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Enhancement of Heat Transfer Characteristics of Plain Fin Coated with Brass and Aluminium

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Abstract: Rate of heat transfer plays a very important role in the performance of thermal systems like heat engines, steam power plants, refrigerators, air conditioners etc. Continuous efforts are being made to improve the effectiveness of the mentioned systems. Thermal conductivity of material effects the heat transfer characteristics the most and can be enhanced by surface coating of various materials. Materials with high thermal conductivity are preferable for providing coating on substrate to improve heat transfer rate. In present work, fins made of Stainless Steel 304 coated with Brass and Aluminum (250 micrometers thickness) by Twin wire arc coating process, is investigated. Experiments were conducted with and without coating at different heat input using Pin Fin Apparatus and calculated Nusselt number, Reynolds number, thermal conductivity, heat transfer coefficient, fin efficiency. From the results obtained, it is concluded that Nusselt number in case of S.S coated with Aluminium is increased by 1.36% compared with coated with brass and 2.1% compared without coating and there is an increase in efficiency of fin coated brass and Aluminium materials by 14-73% compared to without coating.

Keywords: Heat Transfer, Coating Materials, Twin wire coating, Thermal Conductivity, Fin efficiency.

NOMENCLATURE

A	Cross sectional area of fin
h	Heat Transfer Coefficient
K	Thermal conductivity of fin material
ΔT	Temperature difference between before and after heating of air
dT1	Temperature difference of fin between first and last thermocouple
dx1	Thickness of fin between first and last thermocouple
dT1	Temperature difference between before and after heating of duct
dx2	Thickness of duct
P	Perimeter of fin
m	Fin parameter
L	Length of fin
P	Input power
η	Fin efficiency

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I. INTRODUCTION

Heat Transfer is referred as the amount of heat transferred across a thermodynamic system due to temperature difference. Heat transfer is classified into three categories, such as conduction, convection and radiation.

Generally heat is transferred from hot fluid to cold fluid either with direct contact or without contact. Heat transfer is very important parameter in the performance of thermal systems. More experiments are being done as to improve the heat transfer and to shrink the dimensions and occupancy of heat exchangers. The requirement of decrease the volume and weight of heat exchanger has become very important in many thermal engineering applications like all heat engines, This is especially important in modern electrical and electronic systems. Generally fins are utilized in many modern electrical and electronic systems to increase rate of heat transfer by extended its surfaces to maintain the temperature with the specified limits as to avoid overheating of system. Lot of research is being carried out to enhance the performance of fin by changing its the geometry, material, velocity and direction. It is observed from research papers mentioned below that the efficiency of fin cab be improved by increase its thermal conductivity with surface modification using thermal coatings. Usually, thermal coating on material is used to reduce corrosion, scaling and increase the life of material.

The workings of many thermal systems generate energy in the form of heat. This heat may cause serious overheating and sometimes system may fail. Heat removal from the system in optimum way is necessary as to maintain safe operation of the system. The heat generated from the thermal system must be transferred to its surrounding to run the system within its specified working temperatures and also works effectively. Extended surfaces (fins) are used in many thermal systems to increase heat transfer either from the system or to the system. Generally extended surfaces are utilized for natural-convection cooling of electronic devices.

Geometry of rectangular fins with rectangular bases are most effective as they tender an low cost, trouble-free solution to the problem. There are two types of orientations are mostly used in the engineering applications like horizontally based vertical fins and vertically based vertical fins.

