A Review of Surface Coating Technology to Increase the Heat Transfer

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***Abstract*---Heat dissipation is one of the paramount considerations in IC engine design. Loss of heat is encouraged only in an automobile to keep the engine safe. In this paper, a review of the current status of the research and technological development in the field of thermal spray coating process by utilization of Nanomaterials. Generally, the thermal spray concept is used for improving wear resistance, corrosion resistance, and thermal barrier properties of metals. However, no significant attempts have been made to improve thermal conductivity by thermal spray technology. This paper is focused on the limitation of existing heat transfer in Automobile radiator and how the thermal spray Nano coating will improve the heat transfer in an Automobile radiator.**

***Index Terms*—Nano coating, thermal spray, heat transfer, surface coating**

I. INTRODUCTION

An Internal Combustion engine engenders enough heat to ravage itself. Without an efficient cooling system, we would not have the conveyances today. The abstraction of extortionate heat from IC engine is essential to eschew overheating or burning. An automotive cooling system must perform several functions.. a) Remove excess heat from the engine. b) Maintain a consistent engine temperature. c) Help a cold engine warm up quickly. Generally, the heat transfer from surfaces may be enhanced by increasing the heat transfer coefficient between a surface and its surroundings, by increasing the heat transfer area of the surface, or by both. There are several ways to enhance the heat transfer characteristics, which can be mainly divided into active and passive techniques. [1-3].

Active techniques are more compact to utilize and design aspect. As the method requires some external power input to cause the desired flow modification and improvement in the rate of heat transfer. It finds finite application because of the need for external power in many practical applications. Augmentation of heat transfer by this method can be achieved by Mechanical avails, surface vibration, fluid vibration, electrostatic fields, injection, suction and jet impingement. [4].

Passive techniques generally use surface or geometrical modifications to the flow channel by incorporating inserts or adscititious contrivances They promote higher heat transfer coefficients by perturbing or altering the subsisting flow demeanor like treated surfaces, rough surfaces, elongated surfaces, displaced enhancement contrivances, swirl flow contrivances, coiled tubes, surface tension contrivances, additives for liquids and additives for gases. In these techniques, passive techniques are more considerable because active techniques are more intricate from the design perspective. In recent trends, it has been found that a paramount heat transfer enhancement may be achieved while utilizing Nanofluids (passive technique-additives for liquids) [4].

Nanoparticles (<100nm) suspension in conventional fluids is called as Nanofluids which have higher thermal conductivity when compared to conventional base fluids because of suspended solid particles. It conducts more heat from IC engine, but the deficient rate of heat dissipation in automobile radiator it may fail to achieve the desired rate of heat dissipation[5,6,7]. In thermal perspective, if we opted to increment the heat transfer, then we require incrementing the heat transfer area. So we require an immense size radiator to dissipate more heat but the current trends we require a more puissant engine in a minuscule hood space. This review shows that the present status of the research and technological development in the field of Nano coating of thermal spray technology for ameliorating the heat dissipation in automobile radiator are discussed.

II. THERMAL SPRAY TECHNOLOGY

The invention of the first thermal spray process is generally attributed to M.U. Schoop of Switzerland in 1910[8] and is now kenned as flame spraying. Other

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thermal spray processes include wire spraying, detonation gun deposition invented by R.M. Poorman, H.B. Sargent and H. Lamprey and patented in 1955. Plasma spray process invented by R.M. Gage, O.H. Nestor, and D.M. Yenni patented 1962, and high-velocity oxyfuel is invented by G.H. Smith, J.F. Pelton and R.C. Eschenbach and patented in 1958. Thermal spray is the generic term for a group of processes in which metallic, ceramic and some polymeric materials in the form of powder, wire or rod are alimented to a gun with which, they are heated above their melting point[9]. Thermal spraying techniques are coating processes in which melted (or heated) materials are sprayed onto a surface. The feedstock is heated by electrical (plasma or arc) or chemical means (combustion flame). Thermal spraying can provide thick coating (20 µm to several mm approx.)over a sizable area at high deposition rate as compared to other coating processes. The overview of the thermal spray process is shown in Fig. 1.

