Applications of forced convection engineering essay

The experiment was carried out to verify the relationship between Nusselt number , Reynolds number and Prandtl Number using the different concepts of convection. Relative discussions and conclusions

were drawn including the various factors affecting the accuracy of the calculated results.

The main objective of this experiment was to verify the following heat transfer relationship:

Therefore, the experiment is conducted by an apparatus where hot ait from heater is generated and flow through copper tube. Different values of temperatures and pressure were taken and recorded in order to calculate. Besides, graphs plotted and analysed to have a better understanding of convection heat transfer.

Thus a Laboratory experiment was conducted where hot air from a heater was introduced through a copper tube with the help of a blower. Thermocouples were fixed in placed at various locations along the length of the copper tube. The different values of temperature and pressure were measured along with the various sections of the tube and other required values were recorded and calculated. Graphs were also plotted with the data obtained and then analysed.

INTRODUCTION

Heat transfer science deals with the time rate of energy transfer and the temperature distribution through the thermal system. It may be take place in three modes which is conduction, convection and radiation. Theory of convection is presented since this experiment is concerned about convective heat transfer. Convective is the mode of energy transfer between a solid surface and the adjacent liquid or gas that is in motion due to a temperature difference. It involves the combined effects of conduction and fluid motion.

There are two major type of convective

Forced convection is known as fluid motion generated by blowing air over the solid by using external devices such as fans and pumps.

The other type is natural convection which meant by a phenomenon that occurs in fluid segments and facilitated by the buoyancy effect. It is less efficient than forced convection, due to the absence of fluid motion. Hence, it depends entirely on the strength of the buoyancy effect and the fluid viscosity. Besides, there is no control on the rate of heat transfer.

Forced Convection

Force convection is a mechanism of heat transfer in which fluid motion is generated by an external source like a pump, fan, suction device, etc. Forced convection is often encountered by engineers designing or analyzing pipe flow, flow over a plate, heat exchanger and so on.

Convection heat transfer depends on fluids properties such as:

Dynamic viscosity (µ)

Thermal conductivity (k)

Density (Ï)

Specific heat (Cp)

Velocity (V)

Type of fluid flow (Laminar/Turbulent)

Newton's law of cooling

Where

h = Convection heat transfer (W/(m2.°C)

A = Heat transfer area

= Temperature of solid surface (°C)

= Temperature of the fluid (°C)

The convective heat transfer coefficient (h) is dependent upon the physical properties of the fluid and the physical situation.

Applications of Forced Convection

In a heat transfer analysis, engineers get the velocity result by performing a fluid flow analysis. The heat transfer results specify temperature distribution for both the fluid and solid components in systems such as fan or heat exchanger. Other applications for forced convection include systems that operate at extremely high temperatures for functions for example transporting molten metal or liquefied plastic. Thus, engineers can determine what fluid flow velocity is necessary to produce the desired temperature distribution and prevent parts of the system from failing. Engineers performing heat transfer analysis can simply click an option to include fluid convection effects and specify the location of the fluid velocity results during setup to yield forced convection heat transfer results.

TYPICAL APPLICATIONS

Computer case cooling

Cooling/heating system design

Electric fan simulation

Fan- or water-cooled central processing unit (CPU) design

Heat exchanger simulation

Heat removal

Heat sensitivity studies

Heat sink simulation

Printed Circuit Board (PCB) simulation

Thermal optimization

Forced Convection through Pipe/Tubes

In a flow in tupe, the growth of the boundary layer is limited by the boundary of the tube. The velocity profile in the tube is characterized by a maximum value at the centerline and zero at the boundary.

For a condition where the tube surface temperature is constant, the heat transfer rate can be calculated from Newton’s cooling law.

Reynolds Number

Reynolds number can be used to determine type of flow in fluid such as laminar or turbulent flow. Laminar flow occurs at low Reynolds numbers, where viscous forces are dominant. The condition of flow is smooth and constant fluid motion. Meanwhile, turbulent flow occurs at high Reynolds number and is dominated by inertial forces and it produce random eddies, vortices and other flow fluctuations.

