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Thermal Performance Enhancement of Radiators Employing Nano-Fluid: A Review

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***Abstract*— *This paper reviews various Nanofluids for enhancing thermal performance and the determination of thermal characteristics of heat exchangers/radiators. It has been found that different Nanofluids have been employed on different heat exchanger design for the purpose of determining the thermal characteristic and improving performance. These Nanofluids ranging from based fluid (pure water), Al_2O_3, CuO with different nano-particles diameter and volume fraction. Anyway, experimental testing is been carried on various radiators using Nanofluid with better performance enhancement. Another method for determination of thermal characteristics of heat exchanger is the utilization of Computational Fluid Dynamics with Nanofluid. Abundant experiment were carried-out for the nano-fluids preparation using one step and two step method, and were found to be feasible. Studies were conducted for discovery of the mechanism of variation in thermal properties when nano-particles were supplemented in the based fluid. The application of Nanofluid for enhancement of thermal performance of radiators is of advantageous in terms cost, needless design, zero added weight to the existing radiator as compare to other means of enhancement techniques such as increasing surface area to coolant ratio, change of fin and tube material, change of fin design, change of flow arrangement and increasing of radiator core depth.*

***Keywords*— *CFD Tools, Heat exchanger, Thermal Characteristic, Nanofluid, Thermal Performance*.

I. Introduction

The term heat exchanger applies to all equipment used to transfer heat between two streams (or two sources). Typical applications involve heating or cooling of a fluid stream and evaporation or condensation of single- or multicomponent fluid streams. In other applications, the objective may be to recover or reject heat, or sterilize, pasteurize, fractionate, distilled, concentrate, crystallize, or control a process fluid. In a few heat exchangers, the fluids exchanging heat are in direct contact while in most of the heat exchangers, heat transfer between fluids takes place through a separating wall or into and out of a wall in a transient manner. [1]

Radiators are heat exchangers used to transfer thermal energy (heat) from coolant liquid medium to atmosphere for the purpose of cooling the engine. The radiator comprises of core, top and bottom tank. Core is formed with two sets of passageway, one set of tube and also fins. Liquid coolant is flow inside the tubes at the moment's air gets flow through the fins. The heat at that moment in the engine is absorbing by the liquid coolant and conveying in to the radiator, heat transfer takes place between solid body fins and atmospheric air [2].

High amount of heat is generated while engine is running; this can cause the temperature to a very high level, and capable of damaging the engine components. Therefore, for the components of the engine to be secure, the engine should run at minimum required temperature, which is called engine working temperature. The cooling system of an engine, maintains the working temperature by removing excess heat while engine is running. Additives such as coolant, a mixture of water and antifreeze flows through the engine cooling system and take in the excess heat and dissipate it though radiator [2].

Generally radiators are used to cool down automotive engine; radiator failure can result to so many problems like cylinder and piston deformation etc. which can further result to engine failure. A properly function radiator help cooling system work properly which in turn enhance engine performance. Various types of radiators are now in use, in which air is employed as heat transfer medium because of its availability [3].

Automobile engine performance can be enhanced by effective removal of heat transfer from the engine. There are different techniques for heat transfer improvement employed; these are by increasing surface area, efficient geometry, increase of coolant flow rate, enhancing the properties of heat transfer fluid, change of fins material etc. Automobile radiators with flat tubes are characterized with enhanced heat transfer. Flat tube radiators are widely used due their higher heat transfer area and lower air side pressure drop compared to round tube radiators of the same capacity [4].