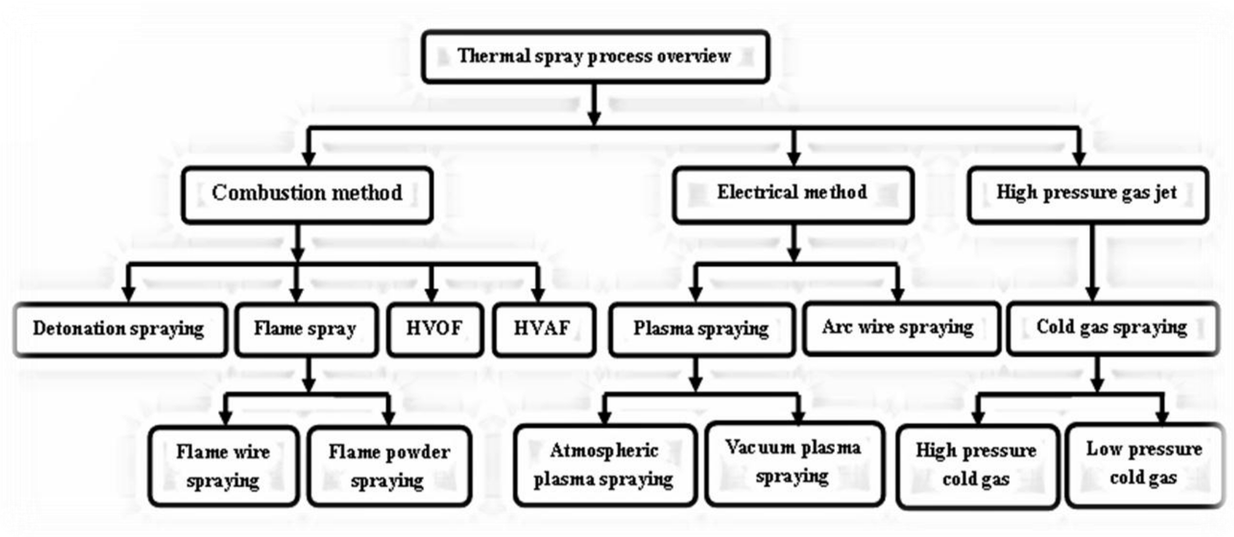

Figure 1. Thermal spray process overview.

Thermal spray coatings are customarily composed by multiple passes of a spray gun over the surface. Thermal spray technology consists of fusing a material in a thermal spray unit and atomizing the fused droplets of material. These fused droplets of molten material are sprayed onto the component to be coated. The size of the droplet is between 5 µm to 100 µm. When the droplets are in the air stream, they don't have the time to cool down. The droplets are cooling down only when they impact the substrate. At impact, they immediately bond at the surface of the substrate. It is shown in Fig. 2. The thermal spray process flow denoted in Fig. 3.

