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Experimental study and CFD analysis of Thermal performance improvement of car radiator by MgO/water nanofluid.

Sumit Wani†, Prof. Ravi H.C. ‡

†PG student, Mechanical Engineering Department, Savitribai Phule Pune University, DYPSOEA, Ambi, Pune, Maharashtra, India.
‡ Assistant Professor, Mechanical Engineering Department, Savitribai Phule Pune University, DYPSOEA, Ambi, Pune, Maharashtra, India.

Abstract

The objective of this study is to improve the thermal performance of car radiator (cross flow) heat exchanger by a new coolant MgO/water nanofluid. Traditional method of cooling system of engine heat involves the use water or EG but we are now using the latest and most promising coolants (nanofluids) which are used commonly everywhere for heat transfer applications. The experimentation includes the study of heat transfer characteristics density, thermal conductivity, dynamic viscosity, specific heat capacity. The observations were recorded to maintain flow between (5-9 lpm) and average heat transfer enhancement found in the range of (40-70%) for different volume concentrations. The experimental results were validated by CFD simulations to check the temperature distributions across the radiator.

Keywords:Radiator, nanofluid, MgO particles, thermal conductivity, heat transfer rate, volume fraction*

1. Introduction

In this research paper our main focus is to improve thermal performance of automobile cooling system so that it dissipate heat more efficiently and fast to surrounding's. In twentieth century, nanofluids is a most promising coolant or heat transmitting agent with superior heat transfer capabilities with good thermal conductivity. Nanofluids are used in various heat exchangers for heat transfer studies more efficiently than conventional fluids or coolants. Car radiator is cross flow type of heat exchanger which is prime component in automobile engine cooling system whose function is to supply coolants to engine when engine is at high temperature. In this study, we are using MgO nanoparticles having size (40 nm) combine with base fluid as water, nanofluid afterpreparation used as a coolant instead of conventional coolant such as water or ethylene glycol. MgO/water nanofluid is used as effective coolant and its thermal performance ability is good as compared to conventional coolants. Experimental study followed by modelling and CFD simulations on STAR CCM$^+$ for validation of outlet temperature.

2. Objectives

1. Study of increase in heat transfer rate (Q) of car radiator for the purpose of effective cooling and dissipation of engine heat.
2. Study of characteristics, properties, preparation and heat transfer applications of new promising coolant MgO/water nanofluid.
3. Study of thermo physical properties of MgOnanofluid like thermal conductivity, density, viscosity and specific heat.
4. Study of variation of heat transfer rate and properties of MgO/water coolant for different volume fractions.
5. Study of convection heat transfer and measurement of increase in Reynolds Number (Re), Nusselt Number (Nu) and convective heat transfer coefficient (h) for different volume flow rates and varying volume fractions MgO/water nanofluid as compared to water as a coolant for engine heat cooling.
6. Modeling and CFD simulations for temperature and velocity distributions across the radiator for a given mass flow rate.

3. Literature Reviews

Xie et al. [1] reported heat transfer enhancement using nanofluids of Al_2O_3, ZnO, TiO_2 and MgO with a mixture of water and ethylene glycol of 55% and 45% respectively. Al_2O_3, MgO and ZnOnanofluids showed superior increment in heat transfer compared to TiO_2nanofluids. Peyghambarzadeh et al. [2] tested a car radiator using Al_2O_3/water based nanofluids. The volumetric concentrations were varied in a range of 0.1-1%. A maximum heat transfer enhancement up to 45% at 1% volumetric concentration was recorded. Naraki, et al. [3] reported experimental results for CuO/water nanofluids tested under laminar flow regime in a car radiator. Volumetric concentration was varied from 0 to 0.4% and inlet temperature was changed from 50 to 80^{0}C. An 8% increase in overall heat transfer coefficient compared with water was reported for 0.4% vol. nanofluids. Hussein et al. [4]

tested TiO_2 and SiO_2 water based nanofluids in a car radiator under laminar flow regime. Volumetric concentration and fluid inlet temperature was changed in a range of 1-2% and 60-80^{0}C.