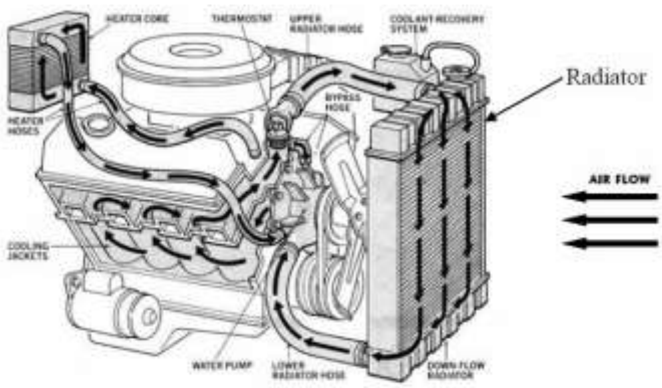

Fig. 1. Schematic of radiator [4]

II. Thermal Performance Enhancement of Radiator Employing Nanofluid Adopting Different Approaches

In passive techniques, heat transfer enlargement is accomplished by following various approaches like

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modification flow passage, considering roughness to augment surface area and turbulence. However, inefficient thermal conductivity of heat transfer fluid often remained the weaker point. For better solution to the problem, the additives size is reduced to nanometre sized particle. Nanofluids are composite of solid-liquid material comprising of solid nanoparticles or nano fibres with size typically of 1-100 nm suspended in liquid. [5]

There are various approaches employed to determine thermal characteristics of heat exchangers. These methods that can be employed to determine thermal characteristics of heat exchangers are by experimental testing, CFD analysis and Computational Performance analysis based on Porous Medium Approach, increasing surface area of radiator core, changing material and dimension of fins etc. The application of Nanofluid for enhancement of thermal performance of radiators is of advantageous in terms cost, needless design, zero added weight of material to the existing radiator as compare to other means of enhancement techniques.

2.1 Thermal Performance Enhancement of Radiator/Heat Exchanger Employing Nanofluid Adopting Experimental Testing

Abundant experiment were carried-out for the nano-fluids preparation using one step and two step method, and were found to be feasible. Studies were conducted for discovery of the mechanism of variation in thermal properties when nano-particles were supplemented in the based fluid. [4]

Hardik et al. [6], considered car radiator oval tube and conducted numerical investigation of it performance by improving radiator to be more compact, also enhance engine performance and reduce fuel consumption. A radiator with range of coolant mass flow rate is under study using Ansys work bench, by evaluating heat transfer of the radiator for water base CuO Nano-fluid. Increasing the volume fraction of CuO enhance heat transfer performance but with increase in pumping power. It is found that heat transfer can be improved without increase in pumping power, this is possible by employment of design experiment method.

A tetrahedrons method is used for the meshing, and a local size of mesh element is 1.7989 X 10^{-4}m. The energy equation is used to calculate the temperature distribution. A different physical property of fluid (ρ, C_p, K, μ) has been identifying as a boundary condition in fluent. The mutual connection for calculating the thermo-physical properties of Nano-fluids which are recommended by many researchers are expressed as follows:

Gabriela and Angel studied equation of density for Nano-fluids as follows:

$$\rho_{NF} = \varnothing \rho_{NP} + \left(1-\varnothing\right)\rho_{BF} \quad (1)$$

Gabriela and Angel studied equation of specific heat for Nano-fluids as follows:

$$C_{PNF} = \varnothing C_{PNP} + \left(1-\varnothing\right)C_{PBF} \quad (2)$$

Gabriela and Angel studied equation of viscosity for Nano-fluids as follows:

$$\mu_{NF} = \mu_{BF}\left(1+2.5\varnothing\right) \quad (3)$$

Gabriela and Angel studied equation of thermal conductivity for Nano-fluids as follows:

$$k_{NF} = k_{BF} \times \frac{[k_{NP} + \left(n-1\right)k_{BF} - \varnothing(n-1)(k_{BF} - k_{NF})]}{[k_{NP} + \left(n-1\right)k_{BF} + \varnothing(k_{BF} - k_{NF})]} \quad (4)$$

Peyghambarzadeh et al. [7], research study was conducted with aim of improving cooling performance of automobile radiator using AL_2O_3/water Nanofluids. Forced convection heat transfer in a water based Nanofluids has experimentally been contrasted to that of pure water in an automobile radiator. The liquid flow through the radiator comprised of 34 upright tubes with elliptical cross-section and air makes a cross-flow inside the tube with constant speed. The outcome of the experiment showed that improving the fluid circulating rate can enhance the heat transfer performance while the fluid inlet temperature to the radiator has in-significant influence. At the same time, application of Nanofluid with low concentrations can improve heat transfer up to 45% in similarity with pure water.

