AN EXPERIMENTAL INVESTIGATION OF NANOFLUID AS COOLANT IN ENGINES

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Abstract - *Transportation system plays a vital role in our society, so it is important to improve the engine efficiency of the automobiles in today's world. For the last few decades engineers have constantly been trying to improve the engine efficiency by bringing necessary changes to various systems that affect engine efficiency. The performance of an engine is affected by various systems such as fuel supply system, lubrication system, transmission system, cooling system etc. Cooling system is one of the important among all. In this project we have developed a new engine coolant called nanofluid and tested it by running some real time experiments and compared it with the available conventional coolant. Also we did thermal analysis of both the nanofluid and conventional fluid. Here we are using ultrafine nanoparticles of aluminium oxide (Al_2O_3) as the nanofluid and water as the conventional coolant. We found that the heat transfer performance and thermal conductivity of nanofluids has been reported to perform better compared to pure fluid.*

Key Words: **Cooling System, Engine Coolant, Heat transfer, Aluminium Oxide, Nanofluid.**

INTRODUCTION

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. There are many systems which influence the engine performance like fuel ignition system, emission system, cooling system, etc. one of the parameters which affects the performance of engine is the cooling rate of radiator in engine cooling system. Addition of fins is one of the approaches to increase the heat transfer 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 has already reached to their limit. As a result, there is a need of new and innovative heat transfer fluids for improving heat transfer rate in an automotive car radiator. In addition, heat transfer fluids at air and fluid side such as water and ethylene glycol exhibit very low thermal conductivity. With the advancement of nanotechnology, the new generation of heat transfer fluids called, "Nanofluid" have been developed and researchers found that these fluids offer higher thermal conductivity compared to that of conventional coolants. Nanofluids which consist of a carrier liquid, such as water, ethylene glycol dispersed with tiny nano-scale particles known as nanoparticles. Nanofluids seem to be potential replacement of conventional coolants in engine cooling system. Recently there has been considerable research findings reported which highlights superior heat transfer performances of Nanofluids. Nanofluids are potential heat transfer fluids with enhanced thermo physical properties and heat transfer performance. It can be applied in many devices for better performances (i.e. energy, heat transfer and other performances).Nanofluids are formed by suspending metallic or non-metallic oxide nanoparticles in traditional heat transfer fluids. This newly introduced category of cooling fluids containing ultrafine nanoparticles (1–100 nm) has displayed interesting behavior during experiments including increased thermal conductivity and improved heat transfer coefficient compared to a pure fluid.

1.1 Objective

The aim is to create a model of the cooling system for doing some experiments with the conventional as well as the nanofluid coolant and to compare the results to find out which has better thermal properties so that it can be used in engines.

1.2 Preparation of Nanofluid

Two step process: This technique is also known as Kool-Aid method which is usually used for oxide nanoparticles. In this technique nanoparticles are obtained by different methods (in form of powders) and then are dispersed into the base fluid. The main problem in this technique is the nanoparticle agglomeration due to attractive Van der waals forces.

One step process: In this process the dispersion of nanoparticles is obtained by direct evaporation of the nanoparticle metal and condensation of the nanoparticles in the base liquid and is the best technique for metallic nanofluids such as Cu nanofluids. The main problems in this technique are low production capacity, low concentration of nanoparticles and high costs. While the advantage of this technique is that nanoparticle agglomeration is minimized. The suspensions obtained by either case should be well mixed, uniformly dispersed and stable in time. Also it should be noted that the heat transfer properties of nanofluids could be controlled by the concentration of the nanoparticle and also by the shape of nanoparticles.

The affecting parameters on the thermal conductivity. Overally we can say that the smaller the size the greater the stability of colloidal dispersion, the greater the stability of colloidal dispersion the greater the probability of interaction and collision among particles and collision among particles and fluid and the greater the effective heat energy transport inside the liquid (Xue 2003).Thermal conductivity enhancement ratio
($K_{effective} = K_{nanofluid} / K_{basefluid}$)

And the parameters that most affect the thermal conductivity of nanofluids are:
1- Particle volume fraction
2- Particle material
3- Base fluids
4- Particle size
5- Temperature

