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Study of forced convection heat transfer With DAQ & ANSYS

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Abstract

The aim of this work is to validate the Dittus-Boelter equation by experimental, correlation and Simulation method. It used to find the value of heat transfer coefficient 'h' for turbulent flow in many fluid transfer systems. This work discusses how the Dittus-Boelter equation is applied to the problem of circular pipe. In experimental verification a DATA ACQUISITION (DAQ) SYSTEM is used to measure the temperature accurately & reliably. This DAQ system also serves the purpose of condition monitoring system, which records the temperature changes of the system continuously. In CFD simulation ICEM CFD for modeling and FLUENT 14 for analysis are used. Results of CFD simulation will be obtained by CFD-POST. Here heat transfer coefficient value is compared by correlations, experiment and CFD simulations, finally the aim of this work is to validate Dittus-Boelter equation.

Keywords: ANSYS; Heat Transfer; CFD; FLUENT; DAQ

1. Introduction

In the study of thermodynamics the average heat transfer coefficient, is used in calculating the convection heat transfer between a moving fluid and a solid. This is the single most important factor for evaluating convective heat loss or gain. Knowledge of h is necessary for heat transfer design and calculation and is widely used in manufacturing processes, oil and gas flow processes and air-conditioning and refrigeration systems. The heat transfer coefficient is critical for designing and developing better flow process control resulting in reduced energy consumption and enhanced energy conservation.

It is also influenced by flow velocity and surface geometry. It may be noted that the physical or thermal properties of the surface material play no part in the process of convective heat transfer. As the fluid properties vary with the

temperature and locations the value of convective heat transfer coefficient vary from point to point, this leads to the situation that analytically derived equation are applicable only to a limited extent

1.1 DITTUS-BOELTER RELATION

The conventional expression for calculating the heat transfer coefficient in fully developed turbulent flow in smooth pipes is the Dittus-Boelter equation.

$$Nu = C Re^m Pr^n$$

Where C, m and n are constant determined experimentally.

We will use these values -

$$C = 0.023, m = 0.8 \text{ and}$$

$$n = 0.4 \text{ for heating of the fluid}$$

$$n = 0.3 \text{ for cooling of the fluid}$$

The properties of this relation have been calculated at the average fluid bulk temperatures. Equation is valid for single phase heat transfer in fully developed turbulent flows in smooth pipes for fluids with Prandtl number ranging from 0.6 to 100 at low heat fluxes. At high fluxes the fluid properties changes resulting in higher errors. At higher heat fluxes the Sieder-Tate equation is used to reduce the error. The work presented is about designing and acquiring data from an experimental setup to verify the Dittus-Boelter empirical relation by finding the heat transfer coefficient. The value of the heat transfer coefficient has been calculated from theory, experiment and CFD simulation to compare the results.

2. Methodology

The below flow chart represents the step by step working procedure of this work. The standard procedure for ICEM-CFD work follows the above components. For the present work, in case of pipe creating the geometry then computational domain is constructed around the pipe geometry, later set the mesh parameters then generates the mesh. Later this mesh is exported in the fluent readable format

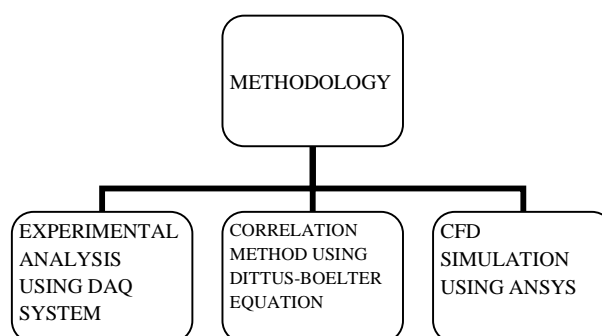


Fig 2.1: Methodology

3. Experimental Set Up Of Forced Convection



Fig. 3.1: Experimental Set Up Of Forced Convection

The experimental set up consists of a blower unit fitted with the test pipe. The test section pipe is grey cast iron surrounded by nichrome heater. Four temperature sensors are embedded on the test section and two temperature sensors are placed in the air stream at the entrance and exit of the test section to measure air inlet and outlet temperature. Test pipe is connected to the delivery side of blower along with orifice to measure flow of air through the pipe. Input to the heater through dimmer stat and measured by voltmeter and ammeter. Air flow is controlled by gate valve and is measured with the help of orifice meter and the manometer fitted on board.

