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# Review of Nanofluid as Coolant in Automobile Radiator

**A. V. Mane[1*], N. V. Sali[2]**

[1]P.G.Scholar (Dept. of Mechanical Engineering) GCE, Karad

[2]Associate Professor (Dept. of Mechanical Engineering) GCE Karad

***Abstract – This paper summarizes application of nanofluid as coolant in automobile radiator cooling system. Many researchers used various types of suspended nano sized particles in base fluid which is used for improving performance of radiator. Results have shown that nanofluid gives augmentation in heat dissipation than conventional coolant. This review is focused on experimental work done using different nanofluid varying different parameters like volume concentration, inlet temperature and flow rate. Researchers have carried out analysis for optimum value of volume concentration of nanoparticle for maximum heat transfer from radiator and also mentioned effects of other parameters on performance of radiator. Various correlations are developed for calculating thermo physical properties of nanofluid. At the end conclusion is drawn from referred papers.***

***Keywords— Nanofluid, Heat Transfer, Enhancement, Radiator, Nusselts Number***

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## INTRODUCTION

Consistent improvement in technology has created high competition in automobile industry for high engine efficiency. The reason for high efficiency is high working temperature but on other hand practically no material can withstand high temperature. Hence removal of extra heat produced is necessary but extraction of more heat results in thermodynamic loss.

Heat rejection directly to surrounding by natural convection is possible for smaller engines only and also it is very difficult to regulate. Hence for larger engines for heat dissipation unmixed flow type of heat exchanger called 'Radiator' is used. Instead of using fins directly on engine, liquid to air heat dissipation in radiator gives more heat transfer rate than air to air cooling.

Further development in automobiles created necessity of more heat dissipation from radiator. In general heat dissipation is calculated as

$$Q = h\, A\, \Delta T \quad \text{........(1)}$$

Where Q is heat transfer, *A* is heat dissipation area, h is convective heat transfer coefficient. From equation (1) it is clear that heat dissipation is increased by enhancing heat transfer coefficient h, increasing surface area *A* or increasing temperature difference $\Delta T$. Increasing $\Delta T$ has some material constraint while increasing surface area *A* increases radiator size and weight which results in more aerodynamic drag. Also design changes in radiator for more heat dissipation has reached maximum limit and further design modification have manufacturing as well as cost constraints. Hence enhancing heat transfer coefficient h by increasing thermo-physical properties of coolant is best way of increasing heat dissipation.

In radiator to avoid freezing of coolant in low temperature country along with conventional coolant like water, antifreeze agent like Ethylene-glycol is mixed in different proportion according to requirement. But Ethylene-glycol water mixture possesses poor thermal conductivity and results in decrease in heat dissipation. Many researchers revealed that suspending small amount of nano sized metallic or non-metallic oxide particles having high thermal conductivity in base fluid called 'nanofluid' enhances heat transfer. Thermal conductivity of some nanoparticle is shown in Fig.1 Invention of such high thermal conductivity material attracted many researchers to use them in heat transfer.