2. LITREATURE SURVEY

Sadollah Ebrahimi et. al[1] studied about application of nanofluid as coolants. Today more than ever ultrahigh-performance cooling plays an important role in the development of energy-efficient heat transfer fluids which are required in many industries and commercial applications. However, conventional coolants are inherently poor heat transfer fluids. Nanofluid a term coined by Choi in 1995 is a new class of heat transfer fluids which is developed by suspending nanoparticles such as small amounts of metal, nonmetal or nanotubes in the fluids. The goal of nanofluids is to achieve the highest possible thermal properties at the smallest possible concentrations (preferably<1% by volume) by uniform dispersion and stable suspension of nanoparticles (preferably<10 nm) in host fluids. We have divided this chapter to four sections. Section 1 has focused on the two methods of synthesizing nanofluids and different methods for dispersing spherical and cylindrical nanoparticles such as Ag, Cu in a host fluid and also the common methods for measuring the thermal conductivity of nanofluids. Section2 has discussed on the thermal conductivity of nanofluids respect to pure fluids to explain the effective thermal conductivity of nanofluids.

Rahul A. Bhoghare et. al[2] did their work on challenges of nanofluid in radiators Nanofluids are potential heat transfer fluids with enhanced thermo physical properties and heat transfer performance can be applied in many devices for better performances (i.e. energy, heat transfer and other performances). Evaluating the heat transfer enhancement due to the use of nanofluids has recently become the center of interest for many researchers. This newly introduced category of cooling fluids containing ultrafine nanoparticles (1–100 nm) has displayed fascinating behavior during experiments including increased thermal conductivity and augmented heat transfer coefficient compared to a pure fluid. In this paper, a comprehensive literature on the applications and challenges of nanofluids have been compiled and reviewed in Automobile sector.

Steve Choi et. al[3] studied about how to improve cooling system efficiency. Nanofluids, nanoparticle-fluid suspensions, are new class of heat transfer fluids engineered by dispersing nanometer size solid particles in heat transfer fluids. Argonne researchers produced nanofluids and discovered nanofluids have a much higher and strongly temperature dependent thermal conductivity at low particle concentrations than conventional radiator coolants without nanoparticles. We have demonstrated that nanofluids have significantly better heat transfer properties than the base fluids. Nanofluids are promising future coolants for the transportation industry. This project is focused on the development of nanofluids as nanotech-based heat transfer fluids. The HV industry problem our project is trying to solve the trend toward higher engine power and EGR inevitably leads to larger radiators and increased frontal areas, resulting in additional aerodynamic drag and increased fuel consumption. Therefore, cooling is one of the top technical challenges facing the truck industry. Therefore, there is a steadily increasing need for new concepts and technology for improving HV cooling system performance.

R J Bhatt et. al[4] did work on the thermal abilities of nanofluids as coolants. Today, the demand of automobile vehicles is on peak. So, it is a great challenge for automotive industries to provide an efficient and economical engine. The performance of an engine affects by various systems like fuel supply system, lubrication system, transmission system, cooling system etc. So, it becomes essential to account them while designing an engine for improves the engines performance. Cooling system is one of the important systems amongst all. It is responsible to carry large amount of heat waste to surroundings for efficient working of an engine. It enhances heat transfer and fuel economy which leads to maximize the performance of an engine. Most internal combustion engines are fluid cooled using either air or a liquid coolant run through a heat exchanger (radiator) cooled by air. The heat transfer through radiator can be improved by maximizing the heat transfer area and increasing the heat transfer coefficient. The heat transfer coefficient can be increased either by using more efficient heat transfer methods or by improving the thermo physical properties of the heat transfer material i.e. coolant. Earlier,

Bhagat UK et. al[5] did a work on Heat Transfer Applications of zinc oxide nanofluids. This paper describes preparation of zinc oxide (ZnO) based nanofluids in polymer matrix. The rheological properties of nanofluid were studied and were applied in heat transfer application. Heat transfer application of aqueous based ZnOnanofluid was tested and it was observed that, the presence of ZnOnanofluid effectively reduces the temperature propagation in a sono-chemically heated system. It is observed that the heat absorption capacity was increased by about 3040% for the ZnO containing nanofluid. For the preparation of nanofluids, as synthesized ZnO nanoparticles were utilized after characterization by various modern tools such as UV-visible, Raman spectroscopy, XRD, SEM, Particle size analysis, and TGA studies. The average particle size of as prepared ZnO nanoparticle was in the range of 19 to 30 nm and XRD analysis revealed hexagonal crystal structure. Nanofluids (NFs) are new class of fluids comprising of base fluid i.e. water, ethylene glycols, oils, bio-fluids, polymer solutions or other common fluids with nanoparticles (1-100 nm) suspended in them.

