Experimental Evaluation of Natural Convection Heat Transfer for Rough Surface

Gajanan Z. Jadhav

Department of Mechanical *Engineering*
D N Patel COE Shahada, Nanadurbar, Maharashtra, India.

S. U. Patel
Department of Mechanical Engineering
D N Patel COE Shahada, Nanadurbar, Maharashtra, India.

V. A. Rane
Department of Mechanical Engineering
GHRIEM's Jalgaon, Maharashtra, India.

Abstract- The objective of the present work is experimental evaluation of natural convection heat transfer from rough surfaces by designing and fabricating experimental set up. In this case upper surface is smooth and lower surface is made rough by applying adhesive and sprinkling sand. The plate inclinations were chosen to be 0^0, 30^0, 45^0, 60^0 and measured with respect to horizontal position. Experiments were performed for power inputs range 212-220V and at different inclination; the results were comparison and analysis for rough surfaces and find out the maximum convection heat transfer coefficient as well as correlation for rough surface.

Keywords – Free convection, rough flat plate, laminar flow, heat transfer coefficient.

I. INTRODUCTION

1.1 MODES OF HEAT TRANSFER

1) Conduction:- is the transfer of energy through substances from particle to particle. It is the transfer and distribution of heat energy from atom to atom within a substance. For example, a spoon in a cup of hot coffee becomes warmer because the heat from the coffee is conducted along the spoon.
2) Convection:- Convection is the transfer of heat energy in a gas or liquid by movement of convection currents. The heat moves with the fluid.
3) Radiation:- Electromagnetic waves that directly transport energy through space. Sunlight is a form of radiation that is radiated through space to our planet without the aid of fluids or solids.

1.2 HEAT TRANSFER BY CONVECTION

There are certain situations in which the fluid motion is produced due to change in density resulting from temperature gradients, which is the heat transfer mechanism called as free or natural convection. Natural convection is the principal mode of heat transfer from pipes, refrigerating coils, hot radiators etc. The movement of fluid in free convection is due to the fact that the fluid particles in the immediate vicinity of the hot object become warmer than the surrounding fluid resulting in a local change of density. The warmer fluid would be replaced by the colder fluid creating convection currents. These currents originate when a body force (gravitational, centrifugal, electrostatic etc.) acts on a fluid in which there are density gradients. The force which induces these convection currents is called a buoyancy force which is due to the presence of a density gradient within the fluid and a body force. Grashoff number (Gr) plays a very important role in natural convection.
Convection is the transfer of heat energy through a material by the bodily movement of particles and will occur in fluids (liquids and gases).Convection arises when a fluid is warmed, and thus expanded. The expanded fluid is less dense and therefore rises and is replaced by colder fluid, which then undergoes the same process. This is called convection current.

Convection can be natural or forced. Natural convection is when the fluid movement is caused by the fluid itself, whilst forced convection uses external means (such as a fan) to drive the fluid movement.
The rate of heat transfer due to convection is given by; $Q = h A(TS - T\alpha)$
Where;
h is the convective heat transfer coefficient, in W/m^2K;
A is the surface area, in m^2;
TS is the surface temperature, in K;
Tα is the fluid temperature, in K.
To lower the heat flow due to convective heat transfer you can reduce the area in contact with the fluid, or decrease the convective heat transfer coefficient. Heat transfer is the area that deals with the mechanism responsible for transferring energy from one location to another when a temperature difference exists. Natural convection is one of the most economical and practical methods of cooling and heating. Natural convection is caused by temperature or concentration induced density gradient within the fluid. Natural convection flow occurs because of influence of gravity forces on fluids in which density gradients have been thermally established.
In the study of heat transfer, both equilibrium and non-equilibrium processes are encountered. The science of heat transfer allows us to determine the time rate of energy transfer caused by the more practical non-equilibrium processes.
With the growing sophistication in technology and with the increasing concern with energy and the environment, the study of heat transfer has, over the past several years, been related to a very wide variety of problems, each with its own demands of precision and elaboration in the understanding of the particular processes of interest. Areas of study range from Atmospheric, geophysical and environmental problems to those in heat rejection, space research and manufacturing systems.

1.3 OBJECTIVE

Experiments were performed for various power inputs and inclination; the results were comparison and analysis for rough surfaces and find out the maximum convection heat transfer coefficient and also finding the correlation for Nusset No. and Raileigh No.

