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Experimental Investigation of Convective Heat Transfer through Rough and Smooth Surfaced Aluminium 6063 Pin-Fin Apparatus

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Abstract— *In reciprocating engines, transfer of heat is the primary task for increasing the engine efficiency and effectiveness rather than liquid cooling; the air cooling is most preferable for its simplicity. By increasing the contact surface and usage of high value heat transfer coefficient metals air cooling is highly possible compared to other metals aluminium fin heat exchanger provides better corrosion resistance due to a better galvanic balance of the materials and more cost effective. In this project, it is to enhance the cooling effect of aluminium 6063 by some design changes. Usually smooth surfaced aluminium 6063 alloy is used as heat exchangers here same aluminium 6063 alloy with rough surface fin has been tested. The flow can be promoted from laminar to turbulent which creates the high contact between air and the metal surface this is one of the heat transfer enhancement method used traditionally and not in practical applications. In this paper comparison has been made and applications had stated.*

Keywords— *Rough surfaced pin-fin, Aluminium 6063, Convective heat transfer.*

I. INTRODUCTION

Fins are surface that extend from an object to increase the rate of heat transfer to or from environment by increasing convection. In engine for better heat transfer even in mode of convection, heat is exchanged efficiently. Most modern internal combustion engine are cooled by a closed circuit carrying liquid coolant through channel in the engine block and cylinder. Head where the coolant absorbs heat to the heat exchanger or radiator Where the coolant release heat into the air thus will not ultimately cooled By the liquid because of the liquid – coolant circuit they are known as water –Cooled .

The successful working of thermal equipments depends on various factors, majorly cooling or heating of its certain parts. Fins are usually analyzed by assuming uniform heat transfer coefficient model on its surface. However, studies by various investigators revealed that it is not constant, but varies along the fin length. It is mainly because of non uniform resistance experienced by the fluid flow in the inter fin region. Increasing the heat transfer area heat dissipation rate improves, but increase of resistance to fluid flow causing reduction in heat transfer. In order to dissipate the heat of very high heat flux densities, the required heat sink must often be larger than device.

II. HEAT TRANSFER

In the thermodynamics, heat transfer is the transfer of thermal energy from a heated body to a colder body. When an object or fluid, is at a different temperature than its surroundings or another body, transfer of thermal energy is also known as heat transfer. Exchange of heat occurs till body and the surroundings reach at the same temperature. According to the second law of thermodynamics, 'Where there is a temperature difference between objects in proximity, heat transfer between them can never be stopped' it can only be slowed down.

2.1 Conduction

Heat conduction is considered to be caused through molecular oscillations in solids and elastic impact in liquids and gases. The basic law of heat conduction in the steady state and in its most simple form is

$$q = kA\Delta t / L \qquad (2.1)$$

Where

q- Rate of heat transfer, k- Thermal Conductivity of the material, A– cross sectional area perpendicular to the direction of heat flow, L – length of heat flow path, Δt- temperature difference causing the heat flow

Heat flow is analogous to Ohm's Law. Rewriting the Equation (2.1), we get

$$q=\Delta t/L/kA \qquad (2.2)$$

It can be seen that q is analogous to I, Δt to E, and L/kA to R. The thermal conductivity k is the quantity of heat which will flow across unit area in unit time when the length of heat path is unity and the temperature gradient across this path is unity. Its numerical value depends on the material being high for metals and low for insulators. For example, the thermal conductivity of copper is over 300 times that of glass.

2.2 Convection

The process of heat transfer from the surface of a solid to moving masses of fluid, either gaseous or liquid is known as convection. This mode of heat transfer is brought about mainly through circulation of the fluid. For example the surface of a warm object situated in still air at a lower temperature heats the air adjacent to the surface. The heated air becomes less dense as its temperature increases and induces convection currents. When the circulation is caused only by differences in density, the process is called natural or free convection. Circulation may be forced mechanically by blowers, pumps etc... In which case the heat transfer is called forced convection.