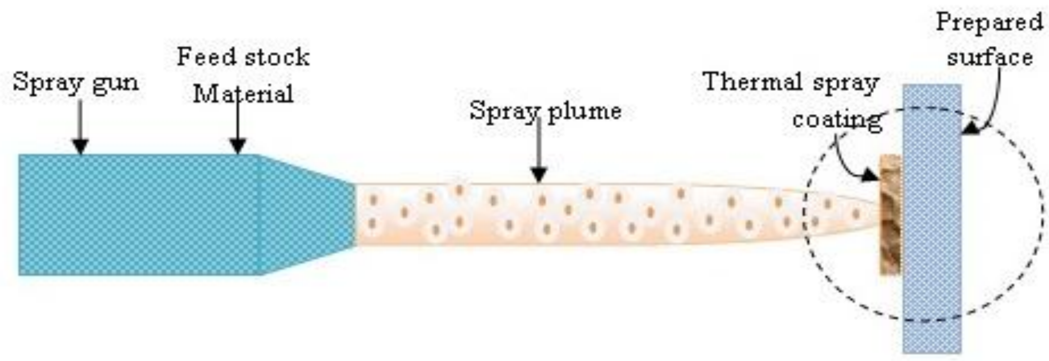

Figure 2. Thermal spray coating

III. Thermal Spray Process Flow Chart

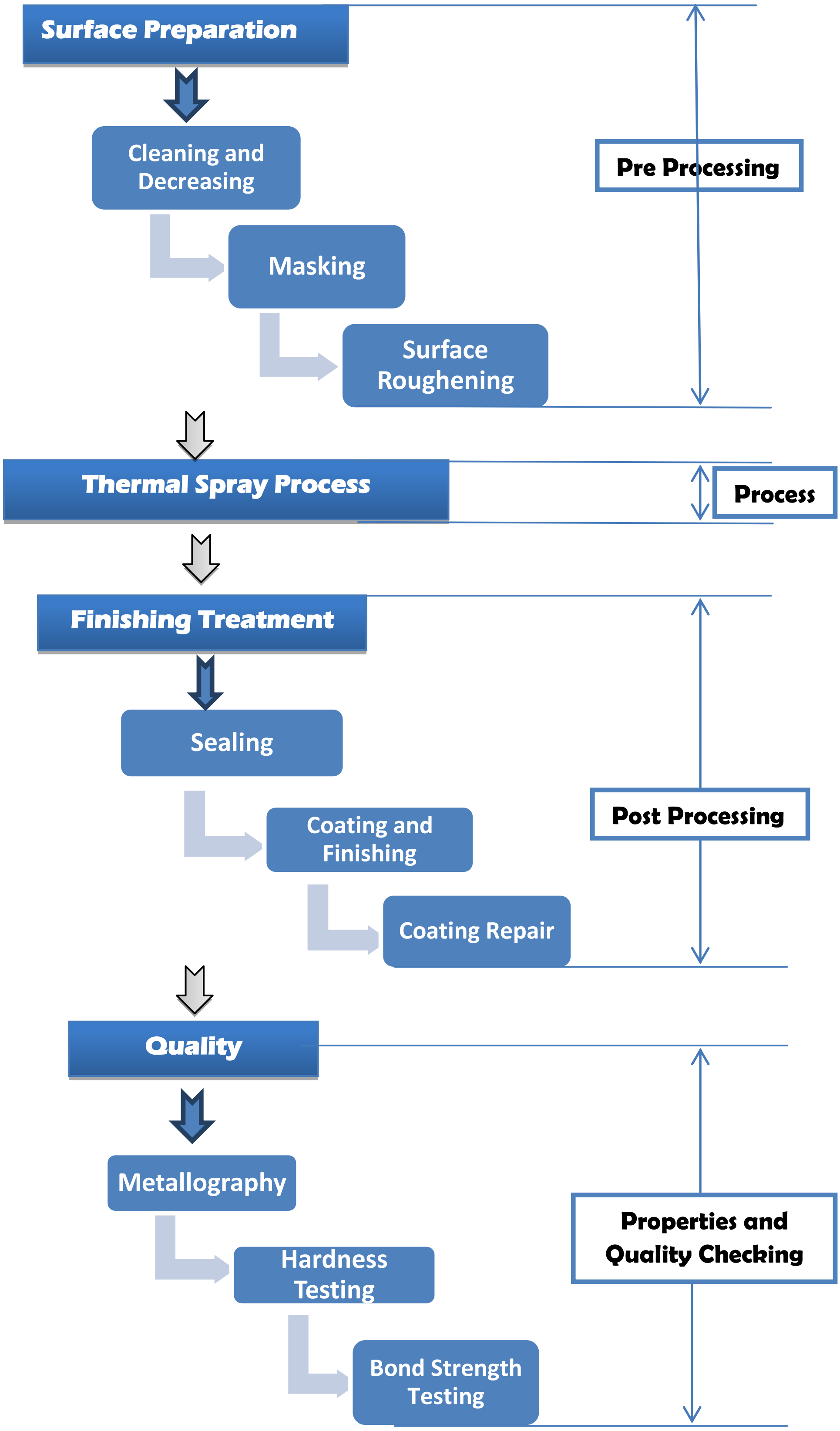

Figure 3. Thermal spray process flow chart.