Specifications:

Length of hollow pipe $L = 0.6$ m

Pipe inner diameter $D_i = 0.032$ m

Orifice diameter $D_o = 0.016$ m

3.2 Lay Out Of Experimental Setup

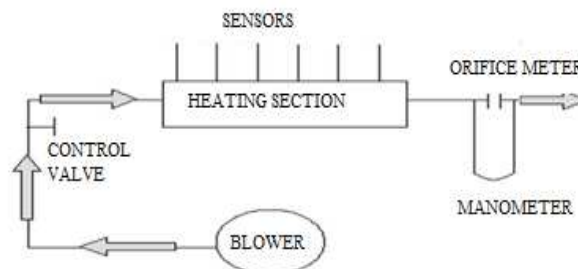


Fig 3.2 Lay Out Of Experimental Setup

3.3 Data Acquisition (DAQ) System

Our DAQ system consists of an Arduino Duemilanove microcontroller and six DS18B20 sensors. The sensors are connected in Daisy chain arrangement and connected to the microcontroller using one wire bus. Another serial port application “COOL TERM” is used to display & save the data sent by these sensors.

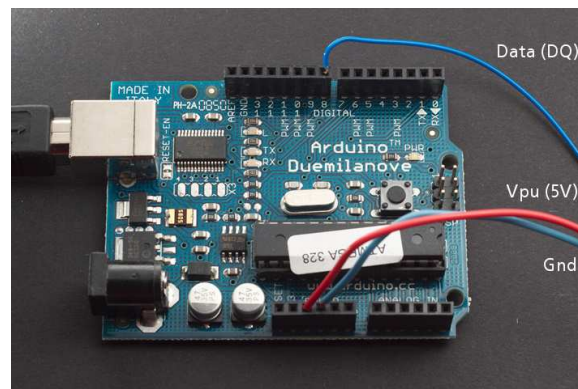


Fig 3.3 Sensors Connected to Arduino

The main advantage of using the DAQ system to measure temp is the accuracy & flexibility. They have a very quick response time compared to thermocouple based system & can also function as a condition monitoring system. The data can be saved to an excel file as shown in fig 3.4.

	A	B	C	D	E	F
1	37.56	52.88	57.81	60.63	58.44	42.56
2	37.56	52.88	57.88	60.63	58.5	42.63
3	37.56	52.88	57.88	60.69	58.5	42.63
4	37.56	52.94	57.88	60.69	58.56	42.56
5	37.56	52.94	57.94	60.69	58.56	42.63
6	37.56	52.94	57.94	60.75	58.56	42.63
7	37.5	52.94	57.94	60.75	58.56	42.63
8	37.56	52.94	57.94	60.75	58.56	42.69
9	37.56	53	57.94	60.75	58.63	42.69
10	37.56	53	58	60.81	58.69	42.69
11	37.56	53	58	60.81	58.63	42.69
12	37.63	53	58	60.81	58.69	42.69
13	37.63	53	58	60.81	58.69	42.69