Chiang Ko-Ta et al [1]. they says that the performance of heat exchanger can be improved considerably using fins with several geometrical shapes. They observed from previous investigations that using of internal fin is best option to enhance the cooling modern electronic systems compared with other available methods . B. Moshfegh et al.[2] to obtain the required uniform rate of heat transfer, cost ,type of fin profile and placing of the finned surface may play vital role. J.R. Welling et al.[3] they recommended that rectangular fin is the most commonly preferable geometry compared to other variations because of its easy preparation, most economical and best heat transfer capacity. There are two types of common shapes of fin configurations are used such as horizontally based vertical fins and vertically based vertical fin in the various applications. But , the horizontal orientation is not utilized because it removes less quantity of heat from the system. F. Harahap et al.[4] ,since the use of extended surface is most suitable, low cost and convenient, surface area can be enhanced by adding extended surfaces to the base material surface to achieve desired rate of heat transfer from the system. It is necessary to take care about optimize the spacing between fins and base material surface as to avoid decreasing the heat transfer by adding fins . even if surface area increases with adding numerous fins, they may also oppose the flow passage and provide boundary layer interferences which may effect on the heat transfer from the system. D.Q. Kern et al. [5] they told that fin is general application in enhancement of rate of heat flow with the help of adding surface area. Increasing surface area using fin is most preferable due to its low weight, less occupancy and low cost.. An extended surface are may also utilized in all types of transport vehicles and also in the engineering applications. Sadik Kacak et al. [6], he proposed the nano fluids which are suitable to transfer more heat compared to other heat transfer fluids. During the 2000s, lot of research is being done to study most effective properties such as viscosity, thermal conductivity and specific volume of nano fluids. Asirvatham et al. [7] proposed experimental work to study the performance of convective heat transfer at the steady state by taking de-ionized water with volume fraction (0.003 % by volume) of copper oxide (CuO) nano particles dispersed to form a nanofluid which passed through a copper tube and observed better results compared to conventional fluids. V.Sreedhar et al.[8] conducted experiments on shell and tube heat exchangers with different types of profiles and observed that Disc-Doughnut Type Baffles shows more heat transfer compared with Segmental type baffles. Felix A. Espana et.al [9] in this work, they have tested the possibility of increasing thermal conductivity of stainless steel coated with brass with the help of Laser Engineered Net Shaping (LENS). It is observed that the thermal conductivity of coated substrate increased by 65% at 100 C° and less thermal resistance is observed between brass and parent material by minimize the dilution with defect free sound interface. They said that low thermal expansion metal matrix composites can generate future based thermal coatings to enhance heat transfer capability by using laser processing. Prabhu et al. [10] explained the importance of nano coating on the substrate and it becomes futuristic important parameter in the field of thermal applications. Prabhu et al. [11] observed that if velocity of fluid is increased then its heat transfer co-efficient is also increased and vice versa. But power is supplied to pump becomes more when increase the velocity of fluid. Hence increasing the heat transfer coefficient is not suitable to achieve the required heat transfer by increasing the velocity of fluid. In another method, heat transfer can be increased by decreasing the atmospheric temperature and it is practically not possible to decrease surrounding temperature. Lastly, heat transfer between the fluids is enhanced by increasing the surface area in case of convective heat transfer which is obtained by adding an extended surface to the parent material. Heat transfer from the extended surface can be increased by providing coating on it with high thermal conductivity materials. R. Senthilkumar et al. [12], Aluminium fins are coated with carbon Nano Tubes using PVD to increase heat transfer from the fins and compared the heat flow characteristics between coated Aluminium fins and non coated Aluminium fins. It is concluded that fin efficiency is enhanced by 5% with Nano coated Aluminium fin than non coated Aluminium fins. J.Nagarani et al. [13], conducted an experiments on elliptical shape of fin manufactured with Stainless Steel coated with multi walled carbon nano tubes at different surface temperatures. Calculated the various heat transfer characteristics like thermal conductivity, heat transfer coefficient, fin efficiency, shaped tube efficiency, temperature distribution at different heat inputs and compared the results with and without coated Stainless Steel. It is observed from the results that thermal conductivity of Stainless Steel coated with multi walled carbon nano tubes is improved by 21.1% compared with non coated Stainless Steel due to surface temperature decreases in case of coated fin. Also the convective heat transfer coefficient of coated Stainless steel is increased by 7% compared with non coated Stainless Steel. The shaped tube efficiency of Stainless Steel coated with multi walled carbon nano tubes is improved by 6.2% compared with non coated Stainless Steel. The fin effectiveness of Stainless Steel coated with multi walled carbon nano tubes is improved by 21.8% compared with non coated Stainless Steel. Coatings are used in the thermal applications like refrigeration, Diesel engine and better performance results are obtained [14, 16, 18]. Long Chen et al.[17], coated Graphene on composite anti-/deicing component used in the helicopter. They observed that thermal conductivity of coated material is effected by thickness of coating and spraying pressure and they concluded that less coating thickness and high spraying pressure are suitable parameters to get high thermal conductivity.