II. EXPERIMENTAL SET UP AND EXPERIMENTATION

2.1. SPECIFICATION OF EXPERIMENTAL SET UP

Sr. No	**Material**	**Quantity**
1	Mild Steel plates(300mm x300mm, 5mm thickness)	2
2	Mica sheet(295mm x 295mm, 1mm thickness)	2
3	Nichrome wire	400 gm
4	Ammeter (0-5A)	1
5	Dimmer stat(0-260V)	1
6	Copper Tube	4.5 ft
7	Thermistors (K type)	7
8	Narmada Sand	1 kg
9	Carbon Insulation	1 Kg

Table2.1: Specification of Experimental set up

2.2. DESCRIPTION OF EXPERIMENTAL SET UP

To study the free convection from inclined rough surfaces, an experimental set up designed and fabricated which is shown in the image 2.1. It consist of two steel plate held with adjustable gap between them. They are embedded with electric heater and designed to produce uniform temperature on it's surface.

Thermistors are mounted on the lower and upper plates to measure temperatures at different locations. Thermistors were soldered on the plate with tip of 0.5mm in order to provide good thermal contact between steel plates.

A copper tube is fixed around the edges of plate through which water is circulated. Copper tube is insulated with carbon to reduce heat losses. The entire assembly is bolted with nuts and mounted on the table.

2.3WORKING OF EXPERIMENTAL SET UP

The heating element is heated by giving power supply through the dimmer stat. The plate is made adjustable using a screw by the help of which their respective position can be altered. The plate was fixed 25cm above the base for all inclinations.

When the power is supplied through the dimmer stat to the heating element, the electrical energy supplied to the heating element was converted to thermal energy and large portion of this thermal energy conducted through both plates and lost as convection and radiation from the plates. After one hour to one and half hour a stage is reached when there is no further deflection shown by temperature indicating device, this stage is called as steady state.

At the steady state the temperature of ambient (T1)upper plate (i.e., T2 anhT3) and lower plates (ie. T4, T5 and T6) are recorded. After this, again the power supply increased by increasing the current and the same procedure is repeated.

Image 2.1: Experimental Setup

2.4 ASSUMPTIONS

- Since the heater is identical, heat transfer for upper and lower plate is same in case of smooth surfaces.
- Consider losses i.e. heat carried away by water (QW) and heat lost by radiation(Qrad)

i) Amount of Heat carried away by water is $Qw=(\rho v/t).CP\ .\Delta T$ (W)

Where ρ =density of the water(1000 kg/m^3)

V = volume of the water (1 lt =10^{-3} m^3)

t=time taken to fill the 1 lt of volume

Cp = specific heat of water (4180 J/kg-K)

ii) Amount of heat lost by radiation is $Qrad= \varepsilon.\sigma\ A(TS^4-T\alpha^4)$ (W)

Where ε = emissivity of the surface

for steel (0.8), sand(0.75)

σ = boltzman's constant (5.67×10^{-8})

A = area of the plate, m^2

TS =average surface temperature, K

$T\alpha$ = ambient temperature,K

2.5 EXPERIMENTAL PROCEDURE

The following procedure was adopted while carrying experimental test

- Set the plate inclination by using Bevel protractor.
- Check the all thermocouples for consistency.
- Apply electric voltage through dimmer stat.
- Measure the power supplied and controls it until the steady state is reached.
- Circulate the water through copper tube, measure the flow rate, and calculate rise in temperature of water.
- Wait until the steady state is reached.
- Note down all the temperatures of upper and lower plates.
- Calculate heat carried away by water and radiation losses for every inclination.
- Change the inclination and repeat the procedure as mentioned above.

III. RESULTS AND DISCUSSIONS

From above procedure we took readings for inclination 00, 300, 450, 600,. From this data we calculate heat transfer cosfficient and Nusset No.
In this , results of experiments are shown in terms of heat transfer coefficient, Nusselt number, Rayleigh number for smooth and rough surfaces from lower plate.

The effect of roughness and inclination on natural convection heat transfer from lower plate was evaluated for 0^0, 30^0,45^0 and 60^0 with respect to horizontal. The experiment was performed in air. In all cases, the heated plate was maintained constant temperature.

Inclination	**Rough surface**	
	Power input(W)	**h(W/m^{2}K)**
0	224	11.57
30	219.5	12.44
45	222.7	12.4
60	221	11.59

Table3.1 Variation of 'h' for different inclinations and power input

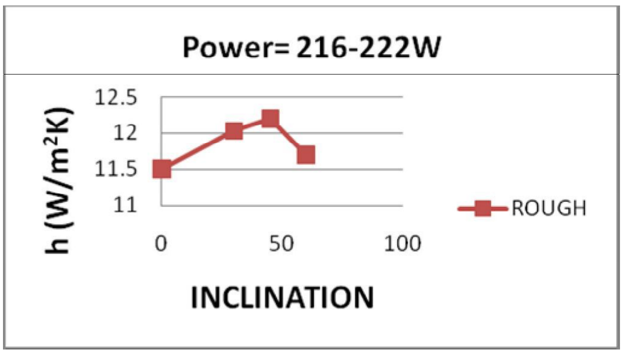

Fig.3.1: Variation of heat transafer coefficent w.r.t. inclination

Heat transfer coefficient (h) depends on ambient temperature, average surface temperature and area of the plate. From the results the value of the heat transfer coefficient slightly increased with increasing the power input for all inclinations.