Reynolds number is a dimensionless number. It is the ratio of the inertia forces to the viscous forces in the fluids. Equation for Reynolds Number in pipe or tube is as below:

Where

Ï = Fluid density (kg/m3)

V = Fluid velocity (m/s)

D = Diameter of pipe

Î¼ = The dynamic viscosity of the fluid (Pa·s or N·s/m^2)

Î½ = Kinematic viscosity (Î½ = Î¼ / Ï) (m^2/s)

Q = Volumetric flow rate (m^3/s)

A = Pipe cross-sectional area (m2)

EXPERIMENT OVERVIEW

Apparatus

Figure 1 : Apparatus being used

The experimental apparatus comprises of a copper pipe, which is supplied with air by a centrifugal blower and heater as figure 1. The test section of the pipe is wound with a heating tape, which is covered with lagging. Six copper constantan thermocouples are brazed into the wall of the test section. Another six thermocouples extend into the pipe to measure the flowing air temperature. In addition five static pressure tapping are positioned in the tube wall. A BS 1042 standard orifice and differential manometer measure the air mass flow rate though the pipe.

Experimental Procedure

Fully close the valve which controlling the air flow rate.

Measure the everage intermal diameter (D) of the test section pipe by using a vernier calliper.

Adjust the inclination angle of the manometer bundle Î± to 30°.

Start the blower and turn the valve to the fully open position gradually,

Adjust the power input to the heating tape to its maximum valve and allow the apparatus to attain thermal equilibrium.

Take down the data and record

Pressure drop through the metering orifice

Pressure and temperature downstream of the orifice

Ammeter and voltmeter readings

Tube wall temperature along the testing section

Air temperature along the test section

Air pressure along the test section

Ambient temperature and pressure.

Repeat the foregoing procedure for another four different flow rate and adjust the heater input to give approximately the same wall temperature at each flow rate.

DATA AND MEASUREMENT TABLE

Property

Symbol

Units

Value

Barometric Pressure

Pb

mm Hg

741. 60

Diameter of the test section pipe

Dp

m

0. 038

Density of water (Manometer’s fluid)

Ï

Kg/m3

1000

Angle of the manometers bundle

Î±

degree

30

Property

Symbol

Units

Test

1

2

3

4

5

Pressure drop across orifice

Î” H

mm H2O

685

565

460

360

260

Pressure drop d/s orifice to atmosphere

Î” P

mm H2O

178

152

120

93

68

Air temperature downstream orifice

t

°C

35

38

38

38

39

EMF (Voltage) across tape

V

Volts

230

200

165

142

129

Current through tape heater

I

Amps

7. 3

6. 3

5. 5

5. 0

4. 0

Flowing air temperature

t1

°C

35. 0

36. 9

38. 2

40. 0

41. 4

Flowing air temperature

t2

°C

36. 1

37. 7

38. 9

40. 6

41. 9

Flowing air temperature

t3

°C

43. 1

43. 6

43. 4

44. 4

45. 6

Flowing air temperature

t4

°C

42. 2

42. 4

42. 4

43. 5

44. 6

Flowing air temperature

t5

°C

49. 6

48. 6

47. 0

47. 3

48. 1

Flowing air temperature

t6

°C

63. 2

59. 6

55. 7

54. 3

54. 6

Tube wall temperature

t7

°C

38. 9

40. 0

40. 6

41. 9

43. 0

Tube wall temperature

t8

°C

81. 20

73. 6

65. 9

62. 2

61. 2

Tube wall temperature

t9

°C

99. 8

89. 1

77. 5

71. 5

69. 5

Tube wall temperature

t10

°C

105. 9

93. 9

81. 3

74. 6

72. 4

Tube wall temperature

t11

°C

106. 5

94. 5

81. 8

75. 1

73. 1

Tube wall temperature

t12

°C

108. 1

95. 5

82. 3

75. 0

72. 5

Air static gauge pressure (Î” l. sin Î±)

P1

mm H2O

385

324

255

195

145

Air static gauge pressure (Î” l. sin Î±)

P2

mm H2O

264

223

175

132

99

Air static gauge pressure (Î” l. sin Î±)

P3

mm H2O

210

181

141

108

79

Air static gauge pressure (Î” l. sin Î±)