From the above studies, there are more information available related to methods for improving heat transfer in the literature. However, rather limited data is available stainless steel coated with high thermal conductivity materials and not with nano carbon tubes and also effect of coating thickness on the substrate.

In this experimental study, stainless steel is selected as substrate and it is coated with Brass and Aluminium of thickness 200 microns using twin wire coating method. An experiment is conducted on pin fin apparatus at different heat inputs and heat flow characteristics are determined and compared for coated fin and without coated fin as to obtain best coating material on stainless to get more rate of heat dissipation from the fin.

II. COATING MATERIALS

Coating is an additional layer added to surface of substrate. The layer acts as a covering for substrate and to boost heat transfer characteristics beside protective from corrosion and increasing lifetime. Coating technology is adopted for both allowing and avoiding of heat flow based on application. Coating materials which avoids heat transferring from or into a body is called Thermal Barrier Coatings. Materials like Copper, Aluminium that have high thermal conductivity are considered as coating material for improving heat transfer of the substrate. Fin is manufactured with Stainless steel 304 and it is taken as substrate which is coated with brass and aluminium.

Specimen dimensions:

Diameter 14.3mm, Length 180mm, Pitch, and Thread length 15mm (M12).

Fin material: Stainless Steel 304 and its thermal Conductivity is 28W/m-k

Fig. 1. Five parallel holes after drilling

A. Brass: It is used as one coating material coated on stainless steel using twin wire arc method. Brass is made with copper and zinc. The varying property of zinc and copper creates different type of brass of different properties.

- Melting point: 900-940^{0}C
- Density: 8.4 to 8.7 g/cm^3
- Thermal Conductivity: 125 W/m K

B. Aluminium: It is used as second coating material coated on stainless steel using twin wire arc method

Properties of Aluminium are given as

- Melting point (933.47K/ 660.320^{0}C),
- Density (2.70g/cm3),
- Thermal conductivity: 204W/m-K @ 20^{0}C

Fig.2. Coating Material Wire

Fig. 3. Coated Stainless Steel

III. TWIN WIRE ARC COATING

Twin Wire Arc Spray is used to provide coating on substrate with Brass and Aluminium materials with thickness of 250 microns. It is economical and core ceramic/metallic coatings or metallic/matrix alloy coatings are made using this process.

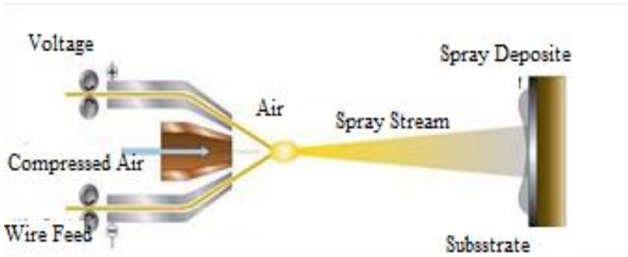

Fig.4. Twin Wire Arc Coating

- The rod is to be coated will undergo Grit Blasting for the parent material to stick on it.
- Then the rod to be coated is placed at some distance from the equipment.
- The material that is to be coated is sent in wire form through two electrodes via rollers, and then these wires are made to meet at a point.
- When current is supplied, wire is heated and melted which is sprayed on substrate with the help of compressed air.
- Coated material is dried as to provide good bond between substrate and coating material.

IV. EXPERIMENTAL SET-UP

Pin Fin Apparatus is very useful to estimate heat transfer from the fin to surrounding as shown in the Fig.5.