IV. Literature Survey

Anand Kumar Dubey, (10) focused on the efficiency of the internal combustion engine cooling system depends mainly on the performance of its units. The main unit in this system is the radiator. The aluminium radiator is able to perform same as a copper radiator with some design modification, increasing the surface area of heat transfer & it can replace the copper radiator in the respect of the performance, heat transfer, cost-competitive & lightweight. Painting of tubes & fins is more sensitive & required in copper radiator due to corrosion and oxidation problem, but in case of an aluminium radiator, it is not so serious because scaling, oxidation & corrosion is not so effective in the performance of radiator. Due to impurity in coolant used in radiator & continuous corrosion after aging the tubes got punctured & leakage problem started in the field actual application; the reworking of these tubes is easy by a brazing process in the case of aluminium radiator than copper radiator but changing of tubes is very difficult in Aluminium radiator which is a major drawback of an aluminium radiator. **David J. et al., (11)** Carried work on the compact heat exchangers. A visualization study was performed to inspect fouling patterns internal to the heat exchanger. More fouling took place on the upper plates. The individual plate visual inspection showed that the bottom plate had a distribution of deposits across the entire plate with a concentration in the corner of the inlet section. The material removed during plate cleaning. These uncoated PHE results were large and differed for other PHE cases. Performance of uncoated PHE's is reduced by 56.5%, while the performances of coated heat exchangers were reduced by 47%. Visual fouling patterns were not consistent with either deposit pattern or accumulation amount. Typically plates accumulated deposits in the corners adjacent to the inlet and discharge. Corrosion was eliminated in all cases using coatings. Enhanced plate designs and utilizing rigidized metals specialized heat transfer surfaces, are currently being evaluated. **Dario borghino et al., (12)** New way to achieve heat dissipation by applying a nanostructured coating. Because of performance, versatility, and economy of material used, their method could see lead to better electronics, heating, and air conditioning. The work focuses on achieving heat transfer performances close to the theoretical maximum, the coating produced a heat transfer coefficient ten times higher than with the uncoated surfaces and dissipating heat four times faster than previously possible.

Chi –Chuan Wang et al., (13) The paper focuses on the data reduction method to obtain the air-side performance of fin and tube heat exchanger. The data reduction methodology for air-side heat transfer coefficient in the literature is not based on a consistent approach. This paper recommended standard procedures for dry surface heat transfer in finned tube heat exchangers having water on the tube side. Inconsistencies address includes the ϵ-NTU relationships, calculations of the tube side heat transfer coefficient and calculation of fin efficiency. Whether entrance and exit loss should be included. **Joshua A. Gordon et al., (14)** has design and simulation of both passive and active plasmonic coated spherical nanoparticles. This behavior must be contrasted with a classical laser, where lasing is maintained as the gain is increased its past threshold value. It is believed that the passing turns-off when the gain increases to such a point that it causes a severe detuning of the structural resonance. Explained about on/off nature of the super resonance, the authors are currently investing both lossy passive and active CNP with a virtual mode analysis. **Tariq Shamim et al.,(15)** discussed combustion assisted thermal spray systems by the numerical investigation. The gas phase temperature, velocity, and pressure were found to depend on a series of parameters, including mass flow rate of the gas phase, fuel/oxygen ratio, reactant preheating and cooling rate. The actual effects of those parameters are different in different parts of the nozzle and the region outside of the nozzle. The gas phase properties have a strong influence on the particle temperature and velocity and also concluded that a particle does not start losing temperature when the gas phase temperature experienced a decrease since the reduced gas temperature is still significantly higher than the particle temperature. The particle size also had significantly influenced by its temperature and velocity. **Yuan Yang Li et al.,(16)** has shown the quantitative effects and effect mechanism of the surface characteristics parameters, including nanoscale roughness, solid-liquid contact angle and effective heat transfer ratio on the modification plain surfaces and nanocone array surface. The HTC prediction correlation for the common plain surfaces and a uniform correlation were proposed and it can well predict the HTC of the heated surface with a simple convex structure.

