Experimental and Computational Fluid Dynamics Heat Transfer Analysis on Elliptical Fin by Forced Convection

Rajeev P. Patil
Department of mechanical engineering
P.V.P.I.T., Budhgaon

Prof. H.M. Dange
Professor, Department of mechanical engineering
P.V.P.I.T., Budhgaon

Abstract

This work includes analysis of heat transfer parameters, heat transfer coefficient and tube efficiency of elliptical fin by forced convection. Also the experimental analysis is verified by computational fluid dynamics software. The heat transfer parameters were experimented at different environmental conditions. The idea behind that was to compare heat transfer coefficient and efficiency at different operating conditions. Air flow rate is also affecting heat transfer and this is taken into account. The experiment is carried for different air flow rate with varying heat input. This project work also includes the Computational Fluid Dynamics analysis of heat transfer parameters. The results obtained by experimental analysis were compared with CFD analysis. For analysis ANSYS FLUENT software is used. Work carried out in Fluent with all actual experimental fundamentals such as inlet air through blower, Heater wattage. The CFD temperature distribution for all cases verifies experimental results.

1. "Introduction"

Fins are one of the heat exchanging devices that are employed extensively to increase heat transfer rates. The rate of heat transfer depends on the surface area of the fin. Radial or annular fins are one of the most popular choices for exchanging the heat transfer rate from the primary surface of cylindrical shape. Optimum elliptical fin dissipate heat at higher rate compared to annular fin when space restriction exists on both sides of the fin. If space restriction is there along one particular direction while the perpendicular direction is relatively unrestricted elliptical fins could be a good choice. In current scenario, the thermal designers put forth a continuous effort to determine the maximum heat transfer rate within the given volume and envelop shape. This can be achieved by changing either the shape of the tube or the shape of the fins. The removal of excessive heat from system components is essential to avoid damaging effect of overheating.

Temperature distribution and heat flux along fin surface can be predicted by computational analysis. The performance of elliptical fin can be analyzed effectively by CFD software. CFD analysis will be useful for the application of heat transfer and fluid dynamics principles. Attempts are made to establish a comparison between the experimental results and results obtained by using CFD software. Computational analysis and subsequent experimental investigations have revealed fins can be used effectively to enhance the rate of heat transfer. It is also revealed that heat transfer coefficient and in turn the rate of heat transfer can further be increased by increasing the surrounding fluid velocity i.e. by forced convection.

2. "Problem definition"

The heat transfer parameters were experimented at different environmental conditions viz. at atmospheric temperature, at above atmospheric temperature, at below atmospheric temperature. The experiment is carried for different air flow rate. The assumptions during the analysis have been taken considering the manufacturing and practical applications and working conditions. Brass is used for the fin material and air is taken as the fluid flowing inside the duct where fin was kept and the flow is taken as laminar.

2.1 Operating conditions

i. Input

a. Operating condition = Steady state
b. Nature of flow = laminar flow
c. By varying heater input i.e. voltage & current
d. By varying air flow rate from blower (forced convection)

ii. Output

Calculation of Heat transfer coefficient, tube efficiency and effectiveness for different set of environmental condition i.e. For 3.7 m/s air flow rate at atmospheric Temperature, at below atmospheric Temperature & At above atmospheric Temperature.
The following assumptions are considered for solving the problem,

i. Fin material is homogenous and its thermal conductivity is the same in all directions and it remaining constant.
ii. The temperature of medium surround the fin is uniform.
iii. The thickness of the fin is small compared with its height &length, so that the temperature gradient across the fin thickness and heat transfer from the edge of the fin may be neglected.
iv. Temperature at the base of the tube is uniform.

3. "Development of system"

3.1 Material selection

Brass is selected for fin & tube material as it is easy to weld. The thermal conductivity of brass is also higher. Brass is the best material from which to manufacture many components because of its unique combinations of properties. Good strength and ductility are combined with excellent corrosion resistance and superb mach inability. Brasses set the standard by which the mach inability of other materials is judged and are also available in a very wide variety of product forms and sizes to allow minimum machining to finished dimensions.

3.2 Fin dimensions

Since the project objective is to calculate heat transfer coefficient and efficiency at different environmental conditions, with considering the blower capacity and structure of air conditioning system used the fin dimensions are decided as,

Fin dimension, Major axis = 80 mm
Minor axis = 53 mm
Thickness = 3 mm
No. of fin = 2
Distance between two fin = 50 mm

Tube dimension, Outer Diameter = 25.4 mm
Inner Diameter = 21 mm
Tube length = 132 mm