It consists of pin fin placed in test section and five thermocouples are placed over the fin surface to measure the temperature and one thermocouple is arranged at the inlet of duct to know the inlet air temperature. Air is supplied into the duct with the help of Blower. U tube manometer is used to measure the discharge of air through the duct. The control panel consists of Dimmer stat to supply the required voltage to the Fin, Voltage ,current and temperature are measured by using Voltmeter, Ammeter and Digital temperature indicator respectively.

Fig. 5. Pin Fin Experimental Set Up.

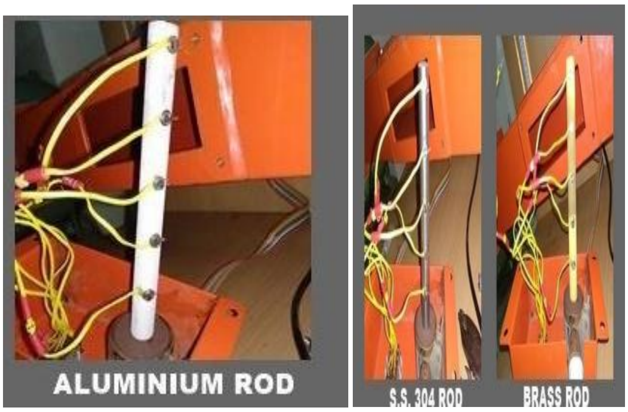

Fig.6. Fin arranged with Thermocouples

Specifications

Duct size= 150 mm x100 mm x 700 mm

Diameter of Fin= 13.4mm

Diameter of Orifice= 14 mm

Diameter of delivery pipe ID= 28 mm

Coefficient of discharge C_d= 0.64

Number of Thermocouples on Fin= 5
Air Blower: 0.24 HP, 2800 rpm, 180 watts

Range of Temperature Indicator-: 0-200

Range of l Voltmeter: 0-200 V AC

Range of Ammeter: 0-2 Amp, AC

Dimmer stat: Open type- 0-2 Amp, 0-230 V, wire wound
Heater: size= 38 mm Dia x 50 mm length, Capacity-250 Watt.

V. RESULTS ANALYSIS

Experiment is conducted on Stainless steel 304 without coating and coated with Brass and Aluminium material with 250 microns using twin wire arc method at different heat inputs between 50 to 75 watts using Pin Fin apparatus shown in fig.7 and required parameters are tabulated at steady state conditions in the following observation tables to calculate heat flow characteristics such as Reynolds number, Nusselt number, Thermal conductivity and fin efficiency.

Table-I. Stainless Steel without coating

S No.	V	I	P	H	T_1	T_2	T_3	T_4	T_5	T_a
	Volts	Amps	Watt s	mm	0_C	0_C	0_C	0_C	0_C	0_C
1	106.1	0.56	60	50	43	37	35	34	34	31
2	107.8	0.57	65	50	44	38	36	35	35	31
3	108.7	0.58	70	50	45	38	36	35	35	31
4	120	0.63	75	50	45	38	38	36	36	31

Table.-II: Stainless Steel Coated with Bras

S No.	V	I	P	H	T_1	T_2	T_3	T_4	T_5	T_a
	Volts	Amps	Watts	mm	0_C	0_C	0_C	0_C	0_C	0_C
1	107.8	0.57	61	50	43	37	35	34	34	28
2	110.7	0.58	65	50	45	38	36	35	35	29
3	114.4	0.61	70	50	46	39	36	35	35	29
4	117.2	0.63	73	50	48	40	38	37	36	31

Table-III: Stainless Steel Coated with Aluminium

S No.	V	I	P	H	T_1	T_2	T_3	T_4	T_5	T_a
	Volts	Amps	Watts	mm	0_C	0_C	0_C	0_C	0_C	0_C
1	97.7	0.52	50.8	50	45	41	39	39	38	31
2	107.2	0.57	61.1	50	48	42	40	40	39	32
3	112	0.59	66.08	50	50	43	40	40	39	33
4	119	0.63	74.97	50	51	44	41	40	40	33

The following formulae are used to calculate the heat flow characteristics of coated fin under different temperatures.