The basic equation for convection is:

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$q=hcA\Delta t$ (2.3)

Where

q- the heat transfer rate, h_{c-} a convection co-efficient of heat transfer, A – the Surface area, Δt- temperature difference between the surface and the main fluid stream

The value of h_c is influenced by many factors including not only the properties of the fluid such as viscosity, density etc... But the flow conditions and surface characteristics as well the resistance concept may also be applied to convection in which case the term $1/Ah_c$ is the thermal resistance.

2.3 Evaporation and condensation

Evaporation and condensation are characterized by a change of state involving a liquid evaporating to the vapour state and a vapour condensing to the liquid state respectively. The basic equation for these processes is the same as that for convection.

Evaporation is a general term used whenever molecules leave the surface liquid changing to the vapour state. The amount of heat necessary to evaporate a unit mass of a liquid to a vapour is called the heat of vaporization. The process may occur with or without boiling. For example water is greater than the partial pressure of water vapour in the air. Evaporation can be speeded up by heating the water. Evaporation usually involves high rates of heat transfer and the co efficient may be as much as 200 times that for air in forced convection.

2.4 Radiation

Bodies under thermal agitation induced by temperature emit thermal radiation in the form of electromagnetic waves ranging in wave length from the long infrared to the short ultra violet. Radiation emitted from a body can travel undiminished through a vacuum or through gases with relatively little absorption. When radiation is intercepted by a second body, part may be absorbed as thermal energy, part may be reflected from the surface, and part may be transmitted still in electromagnetic wave form through the body as in the case of glass.

The basic equation for the radiation from a black body is

$qb= \sigma AT^4$ (2.4)

Where

q- rate of energy emitted by a black body

σ - Stephan –Boltzmann constant

A –surface area

T – Absolute Temperature

For non-Black bodies

$qr=Fe.Fa.\sigma A(T1^4- T2^4)$ (2.5)

Where

F_e is an emissivity factor to allow for departure from body conditions, F_a – is a configuration factor based on the geometry of the system, T_1 and T_2 are the temperature of the hot and cold bodies respectively.

2.5 Aluminum 6063

Aluminium alloy 6063 is a medium strength alloy commonly referred to as an architectural alloy. It is normally used in intricate extrusions. It has a good surface finish, high corrosion resistance is readily suited to welding and can be easily anodised. Most commonly available as T6 temper, in the T4 condition it has good formability. Applications: 6063 is typically used in Architectural applications, Extrusions, Window frames, Doors, Shop fittings, Irrigation tubing. In balustrading the rails and posts are normally in the T6 temper and formed elbows and bends are T4. T4 temper 6063 aluminium is also finding applications in hydro formed tube for chassis.

Aluminium Alloy 6063A: Aluminium alloy 6063A is a variation of 6063 with greater strength but retains the same good surface finish qualities and affinity for anodising. Applications 6063A is used in the same applications as 6063. It is also used in: Road transport, Rail transport, Extreme sports equipment.

2.6 Applications

Aluminum 6063 can be used in automobile Engines Finned engine surface as shown in Figure 2.2. For the purpose of transferring the heat from cylinder to the atmosphere these finned surface can be used.

Fig. 2.2. Fin Arrangement of IC Engine.

III. LITERATURE REVIEW

Deepak Gupta, et al., [1] conveyed in their paper, the cooling mechanism of the air cooled engine is mostly dependent on the fin design of the cylinder head and block. Cooling fins are used to increase the heat transfer rate of specified surface. Engine life and effectiveness can be improved with effective cooling. The main aim of the project is to study and comparing with100cc Hero Honda Motorcycle fins and analyze the thermal properties by varying geometry, material and thickness. Parametric models of cylinder with fins have been developed to predict the transient thermal behavior. The models are created by varying the geometry like rectangular, circular shaped fins and also by varying thickness of the fins 3mm and 2.5mm.

S D Katkade, et al., [2] suggested in their research work, Various methods are used to increase rate of heat transfer without affecting much the overall performance of the system. These techniques are used in heat exchangers. Heat exchangers are used in various applications in day today life. Some of the applications of heat exchangers are-in process industries, thermal Power plants, air conditioning equipment, refrigerators, radiators for space vehicles, automobiles etc.