Lee et al. [5] experimentally studied the mixture of ethylene glycol and CuO nanoparticles of 35 nm size at the concentration of 4.0 vol.% and found a 20% increase in thermal conductivity. Yu et al. [6] experimentally investigated that, the thermal conductivity of nanofluid strongly depends on nanoparticle volume concentrations and it increases nonlinearly with the increase of volume concentration and the enhanced thermal conductivity was found to be 26.5% at 5.0 vol.% concentration. Nguyen et al. [7] experimentally investigated the effect of volume concentrationand temperature on the dynamic viscosity of Al_2O_3–water nanofluid and found that viscosity of the nanofluid considerably increases with the increase of particle volume concentrations, but it decreases with the increase of temperature. Wang et al. [8] investigated the viscosity of Al_2O_3–water nanofluid prepared by mechanical blending with particle size of 28nm at 5 vol.% concentration and viscosity increased by 86% compared to the base fluid. They also investigated Al_2O_3/ethylene glycol nanofluid and found a 40% increase in viscosity. Das et al. [9] also observed that with the increase of particle volume concentration, viscosity of the nanofluid increases. Elias et al. [10] reported findings about thermal conductivity, viscosity, specific heat and density of Al_2O_3nanofluids in water and ethylene glycol used as coolant in car radiator. Volume concentration and coolant temperature were kept up to 1% and 50^{0}C respectively. Viscosity, thermal conductivity and density of the nanofluids were found to increase whereas specific heat of nanofluid was found to decrease with increasing volumetric concentrations. Masuda et al. [11] studied the thermo physical properties of Al_2O_3–water, SiO_2– water and TiO_2–water nanofluids. The transient hot-wire method was used to measure the thermal conductivity of nanofluids. They establish that the thermal conductivity of nanofluids increasing by 32 % at the concentration of 4.3 vol. %. They concluded that temperature did not have any effect on the increase of relative thermal conductivity. Lee et al. [12] conducted an experiment to measure the thermal conductivity of Al_2O_3 and CuO suspended in water and ethylene glycol. Particle sizes of Al_2O3 and CuO were 23.6 nm and 38.4 nm, respectively. Their results indicated that nanofluids had higher thermal conductivity than the base fluid, and it increased with the increasing level of concentration. Wang et al. [13] studied thermal conductivity of Al_2O_3 and CuOnanofluids with a particle size of 20 nm. Each was suspended in water, vacuum pump oil, engine oil, and ethylene glycol. The steady state method was used to measure thermal conductivity. Their results showed that the thermal conductivity of both nanofluids were higher than that of the base fluids and varying with concentration level. Sundar and Sharma. [14] obtained thermal conductivity enhancement of 6.52% with Al_2O_3nanofluid, 24.6% with CuOnanofluid at 0.8% volume concentration compared to water. VahidDelavari et al. [15]The numerical results were the same as for the experimental data, indicating that increasing the concentration of nanoparticles in the base fluid increased the heat transfer coefficient and the Nusselt number. The influence of inlet temperature on Nusselt number of a nanofluid at the same volumetric flow rate was compared with experimental data.Thirumala Reddy. [16] Performance Improvement of an Automobile Radiator using CFD Analysis. Hafiz Muhammad ALI et al [17] Addition of MgO nanoparticles in water considerably enhances the heat transfer rates as compared to pure water. The maximum observed heat transfer enhancement of MgOnanofluid was translating 31% increase in heat transfer rate at 0.12% volumetric concentration and at a flow rate of 8 lpm.

Research Gap

1. Water and EG have less thermal conductivity values;it doesn't gain maximum heatduring engine cooling due to its low thermo-physical properties.
2. Nanoparticles like Al_2O_3 ,ZnO, TiO_2 and SiO_2have less thermal conductivity than MgOnanoparticles.
3. Most of the researchers have used Al_2O_3, CuO and $TiO_2$for thermal performance improvement but no one have used MgO for the same purpose (with single exception only) yet it possesses good thermal conductivity value and ability to be a better coolant for engine cooling system.
5. Conventional coolants like water and EG is less efficient as compared to nanofluids. The scope of this research is to introduce new coolant which has superior characteristics to improve the thermal performance of radiator for engine effective cooling.

4. Methodology:

1. Design, fabrication and purchase of essential instruments of required specification

2.Preparation of MgO/water nanofluid of 2% (m/v) mass concentration in laboratory under lab supervision.

3. Observations are recorded for different volume flow rate for water and different volume concentrations of MgO/water nanaofluid.

4 Experimental results are calculated from observations and heat transfer correlations given in the research papers.

5. Experimental results are validated by use of STAR CCM+ software.

4.1 Experimental Set up and procedure

The experimental set up consists of following specifications: Reservoir tank (40-50 Lit), electrical heater (2000 W), pump (0.5 hp), flow meter (0-25lpm),tubes, valves, forced fan (1500 rpm), digital thermocouples type K with temperature indicator for temperature measurement, cross flow heat exchanger (Car radiator) made of aluminium alloy having 22 tubes equally spaced along entire rectangular area, MgO/water nanofluid prepared with mechanical stirrer by heating and sedimentation for 48 hours.

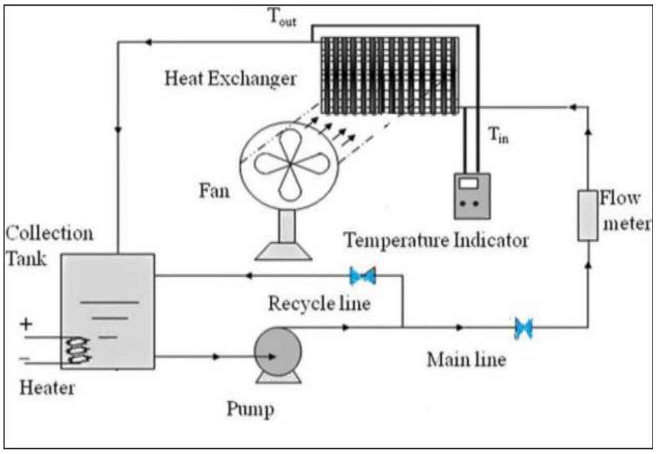

Fig - 4.1: a) Schematic of Experimental Set up.

