Heat Transfer Enhancement Of Radiators Using Various Approaches: Review

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Abstract

This paper reviews heat transfer enhancement of radiators using different approaches. It has been found that different method of heat transfer augmentation has been employed in different radiator design. These methods ranging from fin design modification, increasing core depth of radiator, change of tubes type, increasing surface area of radiator core, change of fin material, change of flow arrangement and changing the different types of fluid and mixture concentration. The performance of a radiator depends on its thermal and hydrodynamic performance. Certain parameters are of importance to the radiator performance such as; convective heat transfer co-efficient, pressure drop, inlet and outlet coolant temperature, air and coolant mass flow-rates, fin type, fin dimension and material. The various approaches are considered, depending on the application requirement and utilizing range. Radiator design modification such as increase in number of fins and tubes, material substitution have their limitations with certain negative consequences like added cost and weight with low efficient thermal performance compare to utilization of Nano-fluid approach. The engine life and its performance depend on coolant temperature. The application of nano-fluid in automobile radiator as coolant greatly affects the performance of the engine which in turn enhances its life span and fuel consumption. This paper attempts to review literature related to various heat transfer enhancement methods in vehicle radiator with different design, and compares the most effective approach amongst the methods taking into consideration cost, weight and thermal efficiency.

1. Introduction

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 [1].

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 [1].

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 [2].

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 [3].

2 The Improved Heat Exchanger

The performance of HE is defined by its thermal performance, by improvement in convective heat transfer co-efficient, h, and by its hydraulic performance, amount of power consumed in pumping fluid.

2.1 Method of Heat Transfer Techniques

There are various techniques on how to enhance heat transfer in

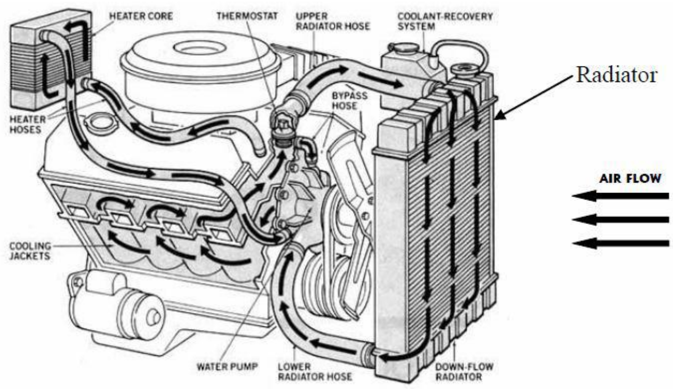

Fig.1: Schematic of Radiator [3]

thermal devices; the following are active approach, passive approach and compound approach of improving heat transfer. The acceptable method is the one that does not require or consume large amount of pumping power with larger heat transfer enhancement.

2.2 Active Method

Active heat transfer enhancement approaches require external power input, it is done with help of mechanical devices, such as fans, blowers.

2.3 Passive Method

The passive method of heat transfer improvement does not require any external power input. This approach of heat transfer enhancement can be achieved by increasing the effective surface area and resistance time of the heat transfer fluid.

2.4 Compound method

When both active technique and passive technique are used simultaneously for increasing heat transfer of any devices, which is greater than by using any one method at a time, then this term is known as the compound method. Uses both external power sources and geometry design changes

3 Heat Transfer Enhancements in Automotive Radiator

There are various approaches to re-designed more compact (effective) radiators. These methods that can be employed to optimized heat transfer performance of new radiator design are by considering and changing the fin design, increasing the core depth of radiator, changing type of tube in the existing radiator, changing flow arrangement, changing fin material, increasing surface area of radiator core and changing the different types of fluids and mixture

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concentration. Using these approaches, extensive work has been carried out on the various types of radiators with primary focus on optimization through study of it thermal performance and hydraulic performance.