3. EXPERIMENTAL SETUP

Our project consists of a frame which carries a tank, heating coil, rotameter, electric motor, radiator, frame box, and temperature reading device. A small pump is placed inside the tank. The nanoparticles are mixed with water and poured into the tank .The mixture is then heated with help of a heating coil up to 50-60c.The hot mixture is then allowed to pass through the tubes to the rotameter. From the rotameter, the mixture flows through the radiator, which consist of a number of tubes arranged in parallel. A fan is fixed to the electric motor and placed in front of the radiator. As the fan rotates, the temperature of the mixture is reduced considerably to a small extent. The temperature reading device consistS of four bridge circuits and three sensors. The sensors are connected to device via copper wires. One of the sensors senses the temperature of hot water in tank, other one is for water flowing through radiator and last is for sensing exhaust air.

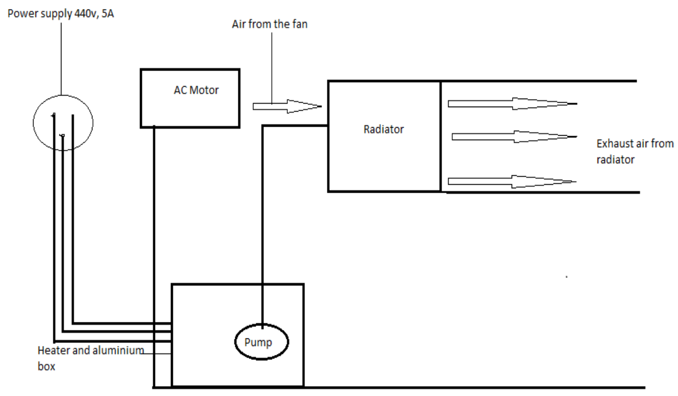

Fig-1 Schematic Diagram of Cooling System

4. ANALYSIS

4.1 Observations

Table -1: Temperature readings of water through the system

Radiator inlet temp (T_1) °c	Radiator tube wall temp (T_2) °c	Air inlet temp (T_3) °c	Air exhaust temp (T_4) °c	Radiator outlet temp (T_5) °c
62	45	29	32	44
60	46	29	31	42
58	45	29	33	40
55	43	29	32	41
54	41	29	31	40

The water was heated with the help of a heater for about 15 minutes, The stainless steel tank has a capacity of 7L of which about 6.75 litre of water is taken the heated water temperature is assumed to be radiator inlet water temperature sensors were placed within the tank which is a thermocouple, one at the radiator wall another one at the radiator outlet and one at the exhaust of radiator to measure the radiator exhaust air temperature. It was found that the water takes about 15 minutes for leveling the temperatures or for attaining equilibrium with various temperatures. Nano fluids were taken at different concentrations since we do not know about the sedimentation but during the first phase of the project it was found from the journals that the CuO nano powder has great sedimentation which is not good for the engine materials. Readings obtained when Al_2O_3 nanofluid is used with ratio of 1.25 litre of water and 75gm of nano powder.

Table -2: Temperature readings of nanofluid of concentration 1 through the system

Radiator inlet temp (T_1) °c	Radiator tube wall temp (T_2) °c	Air inlet temp (T_3) °c	Air exhaust temp (T_4) °c	Radiator outlet temp (T_5) °c
55	39	29	34	40
53	38	29	33	41
49	37	29	32	39
46	36	29	33	37
43	37	29	32	36

We carried out our experiments with aluminium oxide nanopowder which was mixed with a carrier fluid, The carrier fluid we used was water because it is easily available and cheap too. While carrying out the experiments we found that the initial temperatures of nanofluid was low when compared with water since both the fluids are heated about 15 minutes Al_2O_3 showed considerable differences which is a positive sign, Also in case of $Al_2O_3$the time required to attain stability within the system was found decreasing about 5 minutes when compared with water .

The time was found to be about 7-10 minutes subjected to atmospheric conditions. Readings obtained when Al_2O_3nanofluid is used with ratio of 1.25litre of water and 125gm of nano powder. There are a number of factors other than the thermal conductivity of the dispersed phase which should be considered such as the average size of the nanoparticles, the method employed for the preparation of the nanofluids, the temperature of measurements and the concentration of the dispersed solid phase. Due to the high surface energy of nanoparticles they tend to agglomerate to decrease their surface energy. The agglomeration of nanoparticles causes rapid settling which deteriorates the properties of nanofluids. To keep the nanoparticles from agglomeration they are coated with a surfactant (steric dispersion) or charged to repulse each other in a liquid (electrostatic dispersion).Although the addition of the dispersant could influence the thermal conductivity of the basefluid itself, and thus, the real enhancement by using nanoparticles could be over shadowed.