The present paper is a review of the various methods used to increase the heat transfer performance by using different types of fins. The performance of different fin types is evaluated at different Reynolds number, fin pitch, number of tube rows etc.

Y. Pratapa Reddy, et al., [3] Design of machine components plays a vital role in the field of Engineering where it includes the shape of component, size, applied loads, position and materials used. Due to the applied loads namely static, thermal and combined loads etc., the component undergoes stresses and deformations which effects the life of component and also the system. These solutions generally require the ordinary or partial differential equations. Because of the complicated geometries, loadings and material properties, the solution can't be obtained easily. So, in F.E.M the complicated shape of the component is split in to small entities called elements. Element characteristics are studied and then all the elements are combined to make a single system of component.

Mahendra Kumar Maisuria [4] has conveyed in his paper, there is always the loss of heat when passed through anybody having a contact with another. The loss may take place due to the heat leakage to the atmosphere or due to the roughness between the two surfaces. This heat loss at the interface is being calculated and the effect of surface roughness and the heat transfer is also being found out. An experiment is carried out to measure heat conductance at the interface of metal plates of known surface finish. A known energy source is applied to one of the plates, induced a measurable temperature difference between the plates.

Luigi Ventola., et al., [5] in their research article titled "Rough surfaces with enhanced heat transfer for electronics cooling by direct metal laser sintering", conveyed that, On rough flat surfaces, they experience a peak of 73% for the convective heat transfer enhancement (63% on average) compared to smooth surfaces. On rough (single) finned surfaces, the best performance is found to be 40% (35% on average) compared to smooth finned surface. In their experiment they had chosen the four Tested samples made of AlSiMg alloy by direct metal laser sintering (DMLS) , sample 1 has the average roughness of Ra = 16 µm, sample 2 has Ra = 24 µm, sample 3 has Ra = 43 µm and sample 4 has finned surface, roughly Ra = 22 µm as average on both sides. Among these four samples of tested samples higher degree of surface roughness sample had the fin effectiveness of 55.3% at the air velocity of 3.3 m/s up to 57.3% at the air velocity of 15.4 m/s, and the average fin effectiveness of 62.7%. But for the sample 1, has only 5.50% of fin effectiveness.

Sathish G. Kandlikar., et al., [6] has conveyed in his research paper, the effect of surface roughness on pressure drop and heat transfer in circular tubes has been extensively done. The roughness was done by sand grain roughness as a major parameter in defining the friction factor at Reynolds number values much below 2300 during the single phase floe in channels with small hydraulic diameters, in his present work detailed study has been undertakes to investigate the roughness effect in small diameter tubes. The roughness of the inside tube surface is changed by etching it with an acid solution. Two tubes of 1.032 mm and 0.62 mm inner diameter are treated with acid solution to provide three different roughness values for each tube.

L Ventola., et al., [7] has conveyed in his paper, investigated the benefits of micro-structured roughness on heat transfer performance of heat sinks, cooled by forced air. Heat sinks in aluminum alloy by direct metal laser sintering (DMLS) manufacturing technique were fabricated; values of the average surface roughness from 1 to 25 microns (standard milling leads to roughness around 1 micron) under turbulent regimes (Reynolds number based on heating edge from 3000 to 17000) have been explored. An enhancement of 50% in thermal performances with regards to standard manufacturing was observed. This may open the way for huge boost in the technology of electronic cooling by DMLS.

Michael R. Ayer., [8] found through their research, A silicon based sand paper was used to polish the test materials. The surface textures of the aluminum samples were measured using an Olympus LEXT 3100 scanning laser microscope. Area-scale analysis was also used to determine at which scale the most heat transfer was observed.

S.S Joshi, et al., [9] has found through their research project, has demonstrates the use of fin analysis as one of the possible ways for determination of thermal conductivity of material. In the experimental set-up, a suitably designed oil reservoir is used as a heat source. An Aluminium rod is used as reference material and the provision is made in the reservoir to attach a test rod of which thermal conductivity is to be determined. A Multiple Digital Temperature indicator with four PT-100 thermocouples is used to measure the temperatures. The geometries of the test and reference rods are mandatory to be exactly same for analysis. A small software package "THERMOSOFT" is developed using Visual Basic 6.0 in which the temperature readings are to been entered manually to get the thermal conductivity of test material.