3.1 Heat transfer Enhancement in Radiator using Prepared Nano-fluids

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. [3]

A number of researchers as shown in Table 1 below have approached radiators with over-heating problem with Nano-fluids of various types with aim of enhancing the thermal performance and hydraulic performance of the radiator.

Patel *et al.* [4], 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:

$$\rho_{NF} = \emptyset\rho_{NP} + (1-\emptyset)\rho_{BF} \ldots\ldots\ldots\ldots\ldots (1)$$

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

$$C_{PNF} = \emptyset C_{PNP} + (1-\emptyset)C_{PBF} \ldots\ldots\ldots (2)$$

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

$$\mu_{NF} = \mu_{BF}(1+2.5\emptyset) \ldots\ldots\ldots\ldots\ldots (3)$$

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

$$k_{NF} = k_{BF} \times \frac{[k_{NP} + (n-1)k_{BF} - \emptyset(n-1)(k_{BF} - k_{NF})]}{[k_{NP} + (n-1)k_{BF} + \emptyset(k_{BF} - k_{NF})]} \ldots (4)$$

Peyghambarzadeh *et al.* [5], 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:

$$Q = hA\Delta T(T_b - T_w) \ldots\ldots\ldots\ldots\ldots\ldots (5)$$
$$Q = mC_P\Delta T = mC_P(T_{in} - T_{out}) \ldots\ldots (6)$$

Regarding the equality of Q in the above equations:

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

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

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

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

$$f = (0.7LnR_e - 1.69)^{-2} \ldots\ldots\ldots (10)$$

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.

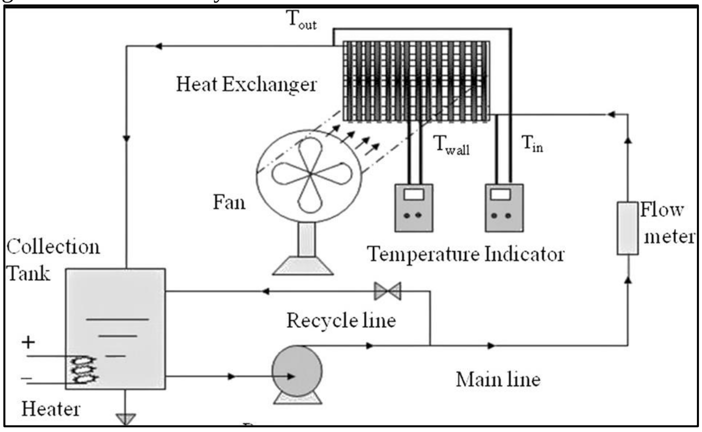

Fig. 2: Schematic of experimental setup [5]

Srinivasu *et al.* [6], 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.

$$h = \frac{mC_P(T_{in} - T_{out})}{A_s(T_b - T_w)} \ldots\ldots.. (11)$$

Deepak [7], 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.

In the case of radiator with flat tube, Aloslous *et al*, [3], 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. 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.

$$\emptyset = \left[\frac{\frac{W_{np}}{\rho_{np}}}{\frac{W_{np}}{\rho_{np}} + \frac{W_{bf}}{\rho_{bf}}}\right] \times 100 \ldots\ldots\ldots\ldots\ldots (12)$$

Effective heat transfer co-efficient is given by

$$h_{o,eff} = \frac{h_o A_o}{A_o w_f} \ldots\ldots\ldots\ldots\ldots (13)$$

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

$$h_{in,num} = \frac{q}{(T_{wall} - T_b)} \ldots\ldots\ldots\ldots.. (14)$$

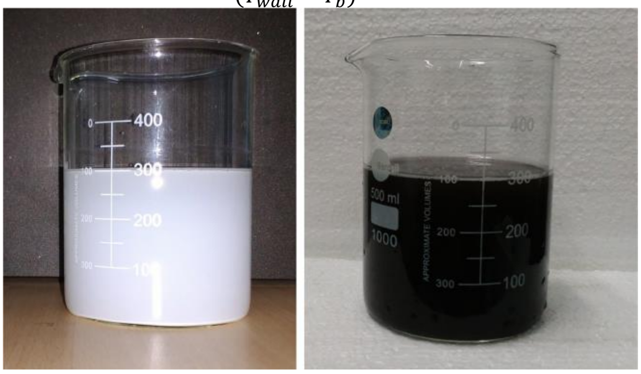

Fig. 3: Al_2O_3-water and CuO-water nano-fluid (0.05%) [3]

Kiran *et al*, [8], 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.

