Analysis of Different Cross Sectional Temperature Distribution during Forced Convection in Ceramic Pipe

[1]Sudha Thakur, [2]Prof. Saurabh Kumar
[1,2]Department of Mechanical Engineering, Raipur Institute of Technology, Raipur, (C.G.), India

***Abstract* – In this work, the effect of ceramic pipe surface paint color on temperature development of vertical pipe flow is investigated experimentally. The heat transfer through convection mode is extremely important in the field of engineering and industrial appliance. In the present work, forced convection heat transfer through a vertical pipe has been analyzed. For the purpose, an experimental setup has been developed. The phenomenon of forced convection is done by using air blower and heating coil is being used for heating. The air is blown through the pipe and temperature variations along the cross-section of pipe are measured and then analyzed. Also determine the heat transfer coefficient, a relationship between non dimensional numbers will be developed.**

***Index Terms* - Forced convection, heat transfer, non-dimensional number**

I. INTRODUCTION

In many practical situations and equipment, we invariably deal with flow of fluids in tubes e.g. boiler, super heaters and condensers of a power plant, automobile radiators, water and air heaters or coolers etc. the knowledge and evolution of forced convection heat transfer coefficient for fluid flow in tubes is essentially a prerequisite for an optional design of all thermal system. Convection is the transfer of heat within a fluid by mixing of one portion of fluid with the other. Convection is possible only in a fluid medium and is directly linked with the transport of medium itself. In forced convection, fluid motion is principally produced by some superimposed velocity field like a fan, blower or a pump, the energy transport is said due to forced convection. The transfer of heat to or from fluids flowing turbulently inside pipe is one of the most important modes of industrial heat transfer. For a typical heat exchanger, the fluid inside the circular tube is subjected to an abrupt contraction at the entrance which may cause turbulence in the fluid and alter the developing velocity and temperature profile at the entrance of the text section. Ideally both profiles are flat at the entrance. Both velocity and temperature profiles start to develop along the tube simultaneously until they limit at a critical L/D after which they are constant and equal to the fully developed profiles. Convection is the concerted, collective movement of groups or aggregates of molecules within fluids) either through advection or through diffusion or as a combination of both of them. Convection of mass cannot take place in solids, since neither bulk current flows nor significant diffusion can take place in solids. Diffusion of heat can take place in solids, but that is called heat conduction. Convection can be demonstrated by placing a heat source (e.g. a Bunsen burner) at the side of a glass full of a liquid, and observing the changes in temperature in the glass caused by the warmer fluid moving into cooler areas.

In other words we can say, Convection is the mechanism of heat transfer through a fluid in the presence of bulk fluid motion and classified as natural (or free) and forced convection depending on how the fluid motion is initiated. In natural convection, any fluid motion is caused by natural means such as the Buoyancy effect i.e. the rise of warmer fluid and fall the cooler fluid. Whereas in forced convection, the fluid is forced to flow over a surface or in as tube by external means, such as a pump or fan. The phenomena is based on Newton's law of cooling, which states that, heat transfer rate during convection is directly proportional to area exposed to the heat transfer and temperature difference between surface and fluid temperature.

$Q = h*A*(Ts-T\infty)$

Where Q= heat transfer coefficient, A is exposed area,

Ts Surface temperature and

$T\infty$ Atmospheric/fluid temperature.

Heat transfer through conduits

Heating and cooling of fluids flowing inside conduits are among the most important heat transfer processes in engineering. The experimental results obtained in forced- convection heat transfer experiments in short pipes can be correlated by an equation of the form

$$Nu = \phi(\mathrm{Re})\psi(\mathrm{Pr}\ f(x/D_h)$$

Where f(x/Dh) denotes the Functional dependence on the aspect ratio. A ceramic material is an inorganic, non-metallic material and is often crystalline. Traditional ceramics are basically clays. The earliest application was in pottery. Most recently, different types of ceramics used are alumina, silicon carbide etc. Latest advancements are in the bio-ceramics with examples being dental implants and synthetic bones. A comparative analysis of ceramics with other engineering materials is shown in table 1. The purpose of presenting this comparative analysis is to show importance of ceramics among different engineering metals and polymers. This comparison would enable to justify application areas of ceramics.