P. Harish, et al., [10] in their paper stated that the Engine cylinder is one of the major automobile components, which is subjected to high temperature variations and thermal stresses. In order to cool the cylinder, fins are provided on the cylinder to increase the rate of heat transfer. The main aim of the project is to analyze the thermal properties by varying geometry, material (Cu and Al alloy6082), distance between the fins and thickness of cylinder fins. The Fins models are created by varying the geometry circular and also by varying thickness of the fins for both geometries.

From literature review the following points has been observed:

- Rough surface fin apparatus can transfer the heat rapidly
- Rather than plated fin apparatus, pin-fin apparatus enhances the cooling
- By increasing the density of pin-fin can produces better results
- Additional cooling enhancing techniques such as thermal grease and blower fan can be used for improved cooling rates
- Porous pin-fin enhances the cooling rate than the solid pin-fin
- By increasing the surface area of the contact with air can provide improved cooling effect.

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IV. SELECTION OF MATERIAL

Aluminium 6063 has been chosen as a testing specimen for the heat transfer process. Because of the following thermal properties Al-6063 alloy has been preferred.

TABLE 4.1. Chemical Composition of Aluminium 6063.

BS EN 573—3 2009 Alloy 6063	
Element	**% Present**
Magnesium (Mg)	0.45- 0.90
Silicon(Si)	0.20- 0.60
Iron(Fe)	0.0- 0.35
Others(total)	0.0- 0.15
Chromium(Cr)	0.0- 0.10
Copper(Cu)	0.0- 0.10
Titanium(Ti)	0.0- 0.10
Manganese(Mn)	0.0- 0.10
Zinc(Zn)	0.0- 0.10
Other(Each)	0.0- 0.05
Aluminium(Al)	Balance

TABLE 4.2. Generic physical properties of Aluminium 6063.

Property	Value
Density	2.70 g/cm³
Melting Point	655 °C
Thermal Expansion	23.5×10^{-6} /K
Modulus of Elasticity	69.5 GPa
Thermal Conductivity	201 W/m.K
Electrical Resistivity	52 % IACS
Electrical Resistivity	0.033×10^{-6} Ω .m

TABLE 4.3. Mechanical properties of Aluminium 6063.

To BS EN 755-2: 2008 Rod & Bar Up To 150mm Dia. & A/F	
Property	**Value**
Proof Stress	170 Min MPa
Tensile Strength	215 Min MPa
Elongation A50 mm	8 Min %
Hardness Brinell	75 HB
Elongation A	10 Min %

4.1 Fabrication of Testing Specimen

Aluminium 6063 is used as a testing specimen: The following three types of surface roughness in the material are made and that is to be tested through the forced and free convective heat transfer pin—fin apparatus.

1. Smooth surfaced
2. Light rough surfaced
3. Rough surfaced

Specimen Dimensions:

- Length: 150 mm
- Effective Length: 102 mm
- Length occupied by Heater: 38 mm
- Diameter: 12 mm
- Distance of T1 from heater : 10 mm
- Distance of T2 from heater: 33 mm
- Distance of T3 from heater: 56 mm
- Distance of T4 from heater: 79 mm
- Distance of T5 from heater: 102 mm

Fig. 4.1. Sample Specimen.

V. EXPERIMENTAL SETUP FOR TESTING

Our experimental testing is carried out in a pin fin apparatus, To calculate the value of heat transfer coefficient form the fin for forced convection Extended surfaces of fins are used to increase the heat transfer rate from a surface to a fluid wherever it is not possible to increase the value of the surface heat transfer coefficient or the temperature difference between the surface and the fluid. The use of this is variety of shapes. Circumferential fins around the cylinder of a motor cycle engine and fins attached to condenser tubes of a refrigerator are a few familiar examples.

It is obvious that a fin surface sticks out from the primary heat transfer surface. The temperature difference with surrounding fluid will steadily diminish as one moves out along the fin. The design of the fins therefore required knowledge of the temperature distribution in the fin. The main objective of this experimental set up is to study temperature distribution in a simple pin fin.