Sheikhzadeh *et al*, [9], 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^{0}C can be improve than it performance in the weather of 20^{0}C.

Hussein *et al*, [10], 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, [11], 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^{0}C to 75^{0}C 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, [12], 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.

Table 1: Heat transfer Enhancement in Radiator using Prepared Nano-fluids

Authors	**Nano-Particles**	**Purpose of Study**	**Outcome of the Study**
Patel *et al.* [4]	CuO	The study aim to examine heat transfer rate for radiator with varying coolant mass flow-rate	It is found that heat transfer can be improved without increase in pumping power, this is possible by employment of design experiment method.
Peygham barzadeh *et al.* [5]	AL_2O_3/water Nano-fluid	The aim of the study is to compare forced convection heat transfer in a water based Nanofluid to that of water in an automobile radiator experimentally	Outcome shows that increasing coolant mass flow-rate can enhance the heat transfer performance while the coolant inlet temperature has minor effects
Srinivasu *et al.* [6]	Water/EG and AL_2O_3 Nano-fluid	im of the study is to examine heat transfer in louver fin radiator and Nano-fluids mixing with base fluid (water + EG)	The results after analysis shows that louver fins element produce more air turbulence at the same time, increasing the volume concentration of Nano-particles, therefore, can enhance heat transfer
Deepak [7]	SiC + water	Aim of the study is to evaluate the performance of louver fin based tube automotive radiator using Nano-Fluid as coolant	The outcome of the study shows that heat transfer rate is better when Nano-fluid SiC + water is used as coolant than the formal coolant

Aloslous *et al*, [3]	Al_2O_3 and CuO	Aim of the study is to determine forced convective heat transfer co-efficient of Al_2O_3 and CuO Nano-fluids through automobile radiator with flat tube experimentally and numerically	1% of volume concentration, forced convective heat transfer co-efficient using Al_2O_3 Nano-fluid increase by 16.4% and CuO Nano-fluids by 13.4%. Radiator area reduces by 2.9% and 2.1% for Al_2O_3 and CuO. Al_2O_3 nano-fluid gives the maximum heat transfer enhancement and stability compared to CuO nanofluids.
Kiran *et al*, [8]	Nano-fluids using CFD	The aim of the study is to compare results from CFD analysis with the experimental results	The outcome of the study shows that computations are found to be in good agreement with that of the experiments.
Sheikhzadeh *et al*, [9]	Ethylene - Glycol/Copper	The aim of the study is to examine thermal performance of a car radiator using ethylene glycol/copper nano-fluids in different environmental conditions	The outcome of the shows that by adding 5% of nano-particles to the coolant fluid, radiator thermal performance in hot weather of 50°C can be better than its performance in the weather of 20°C.
Hussein *et al*, [10]	TiO_2 and SiO_2	The aim of the study is to improve heat transfer of a car radiator experimentally by using TiO_2 and SiO_2 nano-particles scattered in water as based fluid.	Outcome of the study shows that the heat transfer enhances with increasing of nano-fluid volume fraction. The experimental data is accepted with other researchers.
Mehtre and Sandeep, [11]	Al_2O_3	The aim of the study is to converse car radiator thermal performance employing Al_2O_3 Nanofluid in temperature ranges o 40°C to 75°C under different fraction of nano-particles.	The outcome of the study shows that by increasing coolant flow-rate heat transfer performance can be enhances. In addition, increasing air-flow-rate, enhances the heat transfer rate. The rate of heat transfer improvement was found to be 19% to 42% in comparison with pure water.
Yadav and Bharat, [12]	Propylene-Glycol/Water	The aim of the study is explain in detail the modelled radiator employing the finite difference approach and thermal resistance concept.	The outcome of the study shows that water remain the best coolant compare to propylene-glycol and mixture water., with water having contamination of dissolved salt which affect the coolant flow passage and corrosion.