Table 1 Comparison of ceramics with metals and polymers

Property	Ceramic	Metal	Polymer
Density	Low	High	Lowest
Hardness	Highest	Low	Lowest
Ductility	Low	High	High
Wear resistance	High	Low	Low
Corrosion resistance	High	Low	Low
Thermal conductivity	Mostly low	High	Low
Electrical conductivity	Mostly low	High	Low

II. RESEARCH METHODOLOGY

This is an experiment based project which works on the principle of Newton's law of cooling, which states that heat transfer rate during convection is directly proportional to area exposed to the heat transfer and temperature difference between surface and fluid temperature.

$$Q = hA(T_s - T_\infty)$$

Where Q= heat transfer coefficient, A is exposed area,
T_s Surface temperature and
T_∞ Atmospheric/fluid temperature.

The experimental setup is built with a ceramic pipe. The ceramic has a low heat transfer coefficient. To determine cross sectional temperature variation during forced convection, the setup will consist of few thermocouples of 6mm diameters that will placed one by one in apparatus. The experiment is conducted and observations of the temperature variation in the ceramic pipe have been recorded. The flow rate of air can also be varied using flow control valve. The air flow rate has been measured by using anemometer simultaneously and result will be analyzed with some other methodology to validate our outcomes.

$Re = (UD\rho/\mu)$
$Re > 2300$(For turbulent flow)
For short pipe, the relation for Nusselt No
$Nu_a = Nu\,[1 + (D/x)^{0.7}]$
By Dittus Boelter equation
$Nu = 0.023\, Re^{0.8}.Pr^{0.4}$
Bulk mean temperature:-
$T_m = (T_{mi} + T_{mo})/2$

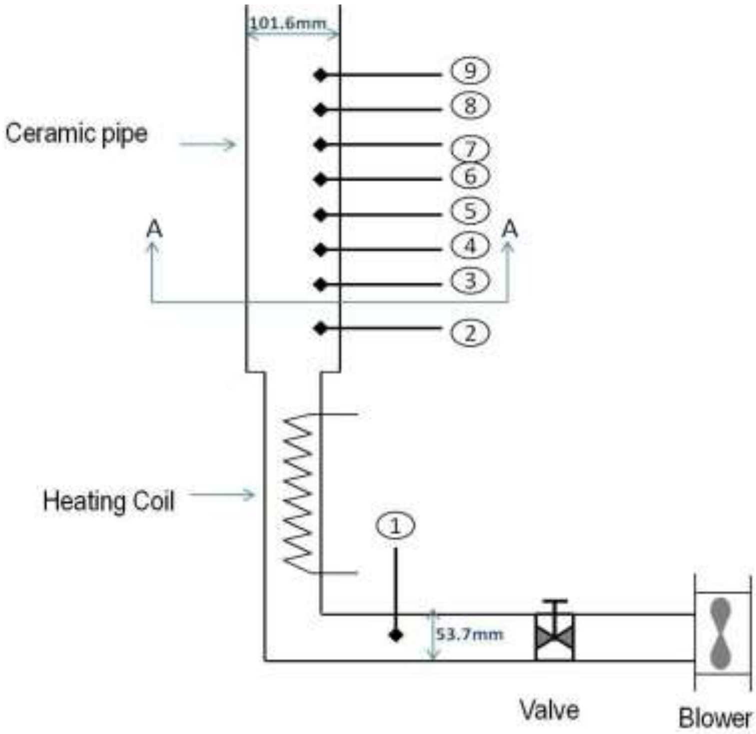

Fig.1. Schematic Diagram for Experiment

Fig.2. Experimental Setup

III. EXPERIMENTAL SETUP

The apparatus consists of a blower unit fitted with the test pipe. The test section is surrounded by a Nichrome band heater. Four thermocouples are embedded on the test section and two thermocouples are placed in the air stream at the entrance and exit of the test section to measure the air temperature. Test pipe is connected to the delivery side of the blower along with the orifice to measure flow of air through the pipe. Input to the heater is given through a dimmer stat and measured by meters. It is to be noted that only a part of the total heat supplied is utilized in heating the air. A temperature indicator with cold junction compensation is provided to measure temperatures of pipe wall at various points in the test section. Airflow is measured with the help of orifice meter and the water manometer fitted on the board. The Contents used for the experimental set up is

1. Blower

2. Valve
3. Ceramic Pipe
4. Thermocouple
5. Digital Temperature Indicator
6. Heater Coil.

The arrangement is made by connecting a blower horizontally in a pipe which is connected with a vertical ceramic pipe. The blower blows the air inside the pipes which passes through the heating coil that increases the temperature of blowing air. To measure the thermal variation inside the ceramic pipes, a number of thermocouples are placed in, along the length of pipe.