Fig 3.4: Recorded Temperature

3.4 Calculation of Heat Transfer Coefficient

1. Results obtained by experimental set up:

$$T_1 = 37.56 \text{ c}, T_2 = 52.88 \text{ c}, T_3 = 57.81 \text{ c}, T_4 = 60.63 \text{ c},$$

$$T_5 = 58.44 \text{ c}, T_6 = 42.56 \text{ c}, H = .12 \text{ m}$$

$$T_s = \frac{T_2 + T_3 + T_4 + T_5}{4} = 57.44 \text{ c}$$

$$T_a = \frac{T_1 + T_6}{2} = 40.1 \text{ c}$$

Properties of air: Density = 1.2 kg/m^3 , $\gamma = 16.9 \times 10^{-6}$,

$$K = 0.027, P_r = 0.711, C_p = 1.005 \text{ kJ/kg}$$

$$A_i = \text{area of inlet is } 8.04 \times 10^{-4} \text{ m}^2$$

Discharge through orifice:

$$q = C_d A_o \sqrt{2gh_a}$$

Where $C_d = 0.65$, A_o is the area of orifice which is $2.01 \times 10^{-4} \text{ m}^2$

$$h_a = \frac{(\text{Density of water} * \text{head of water})}{\text{Density of air}} = \frac{1000 * 0.12}{1.2}$$

$$= 100 \text{ m}$$

$$q = 0.65 * 2.01 * 10^{-4} * \sqrt{(2 * 9.81 * 100)} = 5.79 * 10^{-3} \text{ m}^3/\text{s}$$

$$\text{Velocity } V = (q/A) = 7.2 \text{ m/s}$$

$$\text{Mass flow rate } m = q * \text{density of air} = 6.948 * 10^{-3} \text{ kg/s}$$

Heat Carried by air:

$$Q_a = m * C_p * dT = 34.91 \text{ J/s}$$

$$A = \pi * D_i * L = 0.06 \text{ m}^2$$

$$\text{Now, } Q_a = h A (T_s - T_a)$$

Therefore,

$$h = \frac{Q_a}{A (T_s - T_a)} = \frac{34.91}{0.06 * (57.44 - 40.1)} = 33.55 \text{ W/m}^2 \text{ K}$$

$$\boxed{h = 33.55 \text{ W/m}^2 \text{ K}}$$

2. Result by correlation method

In the correlation method, we use Dittus-Boelter eqn to obtain the value of Nusselt (Nu) number for the given system & with the eqn for Nu we obtain the heat transfer coefficient.

$$Re = \frac{VD}{\gamma} = \frac{7.2 * 0.032}{16.9 \times 10^{-6}} = 13585$$

γ is kinematic viscosity obtained from data hand book properties of air which is 16.96×10^{-6} .

Using Dittus-Boelter eqn,

$$Nu_u = 0.023 Re^{0.8} Pr^{0.4} = 40.64$$

We know,

$Nu_u = \frac{hD}{k}$, where h is heat transfer coefficient, D is pipe inner diameter and k is thermal Conductivity of air at mean temperature obtained from properties

Therefore,

$$h = \frac{Nu * k}{D} = \frac{40.64 * 0.027}{0.032} = 34.29 \text{ W/m}^2 \text{ K}$$

$$\boxed{h = 34.29 \text{ W/m}^2 \text{ K}}$$

Experimental $h = 33.55 \text{ W/m}^2 \text{ K}$. Now validate the correlation using CFD simulation.

4. CFD Simulation

4.1 CFD Analysis of Pipe

There are four basic steps involved in the CFD analysis of pipe. They are given as below:

1. Creating Geometry & meshing
2. Pre-processing
3. Solver
4. Post-processing

4.2 Geometry Model

ANSYS ICEM is used to build a 3D geometry for CFD analysis. The geometry is created and Meshed using ANSYS ICEM CFD. The length of pipe is 600mm and inner diameter is 0.032m.