Fig -4.1:b) Actual Picture of Experimental Set up.

Details:

Collection tank (reservoir) of 40-50 litres contains a coolant fluid which is heated by electric heater (2 KW) up to a certain suitable temperature allows to pass through a pump (0.5 HP) which provides datum head up to 10-12 m. flow control valve is used to regulate the flow supply and flow meter (0-25 lpm) is used to fix constant flow rate from 5 to 9 lpm. Inlet and outlet temperatures of coolant is noted and simultaneously forced fan i.e. exhaust air fan (1500 rpm) is used to cool down the hot coolant fluid flowing through a radiator tubes. Forced convection fan cools down the temperature of hot coolant and cool fluid again passes to collection tank to complete the cycle. Firstly we used water as a coolant and then volume % values of nanofluid (2.5%,5%,7.5% and 9%) by volume are used as as a coolant for cooling of car radiator. The observations are recorded for further calculation of thermal performance.

4.2 Properties of MgO nanoparticles and preparation of nanofluid:

Preparation of MgO/water nanofluid consists of purchasing of MgOnanofluid with high purity about 99% with a particle size of 40 nm. MgO particles are white in colour having density 3.58 g/cm³. While preparing this nanofluid we have to slightly lower down the PH value of water then particles are dissolved in the water properly. Mass concentration taken for preparation is 2% (m/v) i.e. 2gm of MgO is dissolved in 100 ml of water. Solution is prepared by heating and stirring and after that whole solution is kept for sedimentation for 48 hours. Coolants are taken in different volume fractions and investigate the thermal and physical enhancement of properties of prepared coolant.

Table 1: Properties of MgO nanoparticles

Purity [%]	99
Approximate size	40 nm
Color	white
Morphology	Nearly Spherical
True density	3.58 (g/cm^3)

Fig -4.3: Preparation of MgO/water nanofluid.

4.3 Properties of radiator material:

Table 2: Specifications of radiator

Radiator material	(Aluminium alloy 6061),
Density (ρ)	2700 Kg/ m3,
Thermal Conductivity (K)	173 W/m.K ,
Specific Heat Capacity (Cp)	896 J/kg.K
Length	0.42 m
Width	0.32 m
Diameter of cylinder tube	0.006 m

5. Mathematical Formulation:

The thermal and flow properties of nanofluid are calculated using different available correlations as below:
I. Thermal conductivity using Timofeeva correlations as below:

$$K_{nf} = [1 + 3\phi]K_w$$

II. Viscosity of nanofluid using Drew and Passman correlations as below:

$$\mu_{nf} = [1 + 2.5\phi]\mu_w$$

III. The density and specific heat using Pak and Cho correlations as below

$$\rho_{nf} = \phi\rho_{np} + (1-\phi)\rho_w$$

$$Cp_{nf} = \phi Cp_{np} + (1-\phi)Cp_w$$

IV. The rate of heat transfer between coolant and airflow in radiator given as follows:

1. For water:

$Q_w = m_w . C_{pw} . (T_{in} - T_{out}) = h_w . A. (T_w - T_b)$

$h_w = m_w . C_{pw} . (T_{in} - T_{out}) / A. (T_w - T_b)$,

convective heat transfer coefficient for water.

$Nu = h_w .d / K_w$ (Nusselt number)

$Re = \rho_w .V. d / \mu_w$ (Reynolds Number)

2. For MgO/water Nanofluid:

$Q_{nf} = m_{nf} . Cp_{nf} . (T_{in} - T_{out}) = h_{nf} . A. (T_w - T_b)$

$h_{nf} = m_{nf} . Cp_{nf} . (T_{in} - T_{out}) / A. (T_w - T_b)$,

convective heat transfer coefficient for nanofluid.

$Nu = h_{nf} .d / K_{nf}$ (Nusselt number)

$Re = \rho_{nf} .V. d / \mu_{nf}$(Reynolds number)

6. Modelling of Radiator:

Modeling of radiator is done on CATIA V5 (Dassault Systems) software. Dimenations for cad model is taken exactly same as of actual radiator used for experimentation. CATIA enbles us the creation of 3D parts, from 2D sketches. It supports the radiator design from 2D sketcher workbench.