1) Average Surface Temperature (T) = $(T_1+T_2+T_3+T_4+T_5) / 5$
2) Duct Temperature $(T_t)=T_6$
3) Mean film temperature $(T_{mf}) = T_m + T_t$
(Properties of air at T_{mf} obtained from data book)
4) Velocity of air at orifice $V_0 = C_d\,(2gh\rho_w / \rho_a)^{1/2}$ m/s
Where, g= acceleration due to gravity = 9.81 m

h= Manometer reading

ρ_w= density of water = 1000 kg/ m^3

ρ_a= density of air kg/m^3

C_d = 0.64 orifice meter coefficient

5) Velocity of air in duct $_a$ = [V_0 x π/4 x d_0^2]/$(wxb)^2$ / w x b] m/sec

Where, d_0 = diameter of the orifice in m

w = width of duct in m

b = breadth of duct in m

6) Reynold's Number(Re)= (VD)/ υ

Where, D =Diameter of the Pin Fin

V = Velocity of duct in air

υ = kinematic viscosity of the air at T $_{mf}$

7) Nusselt Number: Nu= 0.683 $(Re)^{0.466}$ (Pr $)^{0.333}$ 40<Re<4000

8) Heat Transfer Coefficient (h) = Nu x K $_{air}$/ D

Where,

K $_{air}$ =Thermal conductivity of air at T $_{mf}$

Fin parameter M = $(hp /KA)^{1/2}$

P = perimeter of the pin = πD m

A = Cross sectional area of Fin m^2

K = Thermal conductivity of Fin material

9) Heat Transfer Rate from work piece to air

$$(Q) = (h\ p\ KA)^{1/2}\ (T_A\text{-}T_B)\ \mathrm{Tanh}(mL)\quad W$$

10) Power input= (Convection) + (Heat transfer in fin) + (Heat through the duct)

$$\text{Power input} = h\ A\ \Delta T + KA\ (dT/dx) + K_1A_1\ (dT/dx)$$

Table. IV. Result parameters of All Specimen

Material	Reynolds Number	Nusselt Number	Thermal Conductivity	Fin Efficiency
Stain less Steel	164.87	6.55	28	50.4
S.S with Brass	165.1	6.6	75.4	76.5
S.S with Al	176.19	6.69	166.75	87.5

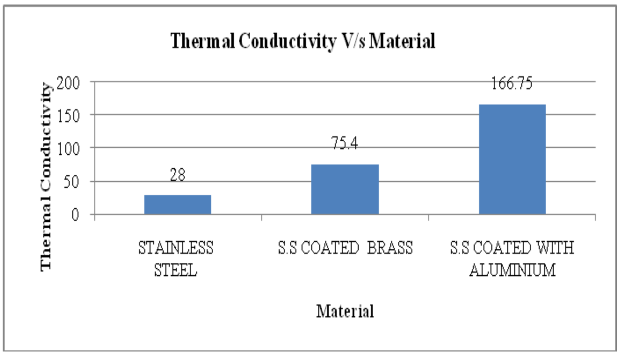

Fig.7: Thermal Conductivity Vs Coating Material

From above graph, it is observed that thermal conductivity of stainless steel (S.S) without coating is 28 W/m °c, S.S coated with Brass is 75.4 W/m °c and coated with Aluminium is 166.75 W/m °c. So, S.S coated with Aluminium has more thermal conductivity compared to S.S coated with Brass and without coating. Thermal conductivity of S.S coated with Aluminium is increased by 6 times compared to without coating and 2.2 times compared with coated with brass.

