kim et al. [14] investigated effect of nanofluids on the performances of convective heat transfer coefficient of a circular straight tube having laminar and turbulent flow with constant heat flux. Authors have found that the convective heat transfer coefficient of alumina nanofluids improved in comparison 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.

III. Experimental test rig and procedure

3.1) 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^{o}C. 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.



TEST RIG SETUP

Figure 1 Schematic of experimental set up

3.2) Assumptions for test condition

The results obtained are based on the following assumptions:

A)Velocity and temperature at the entrance of the radiator core on both air and coolant sides are uniform. B) There are no phase changes (condensation or boiling) in all fluid streams. C) Fluid flow rate is uniformly distributed through the core in each pass on each fluid side. No stratification, flow bypassing, or flow leakages occur in any stream. D) The flow condition is characterized by the bulk speed at any cross section. E) The temperature of each fluid is uniform over every flow cross section, so that a single bulk temperature applies to each stream at a given cross section. Heat transfer area is distributed uniformly on each side Both the inner dimension and the outer dimension of the tube are assumed constant. F) The thermal conductivity of the tube material is constant in the axial direction. No internal source exists for thermal-energy generation. G) There is no heat loss or gain external to the radiator and no axial heat conduction in the radiator. H) Room temperature is 25deg C

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

a) 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 0.05 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.
b) Influence of mass flow rate of the coolant on the thermal performance of automobile radiator. Mass Flow rate of the coolant were varied from 0.03 to 0.08 kg/s while air Reynolds number was kept fixed 84391. The analysis also included a comparison of the thermal performance of automobile radiator with nanofluid with nanofluids at different volume concentration. This part of the analysis focused on total heat transfer, overall heat transfer coefficient and effectiveness o an automobile radiator.

Table 1 - radiator specification

Serial number	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	Al203	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/sm^2)	-	4.65 x 10^{-5}

IV. 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 [15, 16 & 17]. 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 [18] and Xuan [19] 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 [20] in 2013 on the basis of a wide variety of experimental date available in the literature as following equations

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

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

4.1 Heat transfer modeling

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

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

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:

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

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

The Effectiveness of the radiator is given below

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

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

\

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

Total heat transfer in the radiator is given below

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

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

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

Air Heat transfer coefficient can be expressed as follows

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

Where

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

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

4.2 Pressure drop modeling

Pressure drop is given by

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

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

Pumping Power is given by

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

V. Result and discussion

5.1. Influence of volume fraction of Al_2O_3 particles to thermal performance of an automobile radiator

In the present paper thermal performance of the Automobile radiator at constant air Reynolds number (84391) and constant mass flow rate (0.05 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 [15] and chein [15] 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 482 w/m^{2}k can be achieved for 1% Al_2O_3+ mixture of EG/water (50% volume concentration) nanofluid compared 304 w/m^{2}k for based fluid.

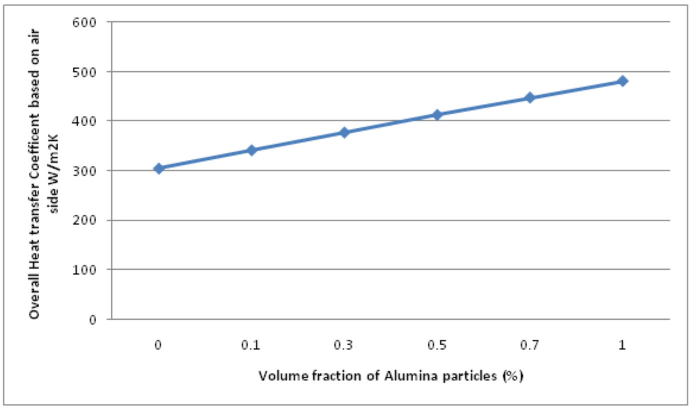


Fig 2 Effect of Al_2O_3 particles to the overall heat transfer coefficient based on air side at constant air Reynolds number and constant mass flow rate .

It showed that it increased overall heat transfer coefficient based on air side up to 40 % from above figure at constant air Reynolds number (84391) and constant mass flow rate (0.05 kg/s) This study also found that heat transfer rate is increased exponentially as the volume fraction of Alumina particles are increased as shown in Fig. 5. This improvement is calculated using Eq. (11). It can be deduced that effectiveness of the radiator is increased with the application of nanofluids. However the percentage of effectiveness does not increase substantially, although the improvement of overall heat transfer coefficient is significant.

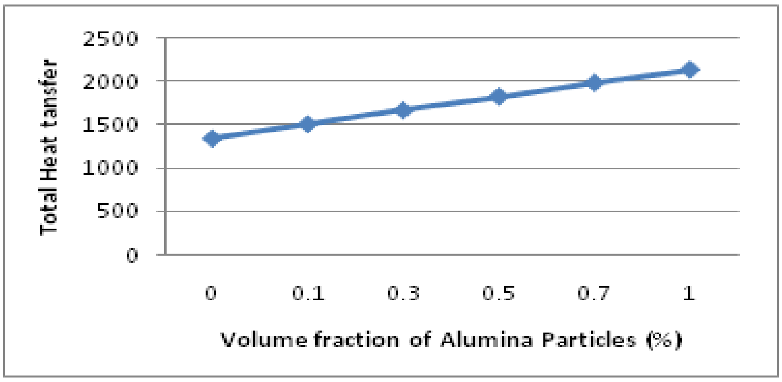


Fig 3 Effect of Al_2O_3 particles to total heat transfer at constant air Reynolds number and constant mass flow rate.