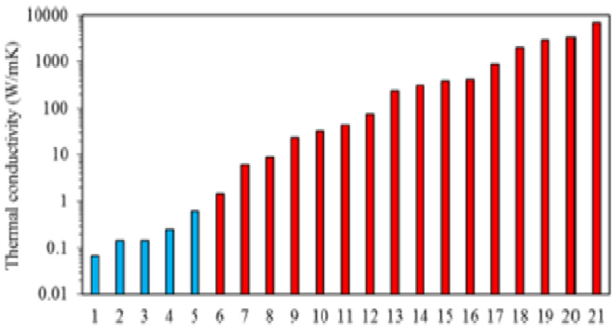


**Fig. 10 Bar chart diagram showing thermal conductivities of different nanoparticles [13]**

| | | | | | |
|---|---|---|---|---|---|
| 1 | Refrigerant(R113) | 8 | TiO2(Rutile) | 15 | Cu(Copper) |
| 2 | Poly-alpha-olefin oil | 9 | ZnO(Zinc oxide) | 16 | Ag(Silver) |
| 3 | Engine oil | 10 | Al2O3(Aluminium Oxide) | 17 | C(Diamond) |
| 4 | Ethylene glycol | 11 | MgO(Magnesium Oxide) | 18 | C(Graphene) |
| 5 | H2O (water) | 12 | CuO(Copper Oxide) | 19 | MWCNT(14nm) |
| 6 | SiO2(Silica) | 13 | Al(Aluminium) | 20 | SWCNT(1.7 nm) |
| 7 | Fe2O3(Iron Oxide) | 14 | Au(Gold) | 21 | SWCNT(1.0 nm) |

Heat transfer using nanofluid is done with faster rate than conventional fluid. Hence size of radiator required becomes compact and air drag also gets reduced. Hence gets higher fuel economy and less weighted cooling system.

## LITERATURE SURVEY OF EXPERIMENTAL WORK IN RADIATOR

Chavan and Pise [1] carried out experimental work on $Al_2O_3$/water as coolant in radiator and compared results with water. $Al_2O_3$ concentration is varied between 0-1% by volume .Results showed that increase in flow rate increases heat transfer. They found that enhancement in efficiency of heat transfer is about 40-45%.S.M. Peyghambarzadeh et al. [2] also

done similar work using $Al_2O_3$ (up to 0.3 vol.%) in three different ethylene-glycol water mixture. Maximum enhancement of Nusselt number is found to be 40%. S. S. Chougule et al. [3] carried out comparative study of radiator performance using CNT and $Al_2O_3$ nanoparticles. For preparing CNT nanofluid functionalization method was used for better stability while $Al_2O_3$ is dispersed without using any surfactant for 0-1% volume concentration. For 1% concentration of CNT and $Al_2O_3$ heat transfer augmentation was found to be 52.03% , 90.76% respectively.

K.Y. Leong et al. [4] carried out similar experiment using CuO nanoparticle in ethylene glycol base fluid. They calculated heat transfer on air side as well as nanofluid side. They also tested effect of air flow rate by varying Reynolds number 4000 to 6000 and coolant flow rate by Reynolds number from 5000 to 7000.He also observed effect of nanoparticle concentration on pumping power and pressure drop. They observed maximum 3.8% increase in heat transfer at 2% CuO concentration. Hafiz Muhammad Ali et al. [5] carried out experimental work in radiator using ZnO nanoparticle in base fluid in range of 0.01% to 0.3 % by volume fraction. SHMP (Sodium Hexa Meta Phosphate) is added in 1:5 proportion for increasing stability of nanofluid..They concluded that at 0.2% ZnO concentration heat transfer rate increase by 46%.They also revealed that beyond 0.3% concentration heat transfer decreases because of high wall shearing forms thicker boundary layer

Devireddy Sandhya et al. [6] tested radiator using $TiO_2$ dispersed in 40/60 mixture of ethylene-glycol and water in 0.1% to 0.5%.Their results showed that 37% increase in heat transfer rate compared to base fluid. They also found that increase in coolant flow rate gives more heat transfer while inlet temperature of coolant has no effect on it. M. Naraki et al. [7] performed an experimental study of CuO nanofluid in laminar flow regime. Enhancement in overall heat transfer coefficient of about 4% found at 0.4% volume concentration of CuO. Taguchi method is used for finding effect of each parameter and its optimum value. Adnan M. Hussein et al. [8] compared performance of radiator experimentally using $TiO_2$, $SiO_2$ nanoparticle. The results of the analysis of variance (ANOVA) showed enhancement of Nusselts number is found to be 22.5% and 11% for SiO2 andTiO2 respectively.