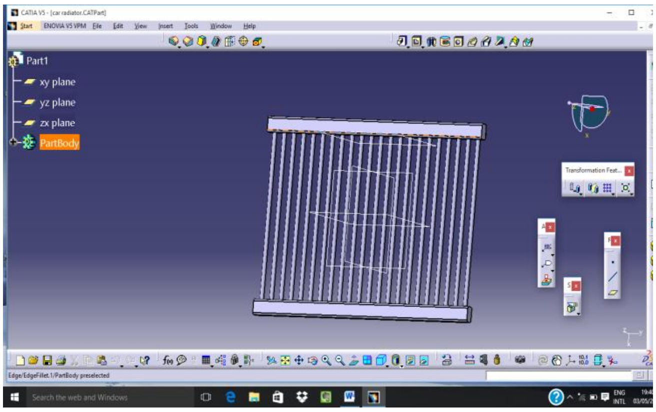

Fig.6 a): Modelling of radiator on CATIA V5

6.1 CFD Simulations:

CFD simulations are performed on STAR CCM+ for total 25 simulations, out of which this paper contains one simulation and results for 5 lpm volume flow rate. Iterations are performed upto 1000 until we conserve the mass, momentum and energy. The model for turbulence is k-€ model, which is used for conservation for kinetic energy at specificdissipation rate.

Meshing

Meshing is performed by importingthe igs. file of radiator in STAR CCM+ created in CATIA V5.

Fig.6 b) represents the polyhedral meshed model created in STAR CCM+ software. The radiator body is divided into inlet, outlet, inlet tank, outlet tank, and radiator pipes for fine mesh. Target mesh size is taken 6 mm for entire radiator body while min. mesh size specified as 10% of target mesh size (i.e. 0.6 mm). All required inlet conditions are specified in physics. Grid independent test is carried out for different mesh sizes for surface and volume mesh; it is carried out for same output results generated for nearby mesh sizes. Boundary conditions for inlet are taken as mass flow rate for different coolants and for outlet is min. static pressure.

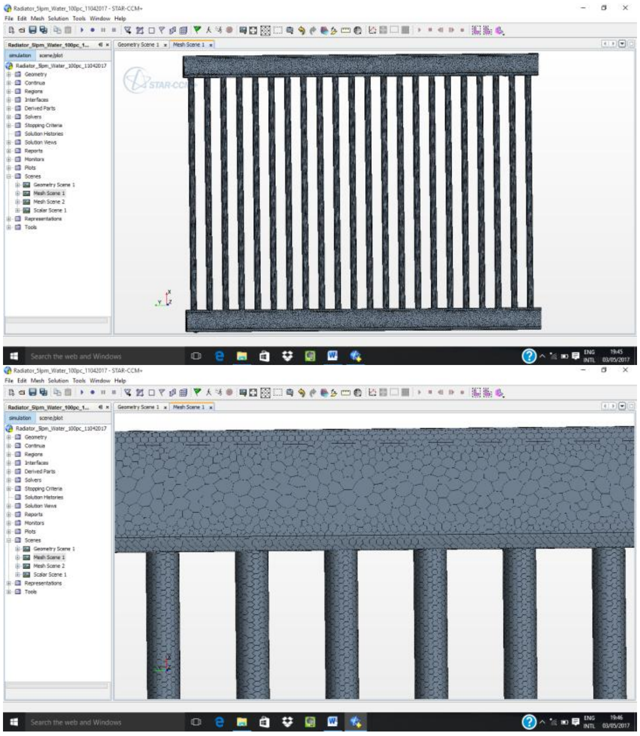

Fig.6.1: Polyhedral meshed model of radiator

Governing Equations:

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

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

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

6.2 Temperature distributions across the radiator:

Temperaturedistributions for flow through the radiator for water and MgO/water nanofluid at 5 lpm is shown below:

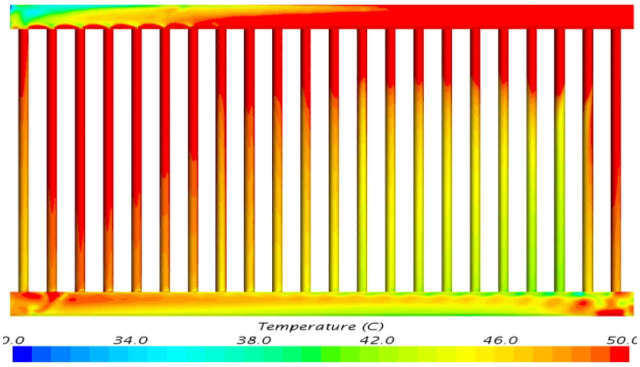

Fig. 6.2: a) Water at 5 lpm

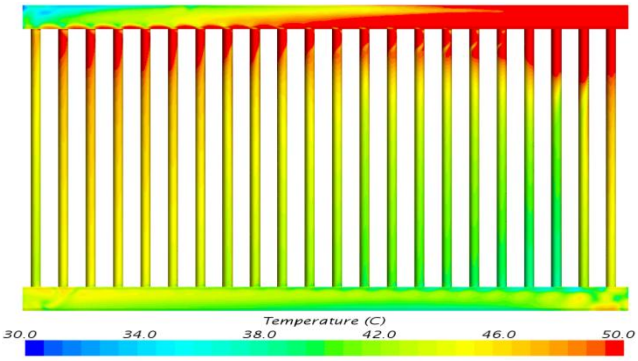

Fig. 6.2:b)MgO/ Water (2.5 vol.%) at 5 lpm

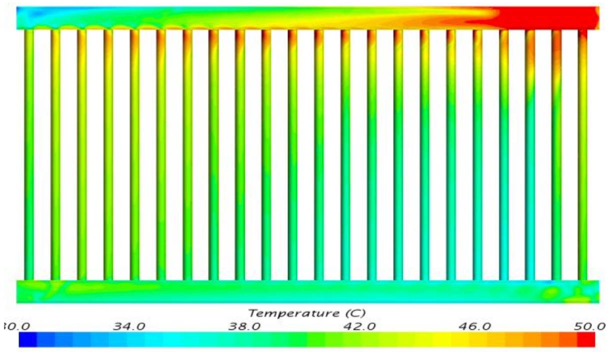

Fig. 6.2:c)MgO/ Water (5.0 vol.%) at 5 lpm

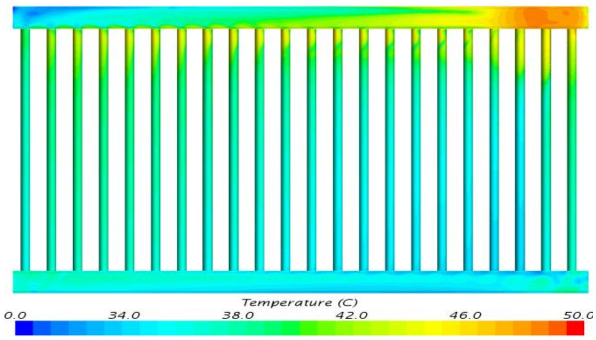

Fig. 6.2:d)MgO/ Water (7.5 vol.%) at 5 lpm

Fig. 6.2 represents the temperature counters for flow for a constant temperature range for identify the cooling of fluid by the use of MgO/water nanofluid. Reddish pattern indicates the heated coolant flow while yellow and sky blue pattern shows the cooling of coolant by forced convection. Cooling is done more efficiently in case of MgO/water nanofluid (fig 6.2 b-d) as we goes on increasing the concentration values as compared to water flow (fig 6.2 a)

6.3 CFD plots:

CFD plots are generated with number of iterations performed while simulations. CFD plots are plotted for inlet and outlet mass flow rate for the conservation of mass, momentum and energy during heat transfer process. Iterations should be done until we get a constant reading as outlet value. Fig 6.3 shows the range of outlet temperature for water and MgO/water nanofluid as a coolant used for a process. Parabolic curve of temperature shows that during initial iterations we have not gated the correct value of outlet temperature after some iterations it shows a constant straight line path as outlet temperature.

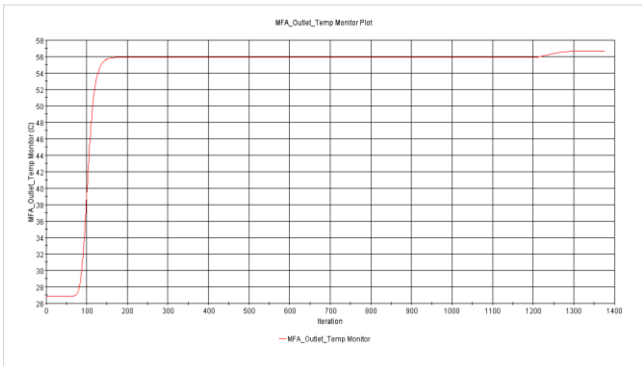

Fig. 6.3: a) T_{out} plot for water as a coolant

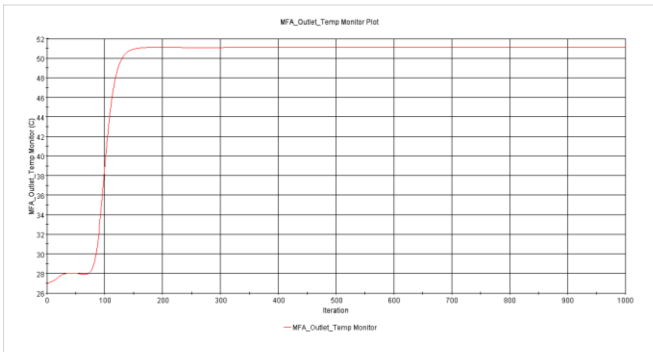

Fig. 6.3: b) T_{out} plot for MgO/water(2.5 vol.%)

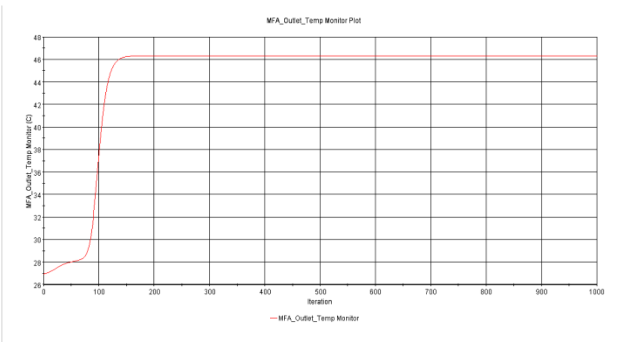

Fig. 6.3: c) T_{out} plot for MgO/water(5.0 vol.%)