3.2 Heat transfer Enhancement in Radiator by increasing surface area of radiator core

Radiator plays a vital function in engine cooling system. When expanding the cooling efficiency of radiator causes increase the life time of engine. The efficiency of the radiator can be increased by changing the surface area or dimension of the tube or increasing the number of fins/tubes. Radiator cooling fins are increases the total surface area of the metal body which provides cooling effect and hence, improve the efficiency to maximum cooling effect. It also speeds up the transfer of heat energy. [1]

Numerous research were carried-out on various radiators using surface area increase of radiator, so that heat dissipation of the radiator can be enhances. Below are some relevant research conducted.

In the case of design and modification of internal combustion engine cooling system, Prakash *et al*, [1], carried-out study work; the aim of the study is to improve thermal performance and life span of the engine. The outcome of the study shows that, nozzle velocity is increasing by inserting two flat plates inside the tube. Increasing nozzle velocity can decrease the pressure, but pressure is proportional to the temperature of coolant inside the radiator. Therefore, the temperature of coolant inside the radiator is decrease. The efficiency of the proposed radiator is increased by 5.37% when comparing with the reference.

According to Sang *et al.* [13], the most effective approach of predicting heat transfer performance of radiator is multi-scale semi-microscopic. These methods consist of microscopic analysis and semi-microscopic analysis. The properties of louver fin element can be foretell by employing microscopic analysis and modeling of the detailed geometry of a fin element, and model for the heat transfer rate and flow friction derived from microscopic analysis are then used for simulations of the full radiator model in semi-microscopic analysis. The result of the analysis showed that the proposed method show a good pact with the experimental data. The proposed method can be used to foretell flow and heat transfer properties of a realistic louver fin radiator with a reduced cost and sufficient accuracy.

Da Silva *et al.* [14], conducted study work on dimensioning procedure of coolant radiators for trucks and buses. The study gives an account of a routine for calculating the frontal area of radiators to the coolant, particularly applicable to trucks and buses. These consist on the determination of heat rejected by the liquid coolant (water). The results of the cooling tests (three test were performed) when compared with the calculation procedure developed, the calculation procedure proved to be very accurate. The results of the temperature of air and water obtained on calculations agreed with the measured values in the cooling tests.

Table 2: Heat transfer Enhancement in Radiator by increasing surface area of radiator core

Authors	Parameters	Purpose of the Study	Outcome of the Study
Prakash *et al*, [1]	Thermal Performance, Nozzle	The aim of the study is to improve	The efficiency of the proposed radiator is

	Velocity, Pressure and Temperature of Coolant inside radiator	thermal performance and life span of engine	increase by 5.37% compare with existing radiator
Sang *et al*, [13]	heat transfer rate, flow friction,	The aim of the study is to employ a method of predicting heat transfer performance of radiator.	The results of the analysis and experimental data show a good pact, justifying the validity of the method
Da Silva *et al*, [14]	Frontal area of radiator, heat rejected by coolant,	The aim of the study is to compare the cooling test result with the calculation procedure developed	Temperature of air and coolant obtained agreed with measured values in the cooling test

3.3 Heat transfer Enhancement in Radiator by changing fin design

Radiators are heat exchangers employed to covey thermal energy from one medium to another for the purpose of cooling and heating. The fins are principal component in the radiator use to cool the hot fluid. Heat dissipation of a radiator can be enhances by changing the fin design. [15]

In the case of change of fin design, Abuthahir *et al.* [15], carried-out research study with the aim of improving heat transfer of the radiator of locomotive engine by changing the fin design. The existing wavy fin is replaced with helical fins in the locomotive engine. Contact area on the radiator fin is increased, and heat transfer of the radiator is optimized.