**Table IV Overview of experimental work carried out in radiator cooling system using nano Fluid**

| Sr. No | Author | Nanoparticle | Base fluid | Experimental Results |
|---|---|---|---|---|
| 1 | Chavan and Pise et al | $Al_2O_3$ | water | Heat transfer enhancement of 45% is found at 1%volume concentration. |
| 2 | S.M. Peyghambarzadeh et al. | Y-$Al_2O_3$ | Ethylene Glycol mixture | Maximum heat transfer enhancement of 40% obtained compared to base fluid. |
| 3 | S S Chougule et al | CNT, $Al_2O_3$ | water | Maximum augmentation in heat transfer found to be 90.76% and 52.03% respectively. |
| 4 | K.Y. Leyong et al. | CuO | Ethylene-glycol | Increase in heat transfer up to 3.8% compared with base fluid |
| 5 | Hafiz Muhammad Ali et al | ZnO | water | Augmentation in heat transfer of 46% at 0.2% by volume concentration |
| 6 | Devireddy Sandhya et al. | $TiO_2$ | Ethylene-glycol and water(40:60) | Increase in heat transfer rate of about 37% |
| 7 | M. Naraki et. al. | CuO | water | Enhancement in overall heat transfer coefficient of about 4% found at 0.4% volume concentration |
| 8 | Adnan M. Hussein et. al. | $TiO_2$, $SiO_2$ | water | Enhancement of Nusselts number is found to be 22.5% and 11% for $SiO_2$ and$TiO_2$ respectively. |
| 9 | Beriache M'hamed et. al. | MWCNT | Ethylene-glycol water (50:50) | Average heat transfer coefficient increased by 196.03% at 0.5% volume concentration |
| 10 | S S Chougule et al | f-MWCNT,S-MWCNT | water | Heat transfer augmentation of about 90.76% higher than base fluid as well as S-MWCNT is obtained |
| 11 | M. Ebrahimi et. al. | $SiO_2$ | water | Nusselts number increases with inlet temperatute volume fraction and flow rate |
| 12 | Vahid Delavar et. al. | $Al_2O_3$ | water | CFD analysis showed for same heat transfer nanofluid requires less flow rate, less pumping power with low pressure drop. |

Beriache M'hamed et al. [9] performed experiment in radiator using MWCNT (Multi Walled Carbon Nanotubes) in ethylene-glycol water mixture (50:50) in laminar flow condition. Augmentation in heat transfer coefficient is found to be 196.03% at 0.5% volume concentration. This increase is due to high thermal conductivity, high specific area, aspect ratio, larger specific surface area , less specific gravity as well as thermal resistance. S. S. Chougule et al. [10] carried out study of radiator performance comparatively using functionalised MWCNT and surface treated MWCNT. They revealed that functionalised MWCNT shows 90.76% higher heat transfer than base fluid while at high temperature heat transfer with surface treated MWCNT deteriorate.

M. Ebrahimi et al. [11] added $SiO_2$ to water and tested performance of radiator. From experimental study they showed that Nusselts number increases with inlet temperature ,volume fraction and flow rate. Vahid Delavar et al. [12] presented numerical study of radiator with $Al_2O_3$ nanofluid using single phase and two phase approach. They found that Nusselt number obtained is different for both approach. Also volume flow rate required for same heat transfer is also less and less pumping power is required Table 1 shows summary of experimental work carried out in radiator using Nanofluid

## THERMO-PHYSICAL PROPERTIES OF NANOFLUID

For finding properties of nanofluid it is assumed that particles are uniformly dispersed in base fluid. Following correlation are used for finding density, specific heat of nanofluid.[1]

*A.* $$(\rho)_{nf} = (\rho)_{np} + (1-\emptyset)\times(\rho_{bf})$$

Where $(\rho)_{np}$ density of nanoparticle is, $(\rho)_{nf}$ is density of nanofluid, $\emptyset$ is volume fraction of nanoparticle.

Similarly for calculating specific heat of nanofluid following energy balance equation is used [1 ], [2],

$$(C_p)_{nf} = \frac{\emptyset\rho_{np}C_p + (1-\emptyset)C_{bf}}{(\rho)_{nf}}$$ 19)

Where $C_p$ , $C_{p_{nf}}$, $C_{pbf}$ is specific heat of nanoparticle, nanofluid and base fluid respectively.