In this study, the following correlations, equation 1, 2, 3 and 4 were used to calculate these physical properties of nano-fluid:

Heat transfer rate can be calculated as follows:

$$Q = hA\Delta T\left(T_b - T_w\right) \quad (5)$$

$$Q = mC_P\Delta T = mC_P\left(T_{in} - T_{out}\right) \quad (6)$$

Regarding the equality of Q in the above equations:

$$N_u = \frac{h_{exp}.d_{hy}}{k} = \frac{mC_P\left(T_{in} - T_{out}\right)}{A\left(T_b - T_w\right)} \quad (7)$$

f is friction factor and was calculated using equation 8 and 9, recommended by Filonenko [19]

$$N_u = 0.0236 R_e^{0.8} P_r^{0.3} \quad (8)$$

$$N_u = \frac{\frac{f}{8}(R_e - 1000)P_r}{1 + 12.7(\frac{f}{8})^{0.5}(P_r^{\frac{2}{3}} - 1)} \quad (9)$$

$$f = (0.7 Ln R_e - 1.69)^{-2} \quad (10)$$

As shown in Figure 1, the experimental system used in this research includes flow-lines, a storage tank, a heater, a centrifugal pump, a flow meter, a forced draft fan and a cross flow heat exchanger (an automobile radiator). The pump gives a constant flow-rate of 10 l/min; the

Flow rate to the test section is regulated by appropriate adjusting of a globe valve on the recycle line.

In the case of radiator with flat tube, Aloslous et al., [4], carried-out research work, both experimentally and numerically. The study aimed at improving inside tube convective heat transfer co-efficient of both Al_2O_3 and CuO and hydraulic performance of the radiator. Reynolds number in the range of 136 to 816 is employed for the analysis and volume concentration in the range of 0.05% to 1% is also considered. At 1% volume concentration of both Nano-fluids inside tube convective heat transfer co-efficient for Al_2O_3 and CuO were improved by 16.4% and 13.2%, at 1% volume concentration cause in increase in viscosity and density which leads to an increase in pumping power.

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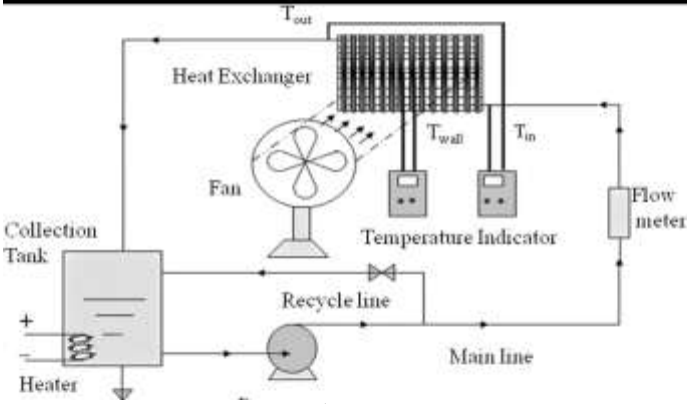

Fig. 2. Schematic of experimental setup [7]

The area of radiator can be reduced by 2.9% and 2.1% for Al_2O_3 and CuO. The optimum values of volume concentration were found to be 0.4% to 0.8% in which heat transfer enhancement dominates pumping power increase. Al_2O_3 nano-fluid gives the maximum heat transfer enhancement and stability compared to CuO nanofluids. Sodium dodecyl benzene sulphate (SDBS) surfactant with 1/4th weight of nano-particles were added. Samples of the prepared nano-fluids are shown in figure 3. Volume concentration of nano-fluids is calculated by using equation 12.