Toure *et al.* [16], designed and fabricated five radiators with different fin pitch wave distance. The fin pitch wave distances are (P = 2.5, 2.4, 2.3, 2.2, 2.1 mm). The results show that among the five sample radiators, the one with best cooling performance and less material consumption is when the pitch, P = 2.1mm.

In the case of Sagar and Chand [17], 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

Akbarian *et al.* [18], considered to evaluate performance of tractor cooling system Perkins diesel engine type and suggesting more effective radiator. The purpose of this study was to examine the performance of the cooling system of the existing tractor engine. The outcome of the evaluation of the tractor engine showed that the ITM 285 tractor was not appropriate for the present type of cooling system temperature, up to 103^{o}C at 34.9^{o}C ambient temperature and the engine over-heated. After designing more effective new type of radiators, these radiators with 7 and 5 rows were evaluated, and were able to work at 46.8^{o}C of ambient temperature in every condition without any over-heating difficulty.

John *et al.* [19], studied radiator with louver fin and compare the one with no louver fin, the aimed of the research is to improve the performance of an automobile radiator using CFD analysis. This research work design a new radiator with louver fins, and another one with no louver fins. The initial parameters are inlet air temperature, inlet air velocity. The original radiator has no louver fins; modified design radiator with louver is done. The material considers is aluminium alloy 6061 for thermal analysis. The outcome to be confirmed are velocity, outlet temperature, heat carried by air heat transfer rate and pressure drop. Modeling is completed in Pro/Engineer/Catia and analysis is done in Ansys.

Gunnasegaran *et al,* [20], carried-out research study with the aims to perform thorough investigation into the effect of geometrical parameters on heat transfer characteristics of compact heat exchanger with louvered fins. The study considered and examined cross-flow heat exchanger with louvered fins. The influence of louver angle and fin pitch on air flow and heat transfer characteristics on cross-flow heat exchanger are investigated numerically. The louver angle of +2^{0}, +4^{0}, -2^{0}, -4^{0} and uniform angle of 20^{0}, with a fixed fin pitch and using three different fin pitches 1.0mm, 2.0mm and 4.0mm, and with the fixed louver angle are tested. A range of Reynold number between 100 and 1000 is also considered.

Table 3: Heat transfer Enhancement in Radiator by changing fin design

Authors	**Paramet ers**	**Purpose of the Study**	**Outcome of the Study**
Abuthahir *et al.* [15]	Contact area, heat transfer rate	The aim is to improve heat transfer of locomotive engine by changing the fin design	The contact area and heat transfer of the radiator is optimised
Toure *et al.* [16]	Fin pitch wave distance,	The aim of the study is to fabricate and analyse five radiators	At fin pitch of 2.1mm, efficiency is at maximum level, with less material consumption
Sagar and Chand [17]	Mass-flow rate, thermal-flux	The aim of the study is analyse using CFD tools on a radiator using different mass flow-rate	The thermal flux is enhanced by 13.43% with the modified model
Akbarian *et al.* [18]	Ambient temperat ure, coolant temperat ure	The aim of the study is to examined the cooling system of tractor engine	Radiators with 7 and 5 rows were evaluated, and were able to work at 46.8^{o}C of ambient temperature in every condition without any over-heating difficulty.
John *et al.* [19]	inlet air temperat ure, inlet air velocity	The purpose of the research is to improve the performance of an automobile radiator using CFD analysis	velocity, outlet temperature, heat carried by air heat transfer rate and pressure drop
Gunnasega ran *et al,* [20]	Louver angle, fin pitch, air flow, heat transfer	The aim of the study is to perform complete investigation into the influence of geometric parameters on heat transfer characteristic	louver angle of +2^{0}, +4^{0}, -2^{0}, -4^{0}, uniform angle 20^{0}, fixed fin pitch, fixed louver angle and varying fin pitch o 1.0mm, 2.0mm and 4.0mm

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3.4 Heat transfer Enhancement in Radiator by changing fin material

Radiator heat dissipation can also be enhances, by changing material made of the existing fin. A lot of research was conducted in terms of material for radiator, so that from the available materials the most efficient is selected as the appropriate.