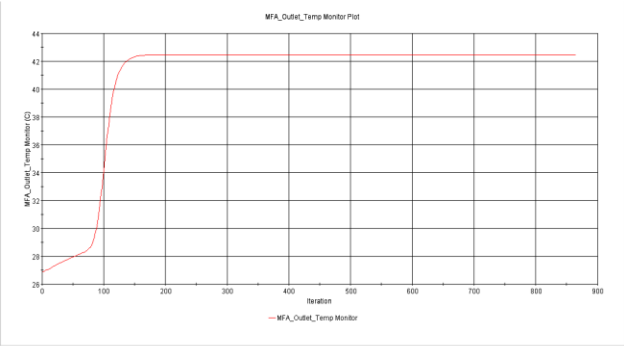

Fig. 6.3: d) T_{out} plot for MgO/water(7.5 vol.%)

6.4 Residual Plots:

Residual plots are generated after complete simulation for the number of iterations for the conservation of mass, momentum and energy during the heat transfer process. Net mass flow out of the control volume is equals to time rate of decrease in mass inside the control volume is the law of conservation of mass. Conservation of momentum principle is based on Newton's second law of motion i.e. Force = m.a (mass × change in momentum w.r.t. to time). Net force is calculated by adding the pressure forces, viscous forces and body forces during the process. Energy conservation principle based on first law of thermodynamics i.e. total energy remains constant during the entire heat transfer process. Rate of change of energy inside the fluid element equals to the addition of net flux into the element and rate of work on element due to the body and surface forces.

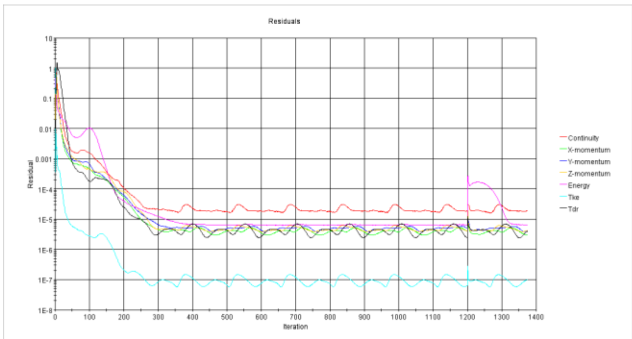

Fig. 6.4: a) Residual plot for water coolant

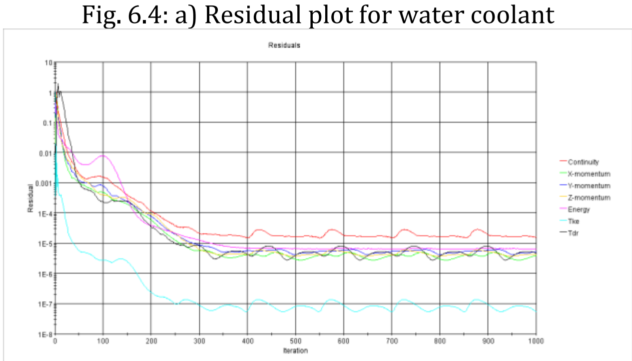

Fig. 6.4: b) Residual plot for MgO/water 2.5 vol. %

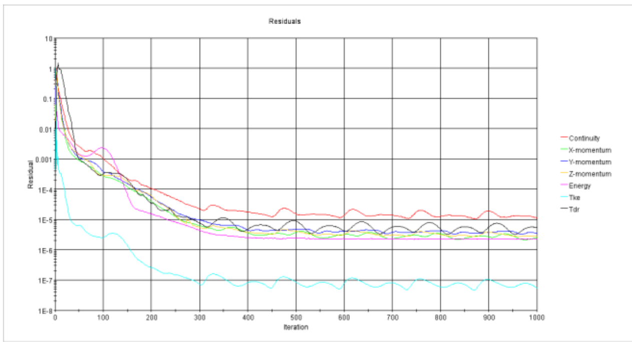

Fig. 6.4: c) Residual plot for MgO/water 5.0 vol. %

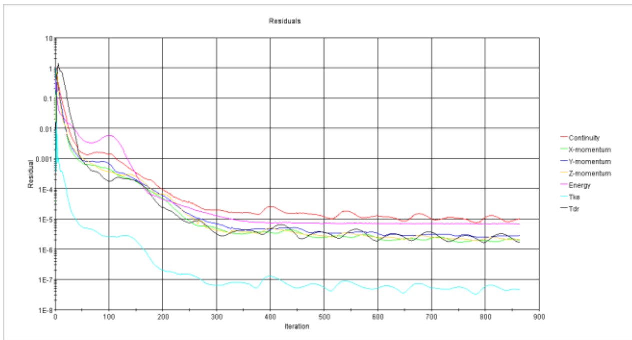

Fig. 6.4: d) Residual plot for MgO/water 7.5 vol. %

Fig. 6.4 shows the conservation of mass, momentum and energy during the entire heat transfer process for the runs of number of iterations. Conservations plots are based on continuity equation, newton's second law and energy conservation principle for a given temperature flux under steady process.k-€ model of turbulence is selected for turbulent flow conditions for conservation of kinetic energy for a given dissipation rate.