For same power input (214-227W), the heat transfer coefficient (h) for smooth surfaces slightly increased till 30^0 and went on decreasing. It reached minimum value at 45^0 and started increasing from there on. For rough surfaces, the values trend was also equal or sometimes greater than smooth surfaces.

Dimensionless Nusselt number depends on the heat transfer coefficient, properties of air and characteristic length. For same power input the values of Nu slightly higher for rough surfaces.

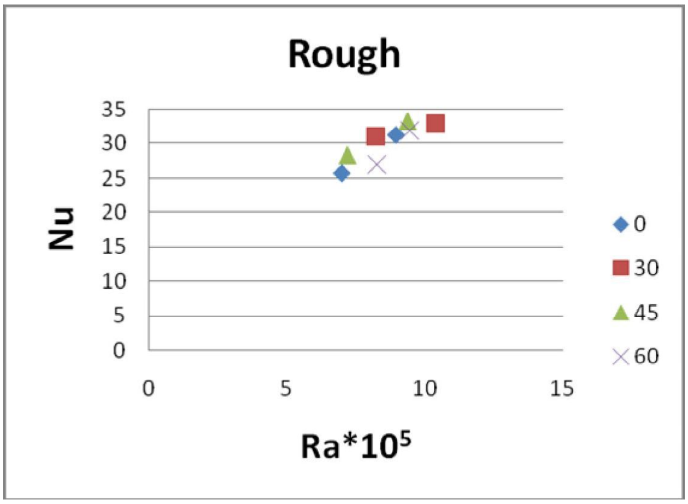

Fig 3.3: Variations of Nu and Ra Number for rough surfaces

In case of smooth and rough surfaces the Ra value lies between $6.3 \times 10^5 \leq Ra \leq 9.0 \times 10^5$ for all inclinations when power input164-170W.
In case of smooth and rough surfaces the Ra value lies between $8.1 \times 10^5 \leq Ra \leq 1.1 \times 10^6$ for all inclinations when power input 214-227W.

IV CONCLUSION

The effects of inclination and roughness on natural convection heat transfer from smooth and rough surfaces were investigated for 0^0, 30^0, 45^0 and 60^0 with respect to horizontal. In all cases the heated plate maintained atconstant temperature.
Heat transfer coefficient (h) depends on ambient temperature, average surface temperature and surface area. From the results the value of the 'h' slightly increased with increasing power input for all inclinations. In case of smooth surfaces, for same power input, the value of the heat transfer coefficient slightly increases with increasing inclination and the minimum value at 45^0 from horizontal and the values of heat transfer coefficient for rough surfaces are slightly increased at 45^0,60^0 and sometimes equal to the values of smooth surfaces.

The correlations are almost equal for smooth and rough surfaces.

$Nu=0.47Ra^{0.30}$ horizontal

$Nu=0.51Ra^{0.30}$ 30^0 from horizontal

$Nu=0.37Ra^{0.32}$ 45^0 from horizontal

$Nu=0.47Ra^{0.30}$ 60^0 from horizontal, all correlations for $0^0 \leq \theta \leq 60^0$, where Ra number lies between $6.0 \times 10^5 \leq Ra \leq 1.1 \times 10^6$

The above results proved that the Nusselt Number is function of Rayleigh Number.

REFERENCES

[1] Fundamentals of Heat and Mass Transfer ,4th edition by Frank P.Incropera, David P.Devitt

[2] Y.Shen and P. Tong:- Turbulent Convection over Rough Surfaces, *Department of Physics, The Chinese University of Hong Kong, Shatin, New Territories, HongKong* Vol 76, Physical Review Letters (1998).

[3] Y.B.Du &P Hong, "Enhanced heat transport in turbulent convection over a rough surface, PHYSICAL REVIEW LETTERS, Vol 81,Aug1998

[4] N.Onur and M.K.Akta**:-** An Experimental Study On The Effect Of Opposin Wall On Natural convection along Inclined Hot Plate Facing downward, ***Int.Comm. Heat Mass Transfer,*** Vol. 25, No. 3, pp. 389-397, 1999

[5] Ademola A.Dare and Moses O.Petrinrin, "Modelling of natural convection along isothermal plates and channels using diffusion velocity method", Maejo International Journal of sci.School,201047-52

[6] A.M. Clausing ,J.J. Berton :- An Experimental Investigation of Natural Convection from an isothermal horizontal plate ***ASME Journal of Heat Transfer***, Nov 1989

[7] 7 C.Limbadri "Experimental Analysis Of Natural Convection Heat Transfer From Smooth And Rough Surfaces",May 2010