$$\varnothing = \left[\frac{\frac{W_{np}}{\rho_{np}}}{\frac{W_{np}}{\rho_{np}} + \frac{W_{bf}}{\rho_{bf}}} \right] \times 100 \tag{11}$$

Effective heat transfer co-efficient is given by

$$h_{o,\ eff} = \frac{h_o A_o}{A_o w_f} \tag{12}$$

Inside heat transfer co-efficient from numerical method is given by

$$h_{in,num} = \frac{q}{(T_{wall} - T_b)} \tag{13}$$

Fig. 3. Al_2O_3-water and CuO-water nano-fluid (0.05%) [4]

Sheikhzadeh et al., [8], study work was carried-out to analyse thermal performance of a car radiator using nanofluids. The aim of the research study is to investigate the Ethylene-Glycol (EG)/Copper nanofluids in different environmental conditions. The outcome of the study shows that by adding more volume fraction of nano-particles, and Reynolds number of inlet air, overall heat transfer co-efficient of air side and rate of heat transfer increases. This shows, by adding nano-particles to the coolant fluid in the radiator, the output temperature can also be reduce. It has been revealed that by adding 5% of nano-particles to the coolant fluid, thermal performance in a hot weather of 50^0C can be improve than it performance in the weather of 20^0C.

Hussein *et al.*, [9], research work was conducted to increase heat transfer in a car radiator employing nano-fluid. The aim of the study is to improve convective heat transfer energy of both TiO_2 and SiO_2 inside flat copper tube of the automobile cooling system. The outcome of the study shows that, there was in-effective friction factor with volume concentration of TiO_2 and SiO_2 for the coolant inside copper tube of the car radiator, also there was influential increase of heat transfer energy improvement, with addition o volume concentration of nano-particles. A highest Nusselt number have been recorded up to 16.4 and 17.85 for TiO_2 and SiO_2. There are 20% and 32% of energy rate improvement, and 24% and 29.5% effectiveness improvement for TiO_2 and SiO_2 nano-fluid relatively.

Mehtre and Sandeep, [10], research work was carried-out experimentally to analyse heat transfer from car radiator employing nano-fluids. The aim of the study is to converse the thermal performance of car radiator using AL_2O_3 nano-fluid in the temperature ranges from 40^0C to 75^0C under various fraction of nano-particles. The liquid flow-rates in the ranges of 50 ltr/h to 200 ltr/h, and air velocity in the ranges of 3.8 m/s to 6.2 m/s. The outcome of the study shows that increasing coolant flow-rate can enhance the heat transfer performance, and also increasing the air-flow rate enhances the heat transfer rate. The rate of heat transfer improvement was found to be 19% t0 42% in comparison with pure water.

Yadav and Bharat, [11], carried-out research studies by evaluating performance of automotive radiator system. There are two methods approached described the modeling of radiator, these are finite difference and thermal resistance concept. In order to conduct the evaluation of the radiator performance various parameters such as mass flow rate of coolant, inlet coolant temperature etc. are changed. A mixture of coolant ratio of 40:60 is used. The outcome of the research showed that from the observation, water is the best coolant but its limitation is that it is corrosive and contain some dissolved salts that degrade the flow passage of coolant.

According to Jaafar *et al.*, [12] forced convective experiment was carried-out on horizontal shell and tube heat exchanger counter flow under turbulence flow situation employing Nanofluid. The outcome of the study shows that convective heat transfer coefficient of base fluid is slightly lower than that of Nanofluid at same mass flow rate at same inlet temperature.