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.

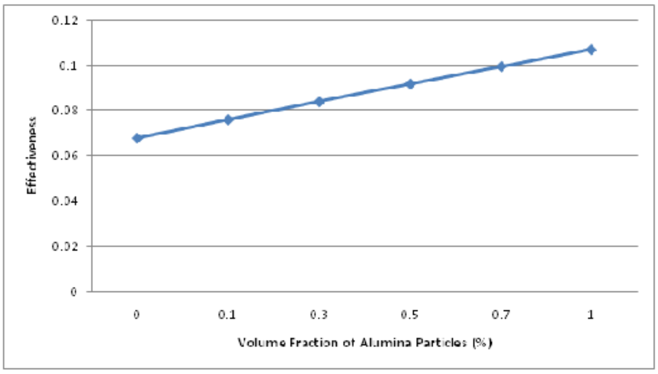


Figure4 Effect of Al_2O_3 particles to Effectiveness at constant air Reynolds number and constant mass flow rate

5.2 Influence of mass flow rate the base fluid on thermal performance of the automobile radiator

This section presents the effect of coolant Reynolds number on the thermal performance of a radiator at a fixed air Reynolds number (84391). Coolant mass flow rate plays vital role in determining the radiator's thermal performance. Engine might be overcooled or overheated if coolant mass flow rate is not properly controlled. The main function of a radiator is to ensure that engine is operating at optimum temperature by not only controlling the air Reynolds number but also mass flow rate.

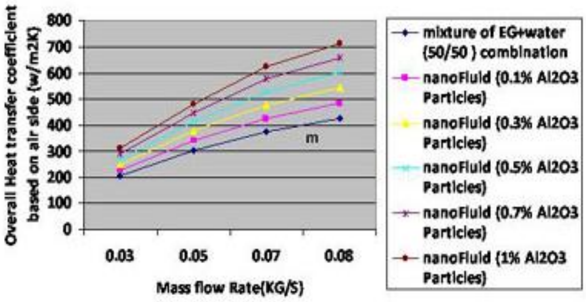


Figure 5 effect of the mass flow rate to overall heat transfer coefficient based on air side.

With increase in the mass flow rate of the coolant flowing through automobile radiator, it increases coolant Reynolds number .Overall heat transfer coefficient based on air side is increased with mass flow rate of the coolant flowing through radiator as shown in Fig. 5. The magnitude of this property for nanofluids is higher than that of a basefluid. Therefore, heat transfer area reduction for the same value of overall heat transfer coefficient can be achieved by using nanofluids. Heat transfer enhancement was also observed with mass flow rate of the coolant.

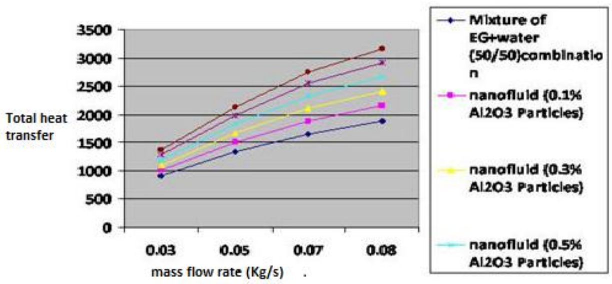


Figure 6 effect of the mass flow rate to Heat transfer rate of Radiator.

For instance, with the addition of 1% Al2O3 particles, 60% improvement of heat transfer rate has been achieved at 84391 and 39343 Reynolds number for air and coolant respectively. It is also observed that the percentage of improvement is decreased with decrease of coolant Reynolds number. Fig. 6 shows heat transfer rate of a radiator using nanofluid is higher than that of a radiator using mixture of water +EG (50% volume concentration)

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.

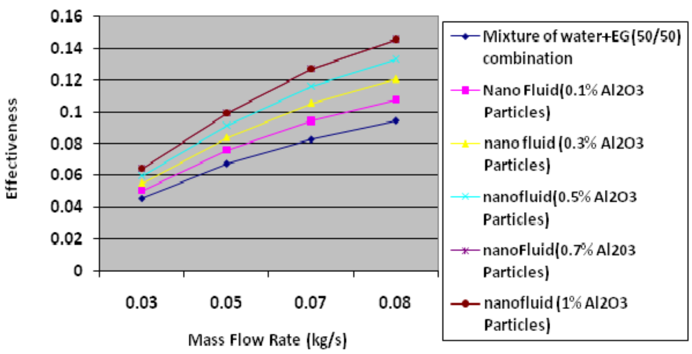


Figure 7 Effect of Mass Flow rate to effectiveness

VI. Conclusions

1) Heat transfer rate is increased with increase in volume concentration of nanoparticles (ranging from 0% to 1%). About 40% heat transfer enhancement was achieved with addition of 1% Al_2O_3 particles at 84391 air Reynolds number and constant mass flow rate (0.05 Kg/s) .
2) Overall heat transfer based on air side increased up 36% with addition of 1% Volume Al2O3 particles than the base fluid at constant air Reynolds number and constant mass flow rate.
3) Effectiveness of the radiator increased up to 40% with addition of 1& volume fraction of Al2O3 particles than the base fluid at constant air Reynolds number and constant mass flow rate.

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