The other end of the duct is connected to the suction side of a blower and the air flows past the fin perpendicular to the axis. One end of the fin projects outside the duct and is heated by a heater. Temperature at five points along the length of the fin. The air flow rate is measured by an orifice meter fitted on the delivery side of the blower. Schematic diagram of the set up is as shown in Figure 5.1. While the details of the pin fin with the effective length alone shown here.

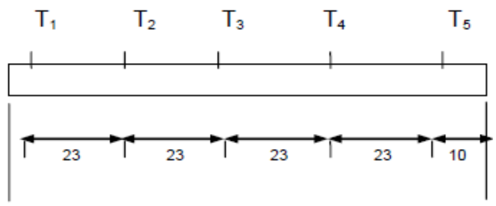

Fig. 5.1. Schematic diagram of Pin-Fin.

Fig. 5.2. Experimental Setup.

5.1 Forced Convection Experimental Procedure

To study the temperature distribution along the length of pin fin forced convection

- Start heating the fin by switching ON the heater and adjust dimmerstat voltage equal to 100 volts, note down the current value.
- Start the blower and adjust the difference of level in the manometer with the help of gate valve.
- Allowed to reach steady state condition of the temperature reading.
- Note down the thermocouple readings (1) to (5).
- Then increase the voltage value and note down the corresponding current value for consecutive 4 readings.
- When the steady state is reached, record the final reading (1) to (5) and also record the ambient temperature reading (6).
- Repeat the same experiment with for the all three fabricated specimen, Smooth surfaced, light rough surfaced and rough surfaced.

5.2 Free Convection Experimental procedure

To study the temperature distribution along the length of pin fin free convection

- Start heating the fin by switching ON the heater and adjust dimmerstat voltage equal to 100 volts, note down the current value.
- Allowed to reach steady state condition of the temperature reading.
- Note down the thermocouple readings (1) to (5).
- Then increase the voltage value and note down the corresponding current value for consecutive 4 readings.
- When the steady state is reached, record the final reading (1) to (5) and also record the ambient temperature reading (6).
- Repeat the same experiment with for the all three fabricated specimen, Smooth surfaced, light rough surfaced and rough surfaced.

5.3 Readings

Specimen 1: Smooth Material

TABLE 5.1. Specimen –1 Free Convection readings.

Input		Fin temperatures °C					Duct fluid temperature °C
V	I	T1	T2	T3	T4	T5	T6
100	0.50	33	32	32	31	31	29
110	0.55	40	37	35	33	31	29
120	0.58	48	45	44	40	41	29
130	0.60	53	47	46	44	43	30

TABLE 5.2. Specimen –1 Forced Convection readings.

Input		Manometer difference	Fin temperatures °C					Duct fluid temperature °C
V	I	H (mm of Hg)	T1	T2	T3	T4	T5	T6
100	0.50	20	58	51	46	41	33	30
110	0.55	20	62	55	50	44	38	30
120	0.58	20	65	58	52	47	41	30
130	0.60	20	70	63	55	53	52	30

Specimen 2: Light rough surfaced Material

TABLE 5.3. Specimen –2 Free Convection readings.

Input		Fin temperatures °C					Duct fluid temperature °C
V	I	T1	T2	T3	T4	T5	T6
100	0.50	34	33	33	32	32	29
110	0.55	42	39	36	34	33	29
120	0.58	51	48	45	43	42	29
130	0.60	56	50	47	45	44	30

TABLE 5.4. Specimen –2 Forced Convection readings.

Input		Manometer difference	Fin temperatures °C					Duct fluid temperature °C
V	I	H (mm of Hg)	T1	T2	T3	T4	T5	T6
100	0.50	20	60	56	53	49	44	30
110	0.55	20	66	61	57	51	46	30
120	0.58	20	70	66	59	54	49	30
130	0.60	20	74	69	63	59	53	30

Specimen 3: Rough surface Material

TABLE 5.5. Specimen –3 Free Convection readings.