In the case of shell and helical coil heat exchanger, Srinivas and Venu [13] conducted a study research to enhance heat transfer using forced convection experimental approach aiming at heat transfer enhancement using CuO/water

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Nanofluid. The outcome of the study shows that improvement of in heat transfer can be obtained in the heat exchanger under study when Nanofluids are employed; also maximum heat transfer rate improvement was obtained for 2% wt. of CuO/water Nanofluid, and Nanofluid has more influence on heat transfer compared to stirrer speed and shell side temperature.

In the case of available energy analysis of a shell and tube heat exchanger employing graphene oxide nano-fluid, Milad *et al.* [14] carried-out experimental analysis with aim of developing and characterization of graphene oxide nano-fluid. The outcome of the study shows that the utilizing graphene oxide nano-fluids as the hot fluid led in less exergy loss in the shell and tube heat exchanger under both laminar and turbulence situations, comparing the available energy loss graphene oxide nano-fluids to distilled water caused 22% and 109% higher available energy loss than in laminar situations.

According to Shahrul *et al.* [15] an experimental investigation on some nano-fluids and their application in a shell and tube heat exchanger were conducted. The overall performance of the shell and tube heat exchanger operated with Al_2O_3-W, SiO_2-W, and ZnO-W were experimentally and carefully examine. The outcome of the study research shows that the overall performance of the shell and tube heat exchanger can be enhanced about 35% by employing Zn-W (with PVP) Ployvinylpynolidone nano-fluids.

In the case of shell and tube heat exchanger Godson *et al.* [16] carried-out experimental investigation of heat transfer characteristics of silver/water nano-fluids in the exchanger. Certain range of Reynolds number with turbulence condition is considered, also volume concentration and heat flux varied between 0.01%-0.03% and 800W/m^2 – 1000W/m^2. The outcome of the study showed an increased in convective heat transfer coefficient of 12.4% and effectiveness of 6.4%. The increased in convective heat transfer coefficient is as a result of improved thermo-physical properties of nano-fluids, and impeded evolvement of boundary layer in the inlet section as a result of additional nano-particles.

In the case of horizontal shell and tube heat exchanger under forced circulation Ramtin *et al.* [17] Conducted experimental study using water based Al_2O_3-gamma nano-fluid with the aim of improving thermal performance. This paper consider the influence of some parameters of hot working fluid such as Reynolds number and volume concentration of a nanoparticles on heat transfer characteristics, thermal performance factor and friction factor. The outcome o the study shows influential increase in Nusselt number as well as the overall heat transfer coefficient of heat exchanger by improvement of Reynolds number.

According to Adnan *et al.* [18] experimental study was conducted on parallel and cross flow concentric tube heat exchanger utilizing alumina and fly ash nanofluids with aim of improving the heat transfer. The experimental investigation present the influence of employing nanofluids produced from alumina or fly ash which is consist of different types of metal oxides in varying concentrations on the performance of parallel flow concentric tube heat exchanger (PFCTHE). The outcome of the experimental investigation revealed that efficiencies of the PFCTHE and CFCTHE enhanced by 31.2% and 6.9% relatively, when working fluid used is fly ash nano-fluid. The enhancement of the efficiency of the heat exchangers were resolved as 5.1% and 2.8% separately, when working fluid used is alumina nano-fluid.

In the case of concentric tube heat exchanger utilizing TiO_2-water based nano-fluid, Rohit *et al.* [19] carried-out experimental study to investigate heat transfer. The aim of the study is to demonstrate the heat transfer of TiO_2-water nano-fluid in fabricated heat exchanger made of copper material. The outcomes of the study from the nano-fluid are comparing with those from base fluid as coolant. The outcome shows that the average heat transfer rates for nano-fluids as a cooling media are higher than those of water base, which have technological importance for the design of efficient concentric heat exchangers.

Kumar *et al.* [20] carried-out thorough investigation, experimentally on inner tube of double pipe U-bend heat exchanger with and without longitudinal strip insert employing Fe_3O_4 nano-fluid. The aim of the experiment is to investigate the heat transfer, friction factor and effectiveness of those heat exchangers. Various concentrations of the Fe_3O_4 nano-fluid which is the hot fluid were employed. Reynolds number range from 15000 to 30000 is considered for the experiment. The outcome revealed that the Nusselt number on the nano-fluid side increases with increasing Reynolds number and particle concentration and with decreasing aspect ratio of the longitudinal strip insert.