Manikandan .D et al.,(17) discussed analysis the thermal spray modification technique in the EN8 steel properties. The work showed that analyzed report of various coating powder like aluminum oxide, Titanium oxide, and Zirconium oxide by using ANSYS Software, and also showed that improvement of Thermal Properties. **Sujithkumar C.S. et al**.,**(18)** Reported heat transfer enhancement by Nanostructured carbon Nanotube coating. The use of CNT coating on the surface enhances the heat flux. The heat flux is mainly due to the increase in the convective heat transfer and area of contact it also found from review CNT coating increases heat transfer rate to some extent. It is also useful to researchers to find out heat transfer rate to some extent so it is useful to researchers to find out heat transfer enhancement by using compound technique i.e. a combination of perforation and CNT coating which will definitely increase heat transfer rate much more than today. **lhoon Jang et al.,(19)** discussed the inertia-capillarity model, to predict the minimum coating thickness in slot coating. Unlike the visco capillary model, it considers inertia effects of the flow exiting the slot. So that, its prediction is more accurate at a high coating speed or a high capillary number than the visco capillary model. In addition, they compared minimum coating thickness determined with the two models and simulations, and found that the inertia – capillary model predictions are in excellent agreement with the simulation results for the entire operating conditions regardless of coating speed or fluid properties under the investigation, and also stated that this model can be applicable to Reynolds number of 50 at least. **M. Amara et al.,(20)** illustrated the three-dimensional numerical model to compute the heat transfer in a two-layer system with imperfect thermal contact and including phase change. The cooling depends strongly on the capacity of the substrate to absorb heat, as determined by its conductivity and thermal diffusivity. The result shows that the effect of the substrate roughness is more noticeable with a low value of thermal conductivity. It is also concluded that the splat fragmentation observed on non-heated substrates can be attributed to the presence of thermal gradients at the interface due to the random nature of surface roughness. For this reason, they implemented the random contact distribution into a multiphase model including the splat spreading and solidification. **K.A. Rajput et al**.,**(21)** Proposed that the carbon Nanotubes coating on heat transfer augmentation increase the heat transfer rate with reduction of weight by using Nano coating. Thermal performance of radiator using Nanofluid or mixture ethylene glycol + water (50% volume concentration) coolant is increased with air Reynolds number. About 70% increment in the total heat transfer coefficient based on the airside at a constant mass flow rate (0.08 Kg/s) and variable air Reynolds number. **R.** Senthilkumar **et al.,(22)** used a rectangular aluminum fin for the experiment to find out convective heat transfer 5rate. The fin was coated with Carbon nanotube using PVD process. The heat transfer rate with and without coating was investigated and compare each other. The temperature and heat transfer characteristics were investigated using Nusselt, Grashof, Prandtl, and Rayleigh numbers and also optimized by Taguchi method and ANOVA analysis. The average percentage of increase in fin efficiency is 5 %.

A. Witry et al.,**(23)** referred Thermal performance of Automotive Aluminium plate radiator higher heat transfer level in the tube, cheaper to manufacture and less weight reduction in weight and required space to fit system on a vehicle is the most challenging task in developing the cooling system. Also efforts to be taken to implement the use of emerging technologies like nanotechnology and to stabilize the results of these systems. In short, future challenges include developing more compact, lightweight, improved performance and economic engine cooling system. **E.** Chu **et al., (24)** discussed three possible failure modes in tube hydroforming: buckling, wrinkling and bursting. The free expansion tube hydroforming had been formulated as elastoplastic bifurcation problems. The geometric stability theory for the elastoplastic buckling and wrinkling of hydroformed aluminium tubes is based on the Donnell form of the cylindrical shell theory by correctly including plasticity in the formulation. Three geometric bifurcation phenomena had been identified in tube hydroforming: global buckling, axisymmetric wrinkling, and asymmetric wrinkling. It had shown that the onset of axisymmetric wrinkling always requires a higher critical axial compressive stress than the axisymmetric one under the context of the free expansion tube hydroforming and hence this model could be ignored in the analysis. **G.N. Xie et al.,(25)** has focused on an experimental system for investigation on the performance of shell and tube heat exchangers is set up, and experimental data was obtained. The ANN was applied to predict the temperature differences and heat transfer rate for heat exchangers. BP algorithm was used to train and test the network. It was shown that the predicted results were closed to experimental data by ANN approach and the research paper recommended that ANN can be applied to simulate thermal systems, especially for engineers to model the complicated heat exchangers in engineering applications.