Table -3: Temperature readings of nanofluid of concentration 2 through the system

Radiator inlet temp (T_1) °c	Radiator tube wall temp (T_2) °c	Air inlet temp (T_3) °c	Air exhaust temp (T_4) °c	Radiator outlet temp (T_5) °c
50	39	29	34	40
47	38	29	33	41
44	38	29	32	39
43	37	29	33	37
41	36	29	32	38

The above experiments were carried out with aluminium oxide nanopowder which was mixed with a carrier fluid having concentration 2 , The carrier fluid we used was water because it is easily available and cheap too. While carrying out the experiments we found that the initial temperatures of nanofluid was low when compared with concentration1 of Al_2O_3 nanofluid since both the fluids are heated about 15 minutes Al_2O_3 with high concentration showed considerable differences, Also in case of Al_2O_3 the time required to attain stability within the system was found decreasing about 8 minutes when compared with water . The time was found to be about 5-9 minutes subjected to atmospheric conditions.

4.2 Calculation

The following data's are related to the radiator which is the heat exchanger in our experiments

Area of radiator= 42 x 35 cm

Number of tubes= 20

Number of fins= 270

Tube length= 35cm

Distance between 2 successive tubes= 1.3cm

flow rate of coolant =0.0124 kg/s

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Air velocity =5 m/s

The heat exchanger which is used for the experiment is the parallel flow heat exchanger, heat exchanger in this case refers to the radiator which we have used for the coolant to flow

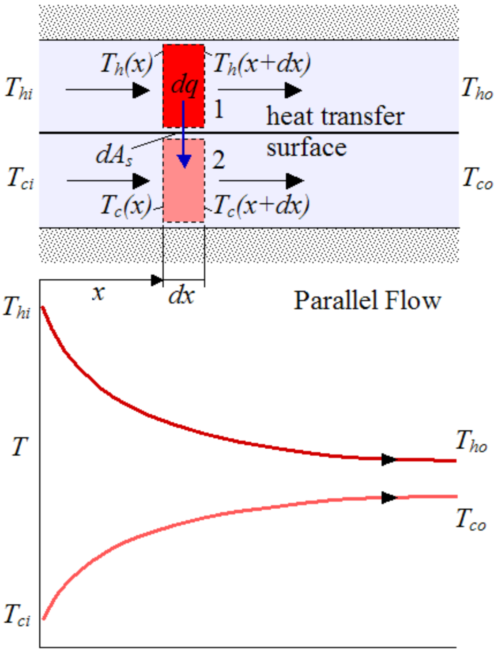

Fig-3 Temperature distribution for LMTD parallel flow heat exchanger

We are going to perform the thermal analysis of both water and nano fluid.

- Water

Air conditions : air temperature at inlet 29 ^{0}c

Film temperature, $T_f = \dfrac{\text{Air inlet temp + tube wall temp}}{2}$

$= (29+33)/2 = 31^0$ c

For the film temperature we are taking corresponding values of different factors from heat and mass transfer data book by C.P Kothandaraman&S. Subramanyan published by new age international publishers.

From data hand book $\rho = 1.163$ kg/m^3

$\mu = 18.68$ Ns/m^2

Reynolds's number, $R_e = (\rho v L) / \mu$

$= (1.1613 \times 5 \times .35)/(18.68 \times 10^{-6})$

$= 10879.16$ Laminar flow.

Prandtl number, $P_r = (C_p\mu) / K$

$= (1005 \times 18.68 \times 10^{-6}) / 0.026831$
$= 0.7$

Nusselt number, $N_u = 0.023 \times 108794.16^{0.8} \times 0.69^{0.4}$

$= 212.1055$

$N_u = (h_o \times L) / K$

$212.1055 = (h_o \times 0.35) / 0.026831$

$h_o = 16.25$ W/m^2 ^{o}c

Radiator water conditions

$T_{f2} = \dfrac{\text{water temp max + air tube temp min}}{2}$

$= (60+30) /2 = 45$

$\rho = 992.5$ kg/m^3 $\mu = 6 \times 10^{-6}$ Ns/m^2

$R_e = \rho v D/\mu$

$= (992.5 \times 07639 \times 0.01) /(6 \times 10^{-6})$

$= 12.63 \times 10^5$ flow is turbulent

$N_{u2} = 0.023\ R_e^{.8}\ Pr^{0.4}$

$= 0.023 \times (12.63 \times 10^5)^{0.8} \times 0.039^{0.4}$

$= 477.83$

$N_{u2} = h_i \times L / K$

$h_i = N_{u2} \times K / L = 477.83 \times 0.6280 / 0.35$

$h_i = 857.36$ W/m$^{2 0}$c Ans.