IV. EXPERIMENTA PROCEDURE

Apparatus is set up as per above points. Here requirement is to determine heat lines or temperature distribution along the pipe with varying flow rate of forced air by regulating the valve. First heating coil is placed vertically in vertical ceramic pipe which generates the heat inside the region. Various thermocouples are placed at particular heights to measure temperature at various points. Also one thermocouple is placed just before heating coil to measure temperature of air before getting heated. Also, thermocouples are marked at particular divisions that helps to determine the temperature across the axis of pipe. Thus heat lines are drawn and analyzed by taking the outcome of measurements taken.

SPECIFICATIONS:
Pipe diameter (Do): 130 mm and 145mm
Blower: Cheston Air Blower 500 w
Orifice Diameter (d): 53.7 mm
Dimmer stat: 0 to 2 amp, 230 volt, AC
Temperature indicator: Digital type and range 0 - 200 °c
Voltmeter: 0 -200 V
Ammeter: 0 – 2 amp
Heater: Nichrome wire heater wound on
Test Pipe (Band Type) 400 watt

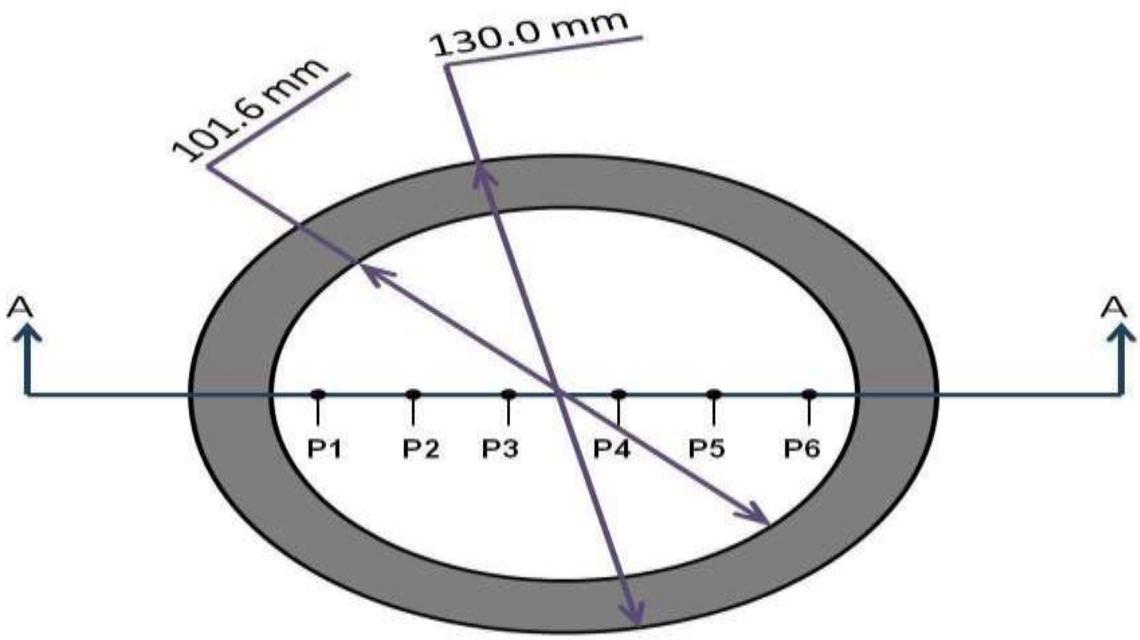

Fig.3. Cross Sectional of Ceramic Pipe

Table. 2. below shows observations taken

Temp. (ċ) ĻTc	P1	P2	P3	P4	P5	P6
1	30	30	30	30	30	30
2	63	63	65	64	61	51
3	62	63	64	63	61	50
4	62	62	64	64	60	42
5	64	65	65	64	62	54
6	63	64	64	63	61	52
7	62	62	63	62	59	48

8	63	64	64	63	60	51
9	63	64	64	63	60	51

Where Temp. = Temperature in degree Centigrade
Tc = Thermocouple

Table.3. Length of points from heating coil;

Thermocouple No	2	3	4	5	6	7	8	9
Length (in mm)	100	155	220	280	345	410	535	610

Velocity of air at the inlet of ceramic pipe for fully opened valve position, is measured by anemometer, i.e. U= 10.5 m/sec. Inlet Velocity (U1) = 16.8 m/sec. Outlet Velocity (U2) = 4.2 m/sec. Following are the graph plotted between Position across the cross sections of ceramic pipe and Temperature for different thermocouple that results is distribution curve shown in the graph.