According to Kumar, [21], research on the suitability of aluminium material over copper material for vehicle radiator was carried-out. The aim of the research study is to delineate the suitability of aluminium material as a replacement of copper material for vehicle radiator. The research takes into consideration some factors such as manufacturability, availability, cost, weight reduction, desirable performance, reliability and easy handling. The outcome of the study shows that aluminium radiator has a number of features that make it very attractive for vehicle applications in general.

Neela and Karampuri [22], carried-out thermal analysis on 150cc engine, the study title is modeling and simulation of fins for 150cc engine. The aimed of research is to redesign a fin and select amongst available material the most efficient and also to enhance the heat dissipation rate. In this research work a parametric model of the cylinder fin body is created. Transient thermal analysis is completed on the fin body using various materials to reduce weight and size and to increase heat dissipation rate. The outcome of the study shows that the aluminium alloy 204, cast iron and aluminium alloy 6061 were considered for the analysis. Based on the thermal analysis, aluminium alloy 6061 has high thermal flux than the other two materials.

In the case cylinder fin body, Kumar and Ramatulasi, [23], take into consideration by calculating its heat transfer rate by varying geometry, and material. Cylinder of an engine is one of the major components that are subjected to thermal stress and temperature gradient. In this study, air is proposed as medium for cooling the engine, by enlarging the surface area of fin, the heat dissipation can be enhanced. The main purpose of the research study is to examine the thermal properties by changing geometry, material and thickness of cylinder fins. The models are created by changing the geometry, rectangular, circular and curved fins. The existing fin thickness is 3.0mm and it is reduced to 2.5mm, and material of the existing cylinder fin body is aluminium alloy 204 with thermal conductivity of 110-150W/m K, the proposed material for the new design cylinder fin body are Aluminium alloy 7075, Magnesium alloy and Beryllium. The 3-D modeling software used is Pro/Engineer and the analysis is done in Ansys. The results showed that the thermal flux is more for Beryllium than other materials; also, by reducing the thickness of the fin to 2.5mm, heat transfer rate is enhanced

Table 4: Heat transfer Enhancement in Radiator by changing fin material

Author	Parameters	Purpose of the Study	Outcome of the Study
Kumar, [21]	Cost, weight, availability, thermal conductivity, manufacturability, desirable performance and easy handling	The aim of the research study is to delineate the suitability of aluminium material as a replacement of copper material for vehicle radiator.	The outcome of the study shows that aluminium radiator has a number of features that make it very attractive for vehicle applications in general.
Neela and Karampuri [22]	Weight, size, heat dissipation	The aimed of research is to redesign a fin and select amongst available material the most efficient and also to enhance the heat dissipation rate	The result of thermal analysis shows that aluminium alloy 6061 has high thermal flux than the aluminium alloy 204 and cast iron
Kumar and Ramatulasi, [23]	Heat transfer rate	The main purpose of the research study is to examine the thermal properties by changing geometry, material and thickness of cylinder fins	The outcome shows that the thermal flux is more for Beryllium than aluminium alloy 204, aluminium alloy 7075 and magnesium alloy; also, by reducing the thickness of the fin to 2.5mm, heat transfer rate is enhanced

3.5 Heat transfer Enhancement by changing flow lay-out on the Radiator

Large number of industries are using thermal systems wherein overheating can cause harm to the system components and result in system failure. The extreme heat generated must be dissolute to surrounding to avoid such problems for regular functioning of systems. This is specifically prominent in cooling of gas turbine blade, process industries, cooling of evaporator, thermal power plants, air-conditioning equipment, radiator of space vehicle and automobile and modern electronic equipment. [24]