7. Results and discussions:

Table 3: Result table for thermal performance enhacement of coolants.

Coolants	Q (W)	h(W/ $m^2.^0C$)	Nu	Re	Error in oulet temp (T_{out})
Water	3841.6	1113.6	10.2	34564.1	2.12%
MgO/H_2O (2.5 vol%)	6037.4	2073.2	10.9	35275.4	0.78%

MgO/ H_2O(5.0vol%)	8223.2	3784.6	14.0	35591.6	1.07%
MgO/ H_2O(7.5vol%)	10648.5	6512.0	18.5	35770.3	3.06%
MgO/ H_2O(9.0vol%)	11967.8	9714.1	24.2	35844.5	5.35%

Table 4: Result table for thermo-physical properties of coolants.

Coolants	ρ(kg/m^3)	K(W/m.K)	μ($N.s/m^2$)	C_p(J/kg.K)
Water	985.2	0.649	0.504×10^{-3}	4183
MgO/ H_2O (2.5 vol.%)	1633.9	1.1357	0.819×10^{-3}	3551.42
MgO/ H_2O (5.0 vol.%)	2282.6	1.6225	1.134×10^{-3}	3278.82
MgO/ H_2O (7.5 vol.%)	2931.3	2.109	1.449×10^{-3}	3126.87
MgO/ H_2O (9.0 vol.%)	3320.52	2.4013	1.638×10^{-3}	3064.2

7.1 Result Graphs:

Fig.7.1-7.2 represents the graph plotted for experimental values and CFD based values of heat transfer rate for all coolants against different volume flow rate. Thebelow graphs clearly represents increase in heat transfer rate as we change the coolant from water to increasing concentrations of nanofluids.
Fig.7.3 is the average value plotted for experimental and CFD based results to show the validations and errors during the experimentation.
Error found is (1-5%) during validation of outlet tempearature of radiator.

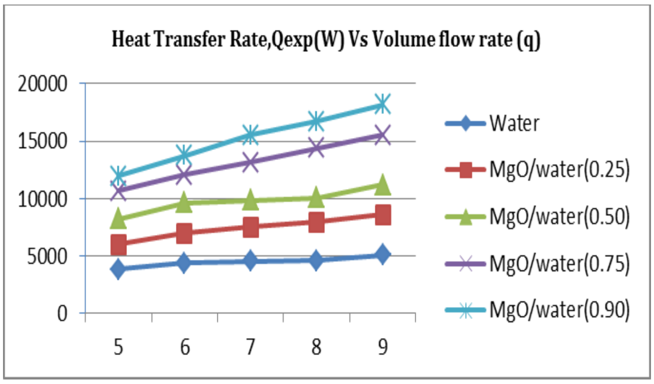

Fig.7.1 Variation of exp. heat transfer rate for different coolants at different flow rates.

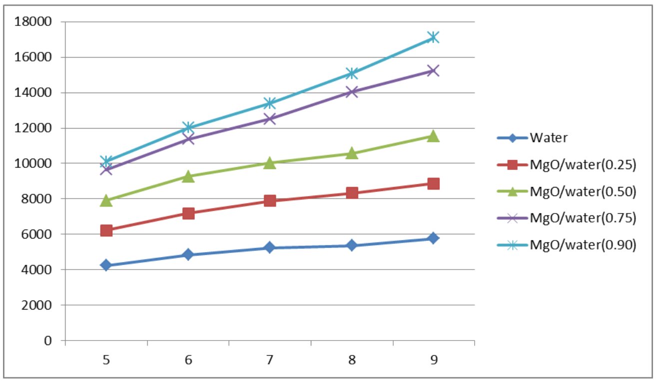

Fig.7.2: Variation of CFD. heat transfer rate for different coolants at different flow rates.

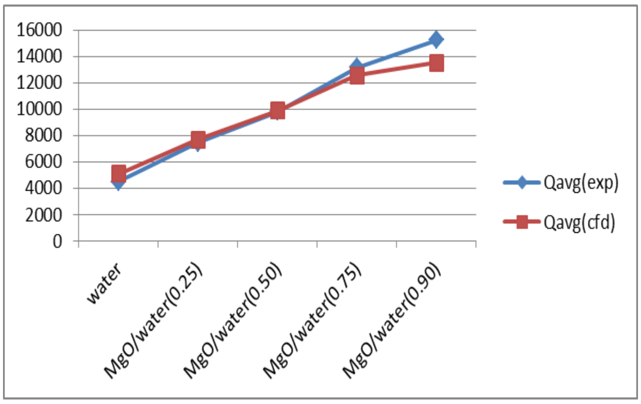

Fig.7.3: Variation of average heat transfer rate(exp&cfd) for different coolants.

Fig. 7.4-7.7 represents increase in the thermo-physical properties of coolants for water and increasing values of MgO/water nanofluid concentration. Density, thermal conductivity and dynamic viscosity shows increment in their values while specific heat shows departure for different values ofincreasing values of MgO/water nanofluid concentration.