Sang M. Kwark et al.,(26) has focused on Nanoparticle coatings was analyzed in Nanofluid pool boiling experiments. The Nano coating developed can significantly enhance the critical heat flux. Ethanol Nanofluid created more uniform Nano coating which outperformed Nano coating created in water Nanofluids. A linear relationship between the CHF enhancement and the quasi-static contact angles of the Nano coating was revealed. **Histochi Asano et al.,(27)** has focused on applied thermal spray coating on a copper heating surface in a horizontal narrow channel, and boiling experiments were carried out for forced convective heat transfer using HCFC-123 as the refrigerant. In their report, boiling heat transfer could be quite enhanced in nucleate boiling. However, deterioration in heat transfer coefficient was observed under the condition of high heat flux and high quality. Since the detoriated heat transfer coefficient was still higher than that the smooth surface, they concluded that the deterioration was caused by a boiling mode transition from nucleate boiling to forced convective evaporation. **C.O. Olsson et al.,(28)** has focused on the thermal and hydraulic performance of 10 radiator tubes. The tubes tested were one smooth tube, two rib-roughened tubes, five dimpled tubes and two offset strip fin tubes. In this report, the enhanced tubes provided increased heat transfer coefficients as compared to the smooth tube, but the related pressure drops were increased comparatively more than the heat transfer. This report shows that rib-roughened tubes showed up to be the most efficient as the volume goodness factor was considered. The offset strip fin tube data agreed within 20% range with the correlations available in the literature and simple correlations were determined each tube. **M. Ramkanth et al.,(29)** carried work on flow maldistribution. A non-uniform flow of fluid over parallel channels having a common inlet and outlet. It is to be found that a problem of flow maldistribution is predominantly in heat exchangers and affect their performances by increasing the pressure drop over the channels and has non-uniform mass flow rate. They used the artificial neural network (ANN) to predict and optimize the size of the heat exchanger and this method is trained by results obtained from the numerical simulations for different conditions. It is also analyzed that the flow maldistribution is minimum when the individual channel diameter is minimized. Increasing the channel diameter increases the non-uniformity in the mass flow rate. Finally concluded that the trained neural network predicts the mass flow rate. Based on these results the heat exchanger is optimized to minimize the flow maldistribution. **Y. Liu et al.,(30)** have focused on the heat transfer performance of the lotus type porous copper heat sink was systematically analyzed under different structural and hydrodynamic parameter conditions through experiments and Fluent -3D numerical simulations. The report showed that the lotus type porous copper heat sinks with the GaInSn coolant had an excellent heat dissipation performance and an experimental heat transfer coefficient of 9.3 W/cm^2 K could only be obtained under a pressure drop as 17.5kPa. The simulations revealed the influence of the structural and fluid hydrodynamic parameters on the heat dissipation performance of the porous copper heat sink, overall simulation results showed that an increased flow velocity and pressure drop, the equivalent heat transfer coefficient increased and the heat dissipation performance improved. However, with increased pore diameter porosity of the porous copper, the equivalent heat transfer coefficient first increased and then decreased. There existed an optimal porosity and pore diameter for the heat sink to conduct a maximal equivalent heat transfer coefficient.