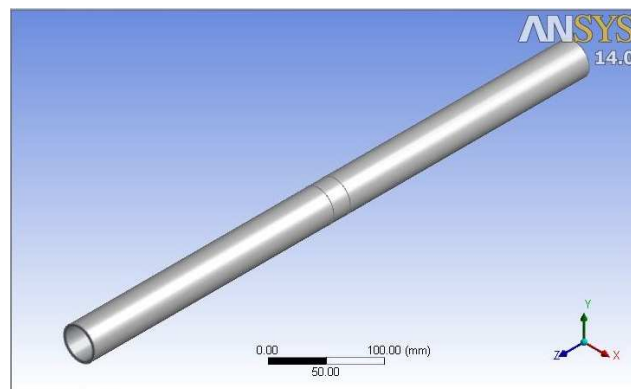


Fig. 4.1: Modelling of Pipe Using ICEM CFD

4.3 Meshing

The computational model is created in ICEM-CFD as per the dimensions shown in Figure 4.2. Later the Tetrahedral Mesh with Smooth Transition grid is generated.

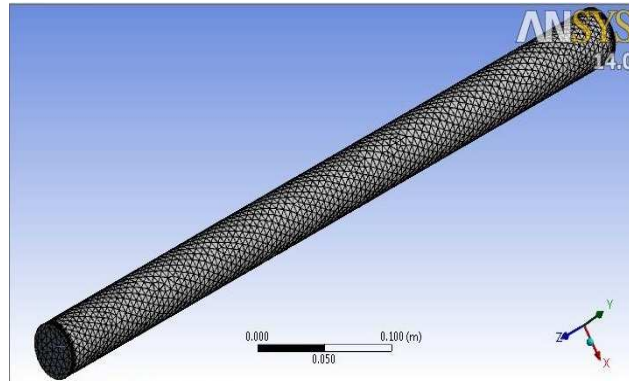


Fig. 4.2: Mesh Generated Using ICEM CFD

4.4 CFD Simulation in FLUENT

The computational model is created in ICEM-CFD as per the dimensions shown in Figure 4.1. Later the Tetrahedral Mesh with Smooth Transition grid is generated. The solver and the boundary conditions are specified in FLUENT i.e. used segregated solver with asymmetric space and k-epsilon for turbulent modelling.

The boundary conditions and reference values are shown below.

Boundary Conditions:

1. Location = inlet

Boundary details, subsonic

Normal speed = 7.2 m/sec

Medium intensity heat transfer

Static temp = 310 k

2. Location outlet

Boundary details

Relative pressure = 1 Pa

Wall Option: no slip wall ,Smooth wall

4.5 Results

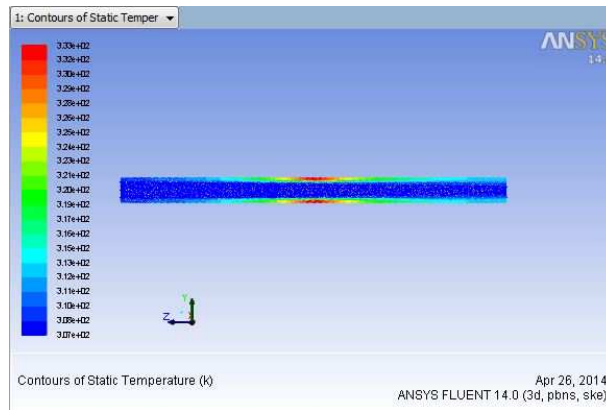


Fig 4.3 : Temperature Plane

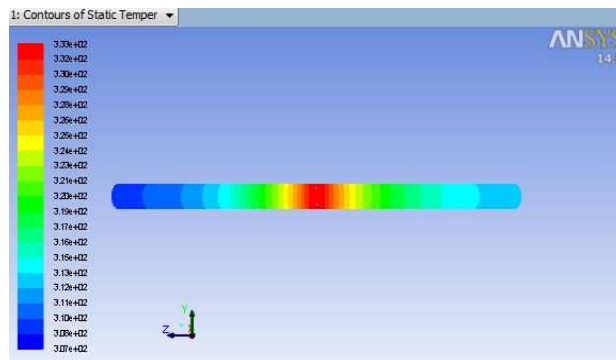


Fig 4.4: Temperature Plane

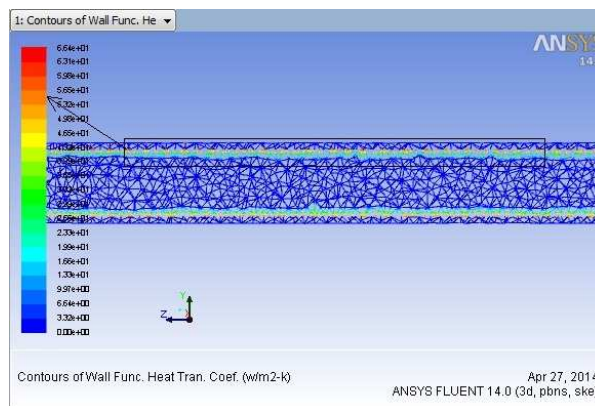


Fig 4.5: Heat Transfer Coefficient

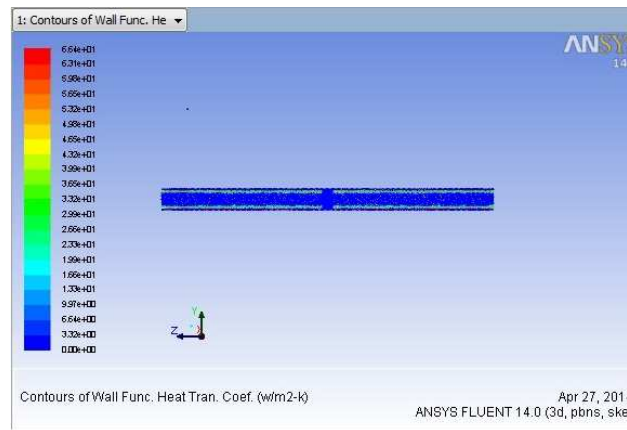


Fig 4.6: Heat Transfer Coefficient

5. Validation of Experimental, Cfd And Correlation

Experimental $h = 33.55 \text{ W/m}^2 \text{ K}$

Correlation $h = 34.29 \text{ W/m}^2 \text{ K}$

CFD simulation $h = 36.5 \text{ W/m}^2 \text{ K}$ (from fig 4.6)

From this, we observe that the value obtained by CFD is very nearer to correlation and experimental hence Dittus-Boelter equation is validated.

The primary objective of this work is to determine heat transfer coefficients (local and average) for different flow geometries and this heat transfer coefficient (h) may be obtained by experimental or theoretical methods.

Theoretical methods involve solution of the boundary layer equations to get the Nusselt number. On the other hand the experimental methods involve performing heat transfer measurement under controlled laboratory conditions and correlating data in dimensionless parameters. Many correlations for finding the convective heat transfer coefficient are based on experimental data which needs uncertainty analysis, although the experiments are performed under carefully controlled conditions. The causes of the uncertainty are many. Actual situations rarely conform completely to the experimental situations for which the correlations are applicable. Whatever the value obtained by experimental, correlation and CFD simulation agree with each other with an error less than 10 %. Hence Dittus-Boelter has been validated

6. Conclusion

By carrying out experiment, simulation and calculation, it is concluded that these correlations give an error well within the range 10 % and usually less in controlled environment. The results clearly validate the use of Dittus-Boelter correlation in many industrial applications. There are many reasons which contribute to the errors. The heat loss does account for errors, but the value of heat loss is negligible as compared to total heat flux. The heaters are local made and do not provide constant surface heat flux although it has been tried to control wattage of each heater.

Secondly all sensors (temperature) are attached in a close proximity of 220 V AC lines coming from heaters. Therefore signals from sensors are distorted and give an error. If somehow these problems are overcome results may improve. Another thing is correlation results must be more but here it is less because this has been taking the property of air at mean temperature of inlet and out let obtained by experiment.

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