For calculating viscosity following Einstien's correlations used[1]

$$\mu_{nf} = \mu_w(1+2.5\emptyset)$$

S.M. Peyghambarzadeh et al.[2] used following correlation while calculating water based nanofluidand for ethylene-glycol based nanofluid

$$\mu_{nf} = \mu_{bf}(123\emptyset^2 + 7.3\emptyset + 1)$$

$$\mu_{nf} = \mu_{bf} + \frac{\rho_p V_B {d_p}^2}{72C\delta}$$

Where $\mu_{nf}$ , $\mu_w$ is viscosity of nanofluid and base fluid respectively .Where distance between the centre of the nanoparticles, δ and C correction factor are calculated

$$\delta = \sqrt{\frac{\pi}{6\emptyset}}d_p \qquad C = {\mu_{bf}}^{-1}(a\emptyset + b)$$

a and b are experimental parameters Modified Maxwells Correlation is used for finding effective thermal conductivity of nanofluid[1 ], as follows

$$k_{nf} = \left[\frac{k_p + 2k_{bf} + 2(k_p - k_{bp})(1+\beta)^3}{k_p + 2k_{bf} - 2(k_p - k_{bp})(1+\beta)^3}\right]\times k_{bf}$$

Where $\beta$ is nano layer thickness to original particle radius thickness ratio, thermal conductivities of particle

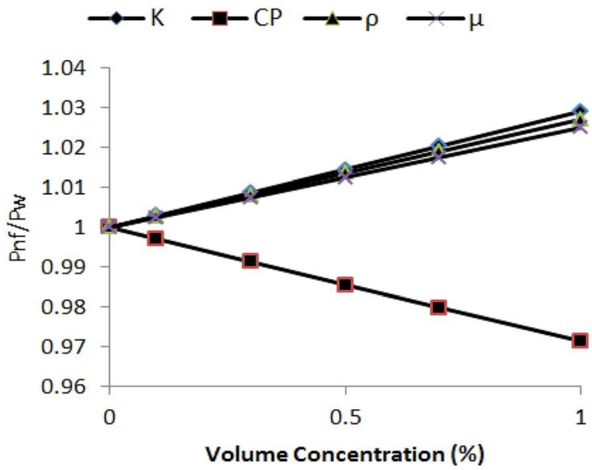


**Fig. 2 Variation of Thermophysical Properties of Nanofluid with Nanoparticle Concentration [1]**

Apart from above correlations S.S Chougule [3],[10] calculated thermo-physical properties like thermal conductivity and viscosity is using special equipment like thermal properties analyser and viscosity meter respectively at different concentration & temperature.

Specific heat decreases slightly while density, viscosity, and thermal conductivity increases in comparison to base fluid as shown in Fig.2

## HEAT TRANSFER CALCULATION

According to Newtons law of cooling heat transfer is given as

$$Q = h\ A\ \Delta T = h\ A\ (T_B - T_W)$$

Heat transfer is also written as

$$Q = m\ C_p\ \Delta T = mC_p\ (T_{in} - T_{out})$$

where $T_B$ - bulk mean temperature

$T_w$ - wall temperature

$T_{in}$, $T_{out}$ - inlet and outlet temperature

$C_p$ - specific heat of nanofluid

$A$ -surface area of tubes

m – mass flow rate of nanofluid

h- convective heat transfer coefficient

Equating above equation Nusselts number is given as

$$Nu = \frac{h \times d_{hyd}}{k} = \frac{mC_p\ (T_{in} - T_{out})}{A\ (T_B - T_w)} \times \frac{d_{hyd}}{k}$$