P4

mm H2O

108

97

81

57

42

Air static gauge pressure (Î” l. sin Î±)

P5

mm H2O

23

31

20

16

14

Air static gauge pressure (Î” l. sin Î±)

P6

mm H2O

â‰ˆ0

â‰ˆ0

â‰ˆ0

â‰ˆ0

â‰ˆ0

Sample Calculations

Based on 1st set data,

Power Input to the tape heater:

Power = = (230 x 7. 3)/1000 = 1. 679

Absolute Pressure downstream of the orifice:

741. 60 + (178/13. 6)= 754. 69 mmHg

Absolute Temperature downstream of the orifice:

T = t + 273 = 365+ 273 = 308 K

The Air Mass Flow Rate:

air = 5. 66x = = 231. 88

231. 88 Kg/hr = 0. 06441 Kg/sec,

Since 1 Kg/hr = Kg/sec

Average Wall Temperature:

= (38. 9+81. 2+99. 8+105. 9+106. 5+108. 1)/6 = 90. 07

Average Air Temperature:

= (35+36. 1+43. 1+42. 2+49. 6+63. 2)/6 = 44. 87

The Bulk Mean Air (arithmetic average of mean air) Temperature:

= (35+63. 2)/6 = 49. 1

The Absolute Bulk Mean Air (arithmetic average of mean air) Temperature:

49. 1+273 = 322. 10 K

The Properties of Air at Tb:

Using the tables provided in “ Fundamentals of Thermal-Fluid Sciences by Yunus A. Cengel”

From the table A-18 (Page958), Properties of Air at 1atm pressure at K

Density, Ï) = 1. 1029 kg/m3

Specific Heat Capacity, Cp = 1. 006 kJ/(kg. K)

Thermal Conductivity, k = 0. 0277 kW/(m. K)

Dynamic Viscosity, µ = 1. 95 x 10-5 kg/(m. s)

Prandtl Number, Pr = 0. 7096

The Increase in Air Temperature:

63. 2-35 = 28. 2

The Heat Transfer to Air:

(231. 88/3600) x 1. 006 x 28. 2 = 1. 827

Where: = Heat Transfer to air

= Mass flow rate

= Specific heat capacity

= Increase in air temperature

The Heat Losses:

1. 679-1. 827 = -0. 148

Where: = Heat losses

= Heat Transfer to air

The Wall/Air Temperature Difference:

90. 07-44. 87 = 45. 2

Where: = Wall/Air temperature difference

= Average air temperature

The Heat Transfer Coefficient:

= ((231. 88/3600) x 1. 006 x 28. 2) / (3. 14 x . 0382 x 1. 69 x 45. 2) = 0. 199 kW/ (m^2 . k)

Where:

= Mass flow rate

= Specific heat capacity

= Increase in air temperature

= Average Diameter of the Copper pipe.

= Length of the tube

= Wall/Air temperature difference

The Mean Air Velocity:

= (4 x (231. 88/3600))/ (1. 1029 x 3. 14 x (0. 0382 ^2) = 50. 9575 m/s

Where:

= Mean air velocity

= Mass flow rate

= Density

= Average Diameter of the Copper pipe.

The Reynolds Number:

The Nusselt Number:

= Nusselt Number

= Average Diameter of the Copper pipe.

= Thermal conductivity

The Stanton Number:

Where:

St = Stanton Number

= Nusselt Number

= Prandtl number

Re = Reynolds number

The Pressure Drop across the testing section:

at Tb = 320. 1 K

= Pressure drop across the testing section

= Absolute pressure downstream of orifice.

= Barometric Pressure

The Friction Factor:

RESULT

Power

Power

kW

1. 679

1. 260

0. 908

0. 710

0. 516

Absolute Pressure downstream of the orifice

P

mm Hg

754. 69

752. 78

750. 42

748. 44

746. 60

Absolute temperature downstream of the orifice

T

K

308

311

311

311

312

Pressure drop across the orifice

â^†H

mm H20

685

565

460

360

260

Air mass flow Rate

air

231. 88

209. 31

188. 57

166. 60

141. 18

Average wall Temperature

tw

90. 07

81. 1

71. 57

66. 72

65. 28

Average air temperature

tair av

44. 87

44. 80

44. 27

45. 02

46. 03

Bulk Mean air temperature

tb

49. 1

48. 25

46. 95

47. 15

48. 0

Absolute bulk mean air temperature

Tb

K

322. 1

321. 25

319. 95

320. 15

321. 0

Density at Tb

ï)