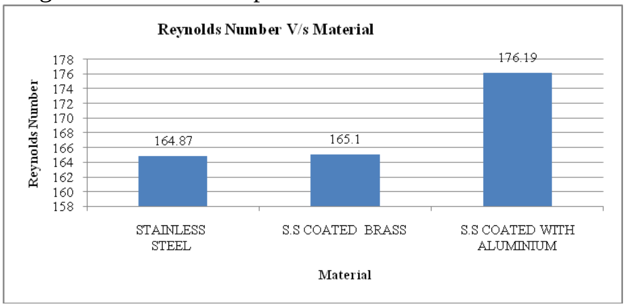

Fig.8. Reynolds Number Vs Coating Material

Above graph is drawn for Reynolds number for different coated stainless steel. It clearly shows that there is an increase in Reynolds number from stainless steel to S.S coated with Aluminium. From this it is observed that increase in percentage of Reynolds number in case of S.S coated with Aluminium by 6.71% compared to coated with brass and 6.86% compared to without coating.

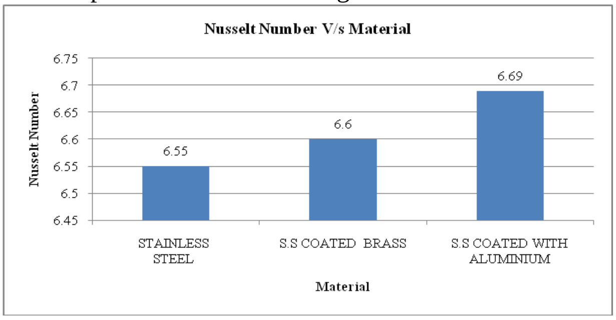

Fig.9. Nusselt Number Vs Coating Material

From the above graph it is observed that stainless steel without coating has the low Nusselt number followed by coated with Brass and Aluminium has highest among all the materials. This shows that the Nusselt number of S.S without coating is 6.55, coated with Brass is 6.6 and coated with Aluminium is 6.69. From this it is observed that Nusselt number in case of S.S coated with Aluminium is increased by 1.36% compared with coated with brass and 2.1% compared without coating.

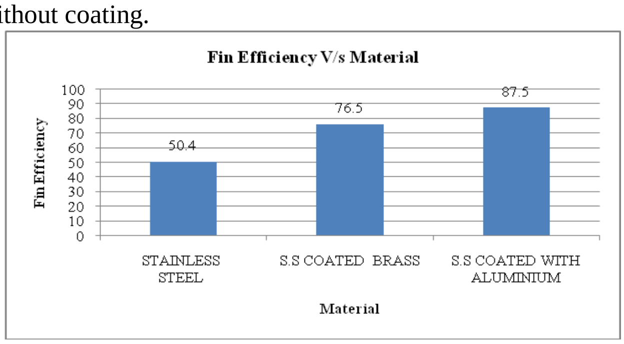

Fig.10. Efficiency Vs Coating Material

From this graph it is observed that fin efficiency of S.S without coating is 50.4 %, coated with Brass is 76.5% and coated with Aluminum is 87.5%. Fin efficiency of S.S coated with Aluminium is more compared to S.S coated with Brass and without coating. The increase in percentage of fin efficiency in case of S.S coated with Aluiminium is 14.3 % compared to coated with brass and 73.6% compared to S.S without coating.

VI. CONCLUSIONS

Based on various observations and obtained results after conducted experiments on S.S with and without coating using pin fin apparatus at different heat inputs, we are concluded with the following statements by comparing substrate coated with different materials.

The performance of fin can be improved by surface coatings instead of single material. The thermal properties of substrate improved by coating with high thermal conductivity of material. The Reynolds number and Nusselt number are calculated and obtained:

(S.S + Aluminium) > (S.S + Brass) > Stainless steel without coating

Thermal conductivity of coated materials is observed as:

S.S coated with Aluminium (166.75), coated with Brass (75.4), without coating (28) W/m K

Efficiency of S.S fin coated with Aluminium is improved by 73.6%, Efficiency of S.S fin coated with Brass is improved by 14.3% compared with Stainless Steel without coating. The heat flow characteristics of fin coated with Brass and Aluminum is more than that of substrate material (stainless steel 304) without coating.

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