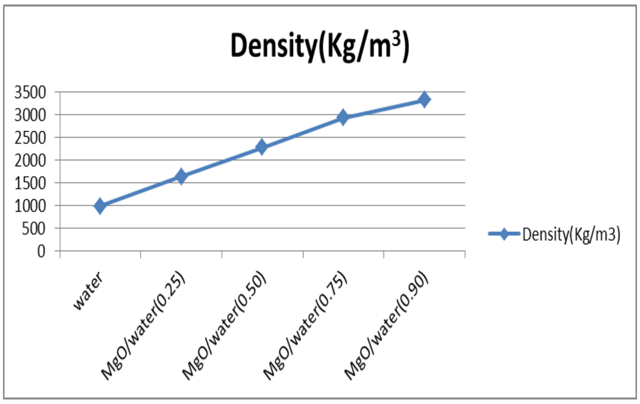

Fig.7.4: Variation of density of fluid with increase in particle volume concentration

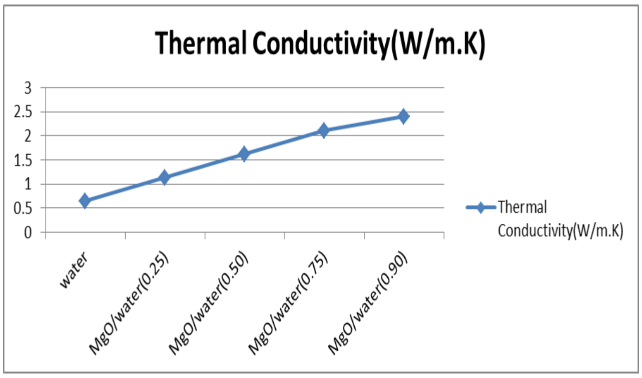

Fig.7.5: Variation of thermal conductivity of fluid with increase in particle volume concentration

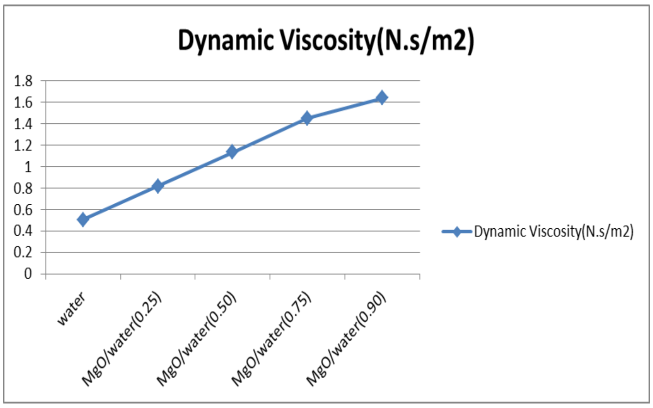

Fig.7.6: Variation of dynamic viscosity of fluid with increase in particle volume concentration

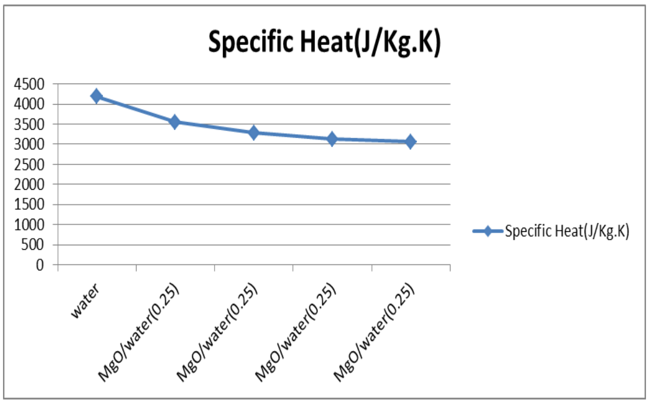

Fig. 7.7: Variation of Specific heat of fluid with increase in particle volume concentration

8. Conclusions:

1. Heat transfer rate is incresed due to the addition of MgO nanoparticles with base fluid as water. The average rate of heat transfer increment for 2.5 vol.% is 39.48%, for 5.0 vol.% is 54.12%, for 7.5 vol.% is 65.83%, for 9.0 vol.% is 70.45% respectively. The recorded enhancement range noted (6037-15218 W)

2. The thermo-physical properties of MgO/water nanofluid like density, viscosity, thermal conductivity is found to increased while specific heat capacity found to be decreased with increased concentrations of volume percentages.

3. Engine cooling is done more effectively with forced heat convection with the use of MgO/water nanofluid instead of conventional coolant as a water; significant increment is found in convective heat transfer coefficient (h), Nusselt no. (Nu), and Reynolds no. (Re)under turbulent flow.

4. The optimum results clearly indicated that (2.5&7.5 vol. %) shows absolute linear increment in heat transfer rate and thermophysical properties. Hence, our suggesion to use MgO/water coolant with above mentioned volume concentrations for best results in thermal performance enhancement of automobile radiator engine cooling system instead of conventional coolants like EG and water.

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