Here $d_{hyd}$ is hydraulic diameter of tube is calculated as

$$d_h = \frac{4 \times Area}{Perimeter}$$

For validating experimental results it is compared with empirical correlations given by Dittus , Boelter as below

$$Nu = 0.023Re^{0.8}\ Pr^{0.3}$$

where $R_e$ is Reynolds number and $Pr$ is Prandtl number

B. $(Re) = \frac{\rho V d_h}{\mu}$ and $Pr = \frac{\mu C_p}{k}$

Vajjah et al [12] developed following correlation for Nusselts number with help of numerical analysis

$$Nu = 1.9421 \times \left(RePr\frac{D_h}{z}\right)^{0.3} \quad \text{for} \left(RePr\frac{d}{z}\right) \geq 33.33$$

$$Nu = 6.1 + 0.003675 \times \left(RePr\frac{D_h}{z}\right)^{'}$$

for $\left(RePr\frac{d}{z}\right) \geq 33.33$

Effectiveness of radiator with cross flow with unmixed fluid is calculated as below

$$\epsilon = \frac{1}{C^*}\left[1 - e^{-\left(1-e^{-NTU}\right)}\right]$$

where $NTU = \frac{U \times A}{(mC_p)_{min}}$ and

Capacity ratio $(C^*) = \frac{(mC_p)_{min}}{(mC_p)_{max}}$

## CHALLENGES IN NANOFLUID APPLICATION

Though nanofluid has showed improved thermal conductivity and heat transfer, there are some problems faced like variation of thermo-physical properties and others as follows-

### *A. Stability of Nanofluid*

Factors affecting stability of nanofluid are particles agglomeration and particles suspension in base fluid. If stability is not maintained, it results in poor performance of the nanofluid. Nanoparticle dispersed in nanofluid forms cluster due to high Van-der waal force of attraction. Under the action of gravity force clustered nanoparticle gets settled down and mixture become non homogeneous. Thus nanofluid shows deteriorated thermo-physical properties.

For increasing stability of nanofluid physical treatment and chemical treatments viz. covalent functionalization, non-covalent treatments are used. In physical treatment ultra-sonication and magnetic stirrer is implemented for well dispersion of nanoparticle in base fluid. In covalent functionalization $HNO_3$, $H_2SO_4$, HCl or combination of this acid treatment is given to nanoparticle so that hydrophobic bond converted into hydrophilic bond

In non-covalent functionalization method surfactant like sodium dodecyl sulfate (SDS), sodium dodecyl benzene sulfonate (SDBS), Chitosan, Gum Arabic is used in small percentage for increasing dispersion of nanoparticle nanofluid.

### *B. Increased Viscosity and Specific heat*

As volume concentration of nanoparticle increases viscosity of nanofluid increases. This results in consumption of more power by pump. K.Y. Leyong et al. [4] found that extra 12.13% power is required for pump to supply nanofluid with 2% copper particles to radiator at 0.2 $m^3/s$ coolant flow rate. Also specific heat of nanofluid gets reduced with addition of nanoparticle compared base fluid. Hence heat carrying capacity of coolant decreases.

### *C. Higher cost*

Higher production cost is another reason for not using nanofluid in common application. For production of nanoparticle at lower cost sophisticated equipment and skilled workers are required.

## CONCLUSIONS

This paper reviewed application of various nanofluids in radiator for increasing heat transfer rate. Following conclusion can be drawn.

i. Nusselts number increases with increase in Reynolds number by increasing flow rate of nanofluid.

ii. Brownian motion of nanoparticle and formation of nanolayer is responsible for augmentation in heat transfer in nanofluid. In Brownian motion particle movement prevents formation of boundary layer hence results in increase in heat transfer.

iii. Optimum amount of concentration of nanoparticle is still not known. Augmentation of heat transfer generally takes place at low concentration of nanoparticle(less than 1%).

iv. Excessive addition of nanoparticle creates uneven distribution of nanoparticle results in deteriorate performance of engine by decreasing heat transfer.

v. Heat transfer is not so much affected by inlet temperature of coolant.

vi. However problems like stability of nanofluid, sedimentation, lower specific heat, high cost, increased pressure drop are faced during nanofluid application.

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**Corresponding Author**

**A. V. Mane***

P.G.Scholar (Dept. of Mechanical Engineering.) GCE, Karad

**E-Mail – akshaykmane@gmail.com**