2.2 Thermal Performance Enhancement of Radiator/Heat Exchanger Employing Nanofluid Adopting Computational Fluid Dynamics (CFD)

Srinivasu *et al.* [21], a study research was using CFD to predict heat transfer performance of louver fin radiator with water/EG and AL_2O_3 Nanofluids. The aim of the study is to enhance heat transfer of radiator with louver fins. The outcome of the study show that louver fin element produce more air turbulence at the same time, enlarging the volume concentration of Nanofluid particles can improve heat transfer performance. In this study, the following correlations, equation 1, 2, 3 and 4 were used to calculate these physical properties of nano-fluid. The heat transfer rate can calculate using equation 6. The convective heat transfer co-efficient h is shown in equation 11.

$$h = \frac{mC_P\left(T_{in} - T_{out}\right)}{A_s\left(T_b - T_w\right)} \tag{14}$$

Deepak [22], study work was carried-out on automotive radiator with louvered fin. The study titled “design and performance analysis of louvered fin automotive radiator using CAE tools. The study aimed is to perform an evaluation on the louvered fin based tube automotive radiator using Nano-fluids as coolant. An automotive radiator (louvered fin type) model is modelled on modeling software CATIA V5 and performance evaluation is done on pre-processing software ANSYS 14.0. The study outline that the Nano-fluids may effectively use as coolant in automotive radiators to improve the performance. The temperature and velocity distribution of coolant and air are analysed by using computational fluid dynamics environment software CFX. The results showed that the rate of heat transfer is better when Nano-fluid (SiC + water) is used as coolant, than the conventional coolant.

Kiran *et al.*, [23], Study research was conducted on louvered fin radiator. The aim of the research is to utilized computational tool ANSYS to perform CFD analysis on a radiator with louvered fin at different mass flow rates. The obtained analyse data from ANSYS and CFD tool are compared with experimental data. Relevant input data, nanofluids properties were obtained from the literature to investigate the heat transfer element. The material for fins is aluminium alloy 6061. The outcome of the study shows that there is good agreement between computational results with that of the experimental results.

In the case of Sagar and Chand [24], radiator with ordinary fin and louver fin were studied, and comparative analysis was conducted. The computational analysis tool ANSYS is used to performed a CFD analysis on a radiator at different mass flow-rates. Heat transfer analysis is performed to analyse the heat transfer rate, material used for the fins of radiator is aluminium alloy 6061. Modeling is performed in Pro/Engineer and analysis is performed in ANSYS. The result showed that by observing the thermal analysis results, thermal flux is enhanced by 13.43% for modified model. The radiator model with louver fins yield better results

III. Conclusions

Based on the reviewed literatures of nanofluids approaches of different types for heat transfer enhancement in radiators/heat exchangers, the following conclusion can be drawn.

1) Heat transfer enhancement of radiator using nano-fluid can be successfully employed, by increasing volume concentration of any of the nano-fluid, by increasing mass flow rate of coolant in the radiator. Thermal performance improvement of different radiator/ heat exchangers design, materials, and condition of service can be optimised at low cost, zero added weight without designing new radiator. The convective heat transfer co-efficient is higher compared to other heat transfer enhancement techniques.
2) Another area of importance in terms of thermal performance enhancement of radiators/heat exchangers is comparison of utilization of Computational fluid dynamics and that of experimental approaches. Thermal performance enhancement using computational fluid dynamics is more accurate, less labour and time, with much computation power compare to experimental testing. The major drawback of experimental testing of heat exchanger using nano-fluid are cost of facilities/equipment, time consuming during installation and operation, with relatively non error free.

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