V. Discussion

In the design of Automotive systems, Many researchers are exploring the conception of utilizing Nanofluids as a coolant to reduce the size of the radiator this will result in better fuel consumption[30-40]. Nevertheless, not many studies have been reported to check the compatibility of Nanofluids to be utilized as a coolant in the engine radiator. A good quality coolant must possess a high thermal capacity, low viscosity, and it should be non-toxic, low-cost, chemically inert, low electrical conductivity and resists oxidation [41]. Dihydrogen monoxide is a fundamental coolant that is commonly utilized as a heat transfer fluid, due to its high thermal conductivity, frugal and it is yarely available. In additament to these some metal, Nanoparticles may increase the heat transfer performance, but some earnest chemical quandary will occur due to different metal contacts in the fluid [42-46]. In the case, the performance of the conveyance will be rigorously affected. The damage occurs due to increment in engine temperature and as the heat that cannot be transferred directly from the engine to the coolant efficaciously. Furthermore, it may cause the quandaries in the radiator that which can further restrict the flow of coolant in the cooling system. And additionally from this review it’s clear that the heat transfer is the main quandary associated with the Aluminum radiator in the modern Automobiles [24]. It can be utilized as an alternative technology which is incremented the heat transfer coefficient by utilizing high thermal conductivity (when compared to aluminium) material coating by this coating method. In this literature review also clear that the thermal spray coating also utilized for incrementing heat transfer [15-21].

VI. Heat Transfer Calculation

Radiator is a cross flow heat exchanger in which the heat is transferred from hot fluid to cold fluid by means of heat exchange principle. As per the thermal calculation for cross flow heat exchanger with one fluid mixed and other fluid is unmixed then the heat exchange rate is given by

$$Q = FUA\Theta_m$$

$$\theta m = \frac{\theta 1 - \theta 2}{\log \frac{\theta 1}{\theta 2}}$$

Θ_m = Logarithmic mean Temperature Difference

Θ_1 = Thermal head at inlet

Θ_2 = Thermal head at outlet

U = Overall heat transfer coefficient

A = Heat transfer surface area

F = Correction factor

For calculation of correction factor F

$$Z = \frac{Tw1 - Tw2}{Ta2 - Ta1}$$

$$P = \frac{Ta2 - Ta1}{Tw1 - Tw2}$$

According to the value of P & Z we can get the value of F from graph.

T_{w1} = Water inlet temperature

T_{w2} = Water outlet temperature

T_{a1} = Air inlet temperature

T_{a2} = Air outlet temperature

Thermal head at inlet $\Theta_1 = T_{w1} - T_{a1}$

Thermal head at outlet $\Theta_2 = T_{w1} - T_{a2}$

$$\text{Where } \frac{1}{U} = \frac{1}{h1A1} + \frac{dx}{KA} + \frac{1}{h0A0}$$

hi = inside convective heat transfer coefficient (W/m^2 K)

ho = outside convective heat transfer coefficient (W/m^2 K)

dx = Thickness of Tubes

Ai = surface area of inner tube (m^2)

Ao = surface area of outer tube (m^2)

K = Thermal Conductivity (W / mK)

VII. Summary & Conclusion

- The present review paper shows that thermal spray technique has been used to prepare Nanomaterial coatings on metal surfaces and additionally the effect of normal Aluminium radiator and Nanomaterial coating on heat transfer enhancement.

- It is found that thermal spray process is the best technique for coating amends the thermal conductivity of the radiator.
- The spray particles have high kinetic energy and high thermal mass so that the particles are bonding together. These particles shrink due to their temperature loss, by this way gripping these roughness peaks.
- With the thermal spray, probably more so than any other coating process, there is almost no limitation on the number of options available for substrate and coating material combinations.
- Nanoparticle-based thin film coatings on tube surface to increment the heat transfer coefficient. Considerable improvement is also expected. The thermal spray Nano coating may improve the overall heat transfer coefficient of the radiator in automobiles.

VIII. Current Research Directions and Future Scope

At present, fundamental understanding of the thermal spray process application of heat transfer in the initial stage. This current research is focused on theoretical and experimental studies to answer the question, "how does coating thickness will increase heat transfer?" and also "how will the different coating material increase the heat transfer?"

The future research should lead to the development of new experimental methods for characterizing and understanding of thermal spray nano-coating in the lab and nature.

A better understanding of the mechanisms behind the thermal conductivity enhancement would likely lead to recommendations for nano-coating in heat transfer areas in industrial applications.

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