1. 1029

1. 1058

1. 1102

1. 1095

1. 1066

Specific Heat Capacity at Tb

Cp

1. 0060

1. 0060

1. 0060

1. 0060

1. 0060

Thermal Conductivity at Tb

K

2. 77

2. 76

2. 75

2. 75

2. 76

Dynamic Viscosity at Tb

Î¼

1. 95

1. 95

1. 94

1. 94

1. 95

Prandtl Number at Tb

Pr

0. 7096

0. 7096

0. 7100

0. 7100

0. 7098

Increase in air temperature from t1 to t6

â^†t a

28. 2

22. 7

17. 5

14. 3

13. 2

Heat transfer to air

air

W

1. 827

1. 328

0. 922

0. 666

0. 521

Heat losses

losses

W

-0. 148

-0. 068

-0. 015

-0. 044

-0. 005

Wall/Air temperature difference

âˆ†t m

45. 2

36. 3

27. 3

21. 7

19. 25

Heat transfer Coefficient

h

0. 199

0. 180

0. 167

0. 151

0. 133

Mean air velocity

Cm

50. 9575

45. 877

41. 167

36. 394

30. 922

Reynolds’s Number

Re

110096. 353

99380.

144

89994.

330

79509.

225

67204.

418

Nusselt Number

Nu

274. 4

249

232

209. 8

184. 1

Stanton Number

St

0. 00351

0. 00353

0. 00363

0. 0037

0. 0039

Pressure Drop across the testing section

â^†P

1746. 42

1491. 59

1176. 73

912. 57

667. 08

Friction Factor

f

0. 01378

0. 0145

0. 0141

0. 0141

0. 0143

Results

Plot A

Experiment

1

2

3

4

5

Y= ln(Nu x Pr-0. 4)

5. 75

5. 65

5. 58

5. 48

5. 35

X= ln(Re0. 8)

9. 29

9. 21

9. 13

9. 03

8. 89

Y-X

-3. 54

-3. 56

-3. 55

-3. 55

-3. 54

Plot B

Experiment

1

2

3

4

5

Y= Nu

274. 4

249

232

209. 8

184. 1

X= Re x Pr

78124. 37

70520. 15

63895. 97

56451. 55

47701. 69

Stanton number:

Reynolds Analogy:

Experiment

1

2

3

4

5

Friction factor

0. 01378

0. 0145

0. 0141

0. 014

0. 0143

Reynolds Analogy

0. 00689

0. 00725

0. 00705

0. 007

0. 00715

Stanton number

0. 00351

0. 00353

0. 00363

0. 0372

0. 0386

DISCUSSION

In order to get more accurate results, there are some suggestions like cleaning the manometer, checking the insulation on the pipe and making sure the valve is closed tightly.

An additional way to prove the heat transfer equation is by re-arranging it.

Nu = 0. 023 x (Re0. 8 x Pr 0. 4)

Substituting in the experimental values into the above equation from section 5. 0 returns the following results below:

Experiment

1

2

3

4

5

Y= Nu

274. 4

249

232

209. 8

184. 1

X= Re0. 8 x Pr0. 4

9415. 08

8674. 51

8014. 48

7258. 34

6344. 14

Y/X

0. 029

0. 0287

0. 0289

0. 0289

0. 029

Comparing this to the heat transfer constant, it shows that there is a little difference only which can be negligible.

It can also be done by taking the gradient of the line from the plot Nu against (Re0. 8 x Pr0. 4)

as shown below:

CONCLUSION

A better understanding of the heat transfer was achieved through conducting the experiment. Theoretical sums and experimental values were found to be approximately similar and the different sources of error have been identified.

The main objective of this experiment was to verify the following heat transfer relationship:

Nu = 0. 023 x (Re0. 8 x Pr 0. 4)

Therefore, relation of forced convective heat transfer in pipe is cleared and the objectives were completed.