V. RESULT AND CONCLUSION

After The surface wall temperature for the heated section of the pipe (outer surface) is shown below (fig. 4). The curve shows a linear response once the thermal boundary layer has developed. The temperature distribution along the centerline of the fluid is shown in fig. 5. The temperature remains constant in the unheated portion and starts rising linearly in the heated section of the pipe.

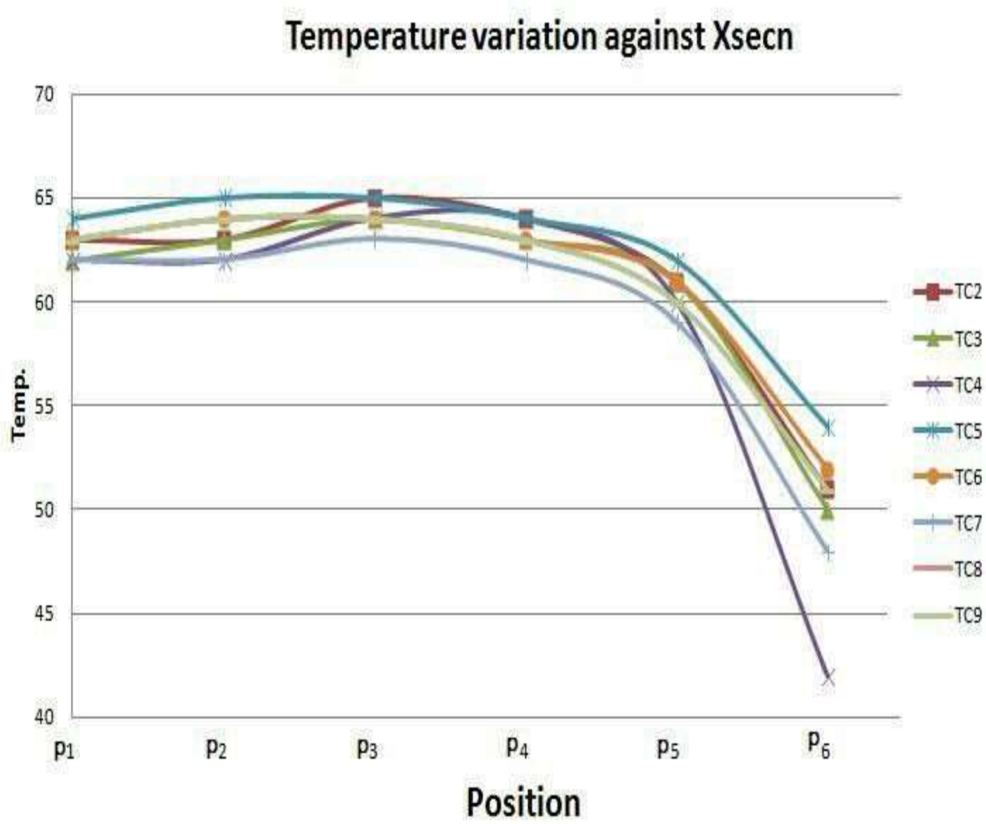

Fig.4. the pipe wall surface temperature of the experimental result

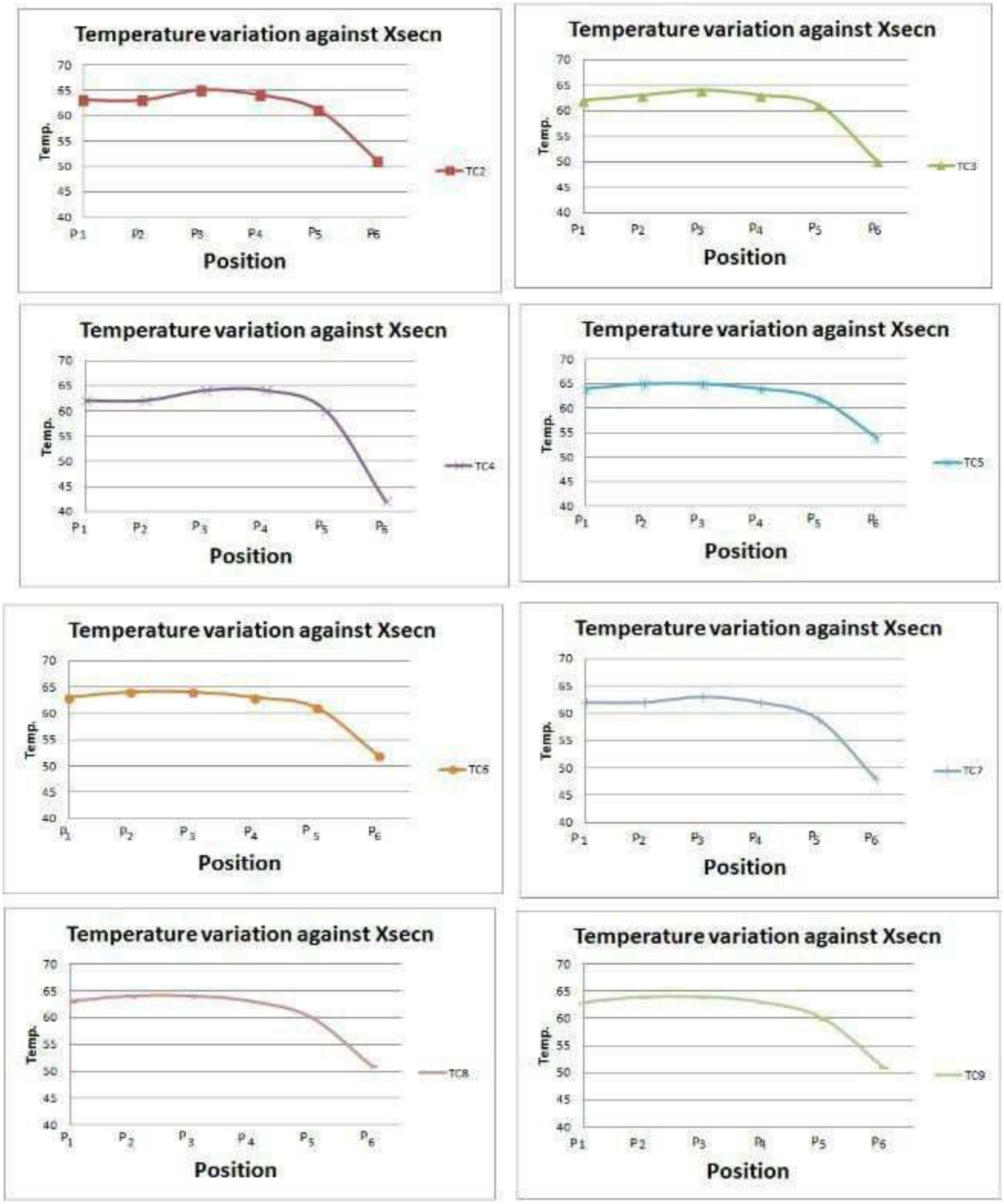

Fig. 5. For individual thermocouples

Hence as shown in graph, as length of pipe increases, the distribution curve is almost same for all the thermocouples taken observation separately and plotted graph individually. Following are the calculation shown for the Nusselt no and average heat transfer coefficient at different thermocouple position along the length of pipe. Properties of Air to be evaluated at Tm. By taking property value of Dry air at 45°C from Heat & Mass Transfer data book, by C.P. Kothandouaman and S.Subramanyam.

Tm ~45°C
ρ~1.1105 kg/m3
μ ~ 19.365 X 10-6 Ns/m3
Pr~ 0.6835
Cp~ 1005 J/Kg K K~ 0.02791 W/mk.

Using above values,
Re= 61176.42
Here, Since Re>2300
So, the flow is Turbulent.Also,
Nu= 133.318

Outcomes are shown through following table.

Thermocouple Position	Average Nusselt No (Nua)	Heat Transfer Coefficient (h)
2-3	338.179	171.61
2-4	251.973	58.604
2-5	222.653	34.524
2-6	205.309	23.388
2-7	193.311	17.404
2-8	181.312	11.633
2-9	176.411	9.654

The effect of temperature distribution during forced convection in vertical pipe has been investigated experimentally. Graph shows almost common curve for each thermocouple throughout the length that is nearly of parabolic shape. Also heat transfer coefficient (h) is decreasing as length of pipe is increasing.

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