Input		Fin temperatures °C					Duct fluid temperature °C
V	I	T1	T2	T3	T4	T5	T6
100	0.50	35	34	33	32	32	29
110	0.55	43	40	37	35	34	29
120	0.58	55	51	48	45	43	29
130	0.60	59	57	54	51	48	30

TABLE 5.6. Specimen –3 Forced Convection readings.

Input		Manometer difference	Fin temperatures °C					Duct fluid temperature °C
V	I	H (mm of Hg)	T1	T2	T3	T4	T5	T6
100	0.50	20	63	61	58	56	53	30
110	0.55	20	66	63	60	58	55	30
120	0.58	20	71	68	65	62	58	30
130	0.60	20	76	71	68	65	61	30

5.4 Model Calculation

Average fin temperature

$T_m= (T_1+T_2+T_3+T_4+T_5)/5$

$T_m=(33+32+32+31+31)/5$

$\mathbf{T_m=31.8^0C}$

$T_f=T_6=29^0C$

$\Delta T=T_m-T_f$

$\Delta T=31.8-29$

$\mathbf{\Delta T=2.8^0C}$

Mean Film Temperature, $T_{mf}=(T_m+ T_f)/2$

$T_{mf}=(31.8+29)/2$ $\mathbf{T_{mf}=30.4^0C}$

From the HMT databook,

$\upsilon=16.00\times10^{-6}m^2/s$, Pr=0.701

$k_{air}=0.02675$ W/mK

$Gr= (g\beta D^3\Delta T)/\upsilon^2$

$Gr=(9.81*3.29*10^{-3}*(12*10^{-3})^3*2.8)/(16*10^{-6})^2$

Gr=609.99

$Nu=0.85(Gr.Pr)^{0.188}$

$Nu=0.85(609.99*0.701)^{0.188}$

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Nu=2.65, Nu=hD/k_{air}

$2.65=h*(12*10^{-3})/0.02675$

$h=5.95\ W/m^2K$

$Q_{fin1} = \sqrt{(hPK_fA)}(T_1-T_f)$

$Q_{fin1} = \sqrt{(5.95*0.037*144*1.13*10^{-4})}(33-29)$

$Q_{fin1}=0.23\ W$

VI. Results and Discussions

For the Aluminium alloy 6063, various grading of surface roughness has been formed and tested through the pin-fin heat transfer apparatus.

Through the observations we found that the rough surfaced pin-fin material provides more heat transfer coefficient than the smooth surfaced material, and rate of heat transfer from the fin is also more for the rough surfaced material. For the automobile applications in IC engine these kind of rough surfaced part can provide the more heat transfer co efficient and more heat transfer rate. Comparative analysis is follows:

6.1 Heat Transfer Coefficient for Free Convection (h)

TABLE 6.1. Heat transfer coefficient for Free convection (h).

S.no	Specimen	Value (W/m^{2}K)
1	Specimen -1(Smooth Surfaced)	7.1427
2	Specimen -2 (Light rough surfaced)	7.5400
3	Specimen -3 (Rough Surfaced)	7.7625

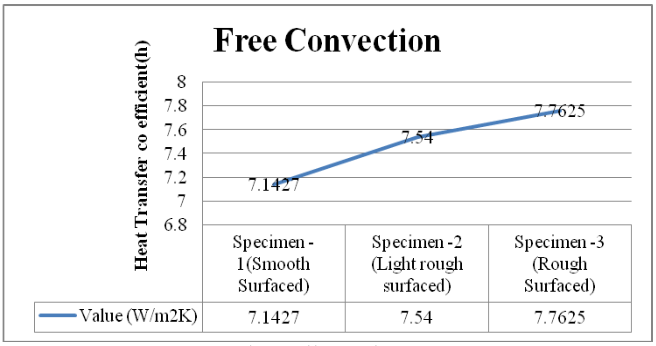

Fig. 6.1. Heat transfer coefficient for Free convection (h).

6.2 Heat Transfer Coefficient for Forced Convection (h)

TABLE 6.2. Heat transfer coefficient for forced convection (h).