In the case of heat transfer improvement for air flow through a duct with different rib insert, Ramdas and Kumar , [24], review various literature on heat transfer intensification, such as surface roughness, plate baffles and wave baffles, perforated baffle, inclined baffle, porous baffle, corrugated channel, twisted tape insert and discontinuous crossed ribs and grooves. The outcome shows that the most efficient approach is half porous baffle.

According to Khurana *et al*, [25], heat transfer can be improving in heat exchanger employing baffles. In this study, rectangular and triangular baffles are considered for Reynold number of 5000. The outcome of the study shows that water flows from inlet to outlet in the case of triangular baffle is 2.1m/s and rectangular baffle is 2.5m/s. The result recommended that different shapes of baffles are considered so that heat transfer rate can be increased. The governing flow equations were justified by finite volume method. These equations are continuity, momentum and energy equations, are employed to simulate the incompressible steady fluid flow and heat transfer in the computational domain, and are given by equation 1, 2, and 3.

$$\left(\frac{\partial \rho}{\partial t}\right) = \rho\left(\frac{\partial V}{\partial x}\right) - \rho V\left(\frac{\partial (lnA)}{\partial x}\right) - V\frac{\partial \rho}{\partial x} \dots\dots\dots (1)$$

$$\frac{\partial V}{\partial t} = -V\frac{\partial V}{\partial x} - \frac{1}{\gamma}\left(\frac{\partial T}{\partial x} + \frac{T}{\rho}\frac{\partial \rho}{\partial x}\right) \dots\dots\dots. (2)$$

$$\frac{\partial T}{\partial t} = -V\frac{\partial T}{\partial x} - \gamma - lT\left(\frac{\partial V}{\partial x} + V\frac{\partial(lnA)}{\partial x}\right) \ldots\ldots(3)$$

Bhambal *et al*, [26], study work was carried-out on helical and partitioned baffles with aim of enhancing heat transfer of shell and tube heat exchanger which supports the tubes and changes the direction of the fluid flow. The outcome of the study shows that helical baffle is more efficient in augmenting heat transfer rate. The employment of helical baffle also reduces shell side pressure drop, pumping cost, size, and weight and fouling.

In case of heat transfer improvement of turbulent channel flow by baffles with rectangular, triangular and trapezoidal upper edges, Chompookam *et al*, [27], conducted experimental study. The rectangular, triangular and trapezoidal baffles were studied. Reynolds number of 5100 and 22,500, rectangular baffle with aspect ratio AR = 10, height = 30mm, working fluid is air. The outcome of the shows that baffle with rectangular upper edge produced higher Nusselt number and friction factor, than triangular and trapezoidal baffles.

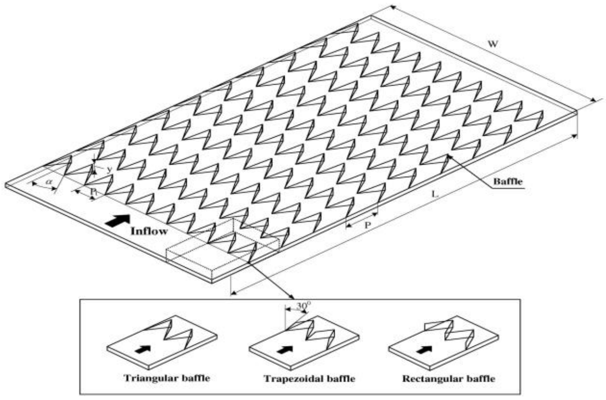

Fig4: Test section with rectangular, triangular, and trapezoidal baffles.