LMTD $= \Delta t_m = [(T_1 - t_2) - (T_2 - t_1)] / \ln [(T_1 - t_2) / (T_2 - t_1)]$

$S = [(t_2 - t_1) / (T_2 - t_1)]$

$R = [(T_1 - T_2) / (T_2 - t_1)]$

$$F = \frac{[\sqrt{(R^2 + 1)} \ln (1\text{-}S / 1\text{-}RS)]}{R - 1\ [2\text{-}S (R+1\text{-}\sqrt{(R^2 + 1)}] / [2\text{-}S (R+1\text{-}\sqrt{(R^2 + 1)}]}$$

LMTD $= \Delta t_m = 20.02^0$ c

$S = (t_2 - t_1) / (T_2 - t_1) = (33\text{-}29) / (44\text{-}29) = 0.266$

$R = (T_1 - T_2) / (T_2 - t_1) = (62\text{-}44) / (44\text{-}33) = 1.636$

$$F = \frac{\sqrt{(1.64^2+1)}\ \ln(1-0.266 / 1-1.64 \times 0.266)}{1.64-1\ [2-0.266\ (1.64+1-\sqrt{(1.64^2+1)})] / [2-0.266(1.64+1-\sqrt{(1.64^2+1)})]}$$

F= 0.79

$\Delta t_{m2} = 0.79 \times 20.025 = 15.859$

U= (1/875.35) + (1/16.25) + (0.35/386)

= 0.1451 W/m² K

$Q = U_{req} \times AF\Delta t_{m2}$

= 14.7 x 2π x 0.005 x 0.35 x 0.73 x 20.025 = 2.25

Effectiveness,ε = Q / Q_{max}

= (2.25/90.24) x 20

= **0.49**

- Nano fluid (Aluminium oxide)

Inlet conditions: Inlet temperature = 55⁰ c, Outlet temperature = 40⁰c

Thermal conductivity, K = 0.7351 W/mK

Volume concentration =8.47%

Density, ρ = 3890 kg/m³

Specific heat = 880 J/kgK

Reynold'snumber, $R_e = \rho v D/\mu$

= (3890 x 0.7639 x 0.01) / (9.6 10^{-6})

= 30.95 x 10^5 - Turbulent flow

Prandtl number, Pr = $\mu C_p / K$

= (9.6 x 10^{-6} x 880) / 0.7351 =0.0114

Nusseltnumber, Nu = 0.023 x $(30 \times 10^5)^{0.8} \times (0.0114)^{0.4}$

= 610.84

Nu = $(h_i \times L) / K$

$h_i = (N_u \times K) / L$

= (610.84 x 0.7351) / 0.35

= 1282.93 W/m² K

Overall heat transfer coefficient, U =1/ $[(1/h_i) + (1/h_0) + (L/K)]$

= 1/ [(1/16.25)+(1/1282.93)+(.35/386)]

= 15.81 W/m² K

Θ_m = LMTD = $[(T_1 - t_2) - (T_2 - t_1)] / \ln[(T_1 - t_2)/(T_2 - t_1)]$

= [(55-32)- (40-28) / ln (55-32) /(40-28)

= 16.90⁰ c

$S = (t_2 - t_1) / (T_2 - t_1)$ = (32-28) / (40-28) = 0.33

$R = (T_1 - T_2) / (T_2 - t_2)$ = (55-40) / (40-32) = 1.875

$$F = \frac{[\sqrt{(R^2+1)}\ \ln(1-S / 1-RS)]}{R-1\ [2-S(R+1-\sqrt{(R^2+1)})] / [2-S(R+1-\sqrt{(R^2+1)})]}$$

= 1.1981/(1.875-1) = 1.36

$\Delta T_m = F \times \Delta T_m$

= 1.36 x 16.90 = 22.98⁰ c

$U_{req} = Q/(AF\Delta T_m)$

$Q = U_{req} \times AF\Delta T_m$

= 15.81 x 2π x 0.005 x 0.35 x 22.98

= 3.994W

$Q_{max} = mC_p\Delta T$

= 0.01053 x 880 x (55-40) = 138.996 W

Effectiveness ,ε = Q / Q_{max}

= (3.994 x 20)/ 138.996

= **0.574**

5. RESULT AND DISCUSSION

As we have completed the calculations from results obtained what we can say is that the heat transfer properties of Al_2O_3 $_{nano}$ fluid was found to be higher than the conventinal coolant water.