S.no	Specimen	Value (W/m^{2}K)
1	Specimen -1(Smooth Surfaced)	100.12
2	Specimen -2 (Light rough surfaced)	100.38
3	Specimen -3 (Rough Surfaced)	100.77

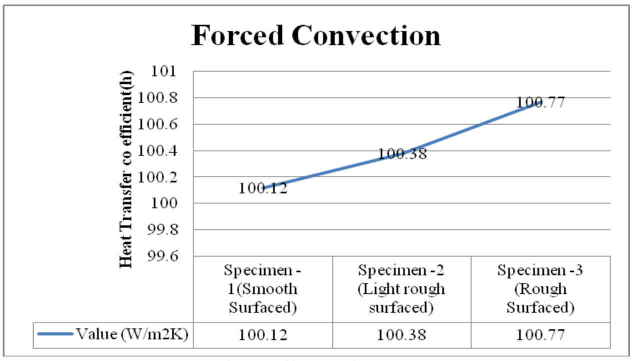

Fig. 6.2. Heat transfer coefficient for Forced convection (h).

6.3 Rate of Heat Transfer from the Fin (Q_{fin}) for Free Convection

TABLE 6.3. Rate of heat transfer from the fin (Q_{fin}) for Free convection.

S.no	Specimen	Value (W)
1	Specimen -1(Smooth Surfaced)	0.8630
2	Specimen -2 (Light rough surfaced)	1.1520
3	Specimen -3 (Rough Surfaced)	1.3302

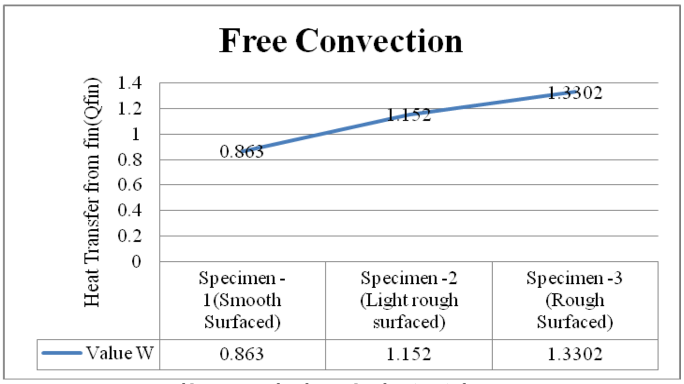

Fig. 6.3. Rate of heat transfer from the fin (Q_{fin}) for Free convection.

6.4 Rate of Heat Transfer from the Fin (Q_{fin}) for Forced Convection

TABLE 6.4. Rate of heat transfer from the fin (Q_{fin}) for Forced convection.

S.no	Specimen	Value (W)
1	Specimen -1(Smooth Surfaced)	8.3843
2	Specimen -2 (Light rough surfaced)	9.2976
3	Specimen -3 (Rough Surfaced)	9.6641

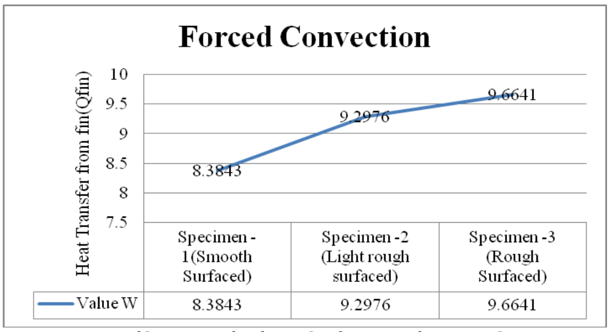

Fig. 6.4. Rate of heat transfer from the fin (Q_{fin}) for Forced convection.

VII. Conclusion

In this Paper, An aluminium 6063 rod for three various surface roughness has been fabricated and tested for the heat transfer coefficient (h) and for heat transfer rate (Q_{fin}). Comparing the smooth surfaced rod, rough surfaced aluminium 6063 rod is having the high heat transfer co efficient and Heat transfer rate. Also compared with the free and forced convective heat transfer process, forced convective can replace more amount of heat from the pin-fin material. This research work brings the output of good results in rough surfaced fin material that can be used for the practical applications such as IC Engines in automobile industry.

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