Table 5: Heat transfer Enhancement in Radiator by changing flow lay-out

Authors	Parameters	Purpose of the Study	Outcome of the Study
Khurana *et al*, [25]	Velocity, Reynold number,	The aim of the study is examine different baffles geometry	. The governing flow equations were justified by finite volume method
Bhambal *et al*, [26]	pressure drop, pumping cost, size, weight and fouling	Aim of study is to enhances heat transfer of shell and tube heat exchanger which supports the tubes and changes the direction of the fluid flow	The outcome shows that with employment of helical baffle also reduces shell side pressure drop, pumping cost, size, and weight and fouling.
Chompookam *et al*, [27]	Reynold number, Nusselt number, friction factor	The aim of the study is examine different baffles geometry	The outcome of the experiments show that baffle with rectangular upper edge produced higher Nusselt number and friction factor, than triangular and trapezoidal baffles.
Ramdas and Kumar , [24]	Corrugated surface, heat transfer enhancement, air-flow	The aim of the study is to review various literature on heat transfer intensification	The outcome shows that the most efficient approach is half porous baffle

3.6 Heat transfer Enhancement by changing radiator tube type for coolant flow

Another method of enhancing heat transfer in heat exchangers is by introducing dimples formation over the tubes of heat exchanger; this can aid uniform and enhancement of heat transfer.

Livingston and Selvakumar, [28], carried-out study work with the aim of effectively improves heat transfer and also to dissipate it uniformly in finned tube heat exchanger. A special fin or dimple is introduces over the tube which in turn leads to creation of uniform heat transfer around the tube.

In the case of circular channel with almond shape dimple, Patil and Deshmukh, [29], carried-out an experimental study with the aim of improving heat transfer, an almond dimple type were fabricated with diameter of 19mm and dimple depth 0f 3mm. the Reynold number based on the channel hydraulic diameter was changing from 25000 to 95000. There is comparison between the staggered configured dimples with base line plain tube. The outcome shows that staggered arranged dimples in a circular tube have 66% more thermal performance factor than in-line arrangement.

According to Mat *et al*, [30], by employing passive technique to introduce grooves on tubes, heat transfer is effectively improved. At a low Reynold number ranges of 100 to 1300. Computational Fluid Dynamics (CFD) simulation of fluid flow and heat transfer analysis of spirally groove tube is examined. The outcome of the shows that spirally corrugated tubes have heat transfer improvement ranges of 19.6% to 71.3% with appreciable pressure drop.

Table 6: Heat Transfer Enhancement in Radiator by changing tube type for coolant flow

Authors	Parameters	Purpose of the Study	Outcome of the Study
Livingston and Selvakumar, [28]	Heat transfer	The aim of the study is dissipate and improve heat transfer uniformly in the heat exchanger	The dimple is introduces over the tube which in turn leads to creation of uniform heat transfer around the tube.
Patil and Deshmukh, [29]	Reynold number, heat transfer	The aim of the study is to improve heat transfer	Comparison between staggered and in-line dimples, staggered dimples is more efficient with 66% more thermal performance
Mat *et al*, [30]	Reynold number,	The aim of the study is to	Spirally corrugated tubes

	fluid flow, heat transfer, pressure drop	employ CFD tools and passive technique of heat transfer enhancement	have heat transfer improvement ranges of 19.6% to 71.3% with appreciable pressure drop.

4 Conclusions

Based on the reviewed literatures of various approaches of heat transfer enhancement in radiators, 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 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) Thermal performance of radiator can also be optimised by employing others techniques such as increasing surface area of radiator, changing fin design, changing flow lay-out, changing fin material and modifying tube design. All these techniques also enhances heat transfer rate of new design radiator, but with additional cost, weight and design alteration. These three factors affected the total cost of new design radiators.
3) Comparison between convective heat transfer co-efficient of nano-fluid approach and other approaches. The nano-fluid convective heat transfer co-efficient is more effective than the rest of the approaches, with advantages of less cost, zero added weight and without necessary designing new radiator.

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