We found that the time required for water and nanofluid for the cooling has variations for the same heating range water will take about 15 minutes for leveling the temperatures at the same time and at same inlet conditions 1% volume fraction of nano fluid will take 8 to 10 minutes for the cooling and the other will take about 6 or 7 minutes. Also we found out that the heat released during cooling for Al_2O_3nanofluid is more than conventional water and from the calculations which is done above also the heat exchanger effectiveness varies with the fluids with nanofluid giving larger effectiveness values other than water

Heat released during cooling by Nanofluid

$Q_{nanofluid} = U_{req} \times AF\Delta T_m$

$= 15.81 \times 2\pi \times 0.005 \times 0.35 \times 22.98 = 3.994W$

Heat release during cooling by water

$Q_{water} = U_{req} \times AF\Delta t_{m2}$

$= 14.7 \times 2\pi \times 0.005 \times 0.35 \times 0.73 \times 20.025 = 2.25$

As we can see the heat release during cooling by the nanofluid is more than that of water, So what we can infer from this is that the cooling is more effective with the nanofluid

Heat exchanger effectiveness of water, $€_{water} = 0.49$

Heat exchanger effectiveness with nanofluid, $€_{nanofluid} = 0.57$

Also the heat exchanger effectiveness of the radiator also increases with the nanofluid as coolant. Another thing which can be seen from the result is the thermal conductivity of nanofluid is more than the base fluid water

$(K_{effective} = K_{nanofluid}/K_{basefluid})$

$K_{effective} = 0.7351/.628$

$=1.171$

Time is also a considerable factor in our analysis as we can see that the time required for cooling the engine after the initial start up is about 15 minutes for water but for nanofluid it is about 5-9 minutes which varies according to different volume fractions of nanofluid.

6. CONCLUSION

In our project we implemented a model of automotive cooling system in which any kind of coolants can be used. The selection of nanofluid is of prime importance and the problem we faced in selecting such a nanofluid was that the availability of nanopowder which has to be mixed with a carrier liquid in order to produce the required nanofuid. In selecting the carrier liquid we had a lot of options including water, ethylene glycol, glycerine etc, All the components are set accordingly and proper flow of the fluid is maintained and the model is functioning properly giving a positive result. It has been seen that nanofluids can be considered as a potential candidate for Automobile application. Automobile radiators can be made energy efficient and compact as heat transfer can be improved by nanofluids. Reduced or compact shape may results in reduced drag, increase the fuel economy, and reduces the weight of vehicle. Exact mechanism of enhanced heat transfer for nanofluids is still unclear as reported by many researchers. There are different challenges of nanofluids which should be identified and overcome for automobile radiators application. Nanofluids stability and its production cost are major factors that hinder the commercialization of nanofluids. By solving these challenges, it is expected that nanofluids can make substantial impact as coolant in heat exchanging devices. Challenges of Nanofluids: Many interesting properties of nanofluids have been reported in the review. In the studies, thermal conductivity of nanofluids has received the maximum attention by many researchers. Conversely, the use of nanofluids in a wide variety of applications appears promising. But the development of the field is hindered by

(i) Lack of agreement of results obtained by different researchers

(ii) Poor characterization of suspensions

(iii) Lack of theoretical understanding of the mechanisms responsible for changes in properties.

Experimental studies in the convective heat transfer of nanofluids are needed. Many issues, such as thermal conductivity, the Brownian motion of particles, particle migration, and thermo physical property change with temperature, must be carefully considered with convective heat transfer in nanofluids. Therefore, Bhogare et al. concludes several important issues that should receive greater attention in the near future as per following
.

- Long Term Stability of Nanoparticles Dispersion
- Increased Pressure Drop & Pumping Power
- Higher Viscosity
- Lower Specific Heat
- Higher Cost
- Difficulties in Production of Nanofluids

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