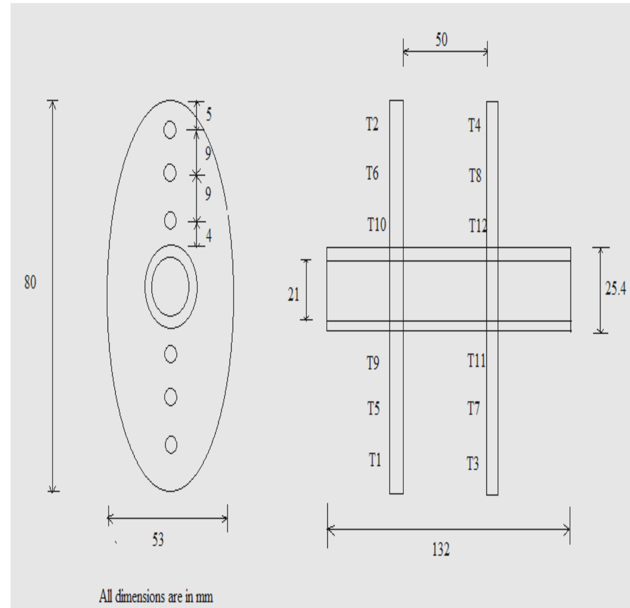


Figure 1: Elliptical fin layout & thermocouple location


Figure 2: Elliptical fin set up with thermocouple locations

3.3 Duct sizing

The fin assembly has to keep in a rectangular duct. The duct dimensions of air conditioning unit is 250 x 250 mm .Since the a/c unit has two compressors and with considering blower capacity (600 Cubic feet min) the fin duct is attached to a/c duct by a diffuser. So the duct dimension are decided as,

Duct Dimension 150 mm x 150 mm
Length 1000 mm

The finned type air heater of 150 W capacity is installed inside the circular tube.

3.4 Thermocouple selection & location

The K-type thermocouples are used. Since the base temperature and surface temperature is to be measured on elliptical fin, thermocouples are fix at six locations on major axis of each fin by screw as shown in figure. T1 to T4 are fixed at the tip of fin. T5 to T8 are fixed at the middle of fin as shown in figure. T9 to T12 are fixed at the base of circular tube. These thermocouples are connected to the temperature indicator.

Inlet air temperature is measured with the help of thermometer kept in duct.

3.5 Control panel

Control panel consist of Temperature indicator, Voltmeter to measure voltage, dimmer stat to control heat input, ammeter to measure current and switch to start the unit. The voltmeter, ammeter are attached as shown in the layout.

3.6 Experimental setup

The experimental set-up has a circular tube heat exchanger with elliptical fins assembly, rectangular duct and control panel. The control panel is attached behind the rectangular duct that it is easy to display the indicators with the help of nut & bolts. The thermocouples are attached to the fin with the help of screws. The thermocouples are connected to the temperature indicator at appropriated locations. The fin assembly is kept inside the rectangular duct on supporter. The entire assembly is then attached to the duct of a/c unit.

The thermocouples are located at the base to measure the base temperatures namely Tb9, Tb10, Tb11 and Tb12 respectively. The average of these four temperature measurements is taken up as the fin base temperature (Tb) and it is the outer surface temperature of the circular tube. The other eight thermocouples are located on the fin surface namely Ts1, Ts2, Ts3, Ts4, Ts5, Ts6, Ts7 and Ts8 respectively. The average of these temperature measurements is taken up as the fin surface temperature (Ts) and it is as shown in the figure. The $T\infty$ is the ambient air temperature around as well as nearer to the test specimen. The fin apparatus is kept in a rectangular duct of 150 x 150 mm. The unit is attached to air conditioning unit for creating different environmental conditions. The forced convection is created by a blower. The readings are taken at different flow rates. Control panel consists of a dimmer stat to vary voltage. A voltage & current indicator as well as temperature indicator is placed to measure temperature of all sensors. A thermometer is placed to measure inlet air temperature. The thermal properties of fin material and the specifications of fins with heat exchanger are listed in Table. The horizontal circular tube is placed on supporters so as to prevent ground effects.

The different environmental conditions are created by an air conditioning unit by cooling of air & heating of air. The a/c unit consists of two compressors. The cooling of air can be done either operating of any one a/c system. Heating of air can be controlled with the help of heat input. The humidity level can be checked with the reading from DBT & WBT. In order to ensure that heat transfer takes place in a proper way a thermometer is installed at the entrance of the duct to measure air temperature.

Figure 3: Fin assembly inside the duct

3.7 Specifications

Table 1: Material properties

Thermal conductivity	109 $W/m^2\ ^0C$
Density	8522 kg/m^3
Specific heat	385 J/kg K

Table 2: Specification of heater

Heater type (Inside tube with fin)	Cartridge, 150 W
Voltage	230 V
Current	2 Amp, AC

Table 4: Specification of blower

Blower specification	1 HP motor at 2900 RPM, 1.8 Amp, 8 inch Diameter impeller Air flow 600 cfm
At 50 % blower capacity	3.7 m/sec

Table 3: Specification of fin

Fin Material	Brass (Cu 70% and Zn 30%)
Fin thickness	3 mm
Elliptical fin major & minor axis	80 mm & 53 mm
No. of fin	2
Distance between two fin	50 mm
Outer Diameter	25.4 mm
Inner Diameter	21 mm
Tube length	132 mm
No. of thermocouples on each fin	3 on both sides on major axis (Total 6)
Distance of thermocouples on fin from base of tube	4 mm, 9mm, 9mm
Duct Dimension:	150 mm x 150 mm
Duct Length	1000 mm

4. "Experimental results"

4.1 Result table 1

Flow Rate 3.7 m/s and At Atmospheric Temperature

V	I	Q in W	h in W/m^2 ^{0}C	χ in%
60	0.215	12.9	2.41	70.80
80	0.281	22.48	2.19	79.13
100	0.351	35.1	2.11	81.49
120	0.416	49.92	1.92	87.53

4.2 Result table 2

Flow Rate 3.7 m/s and At Above Atmospheric Temperature

V	I	Q in W	h in W/m^2 ^{0}C	χ in%
60	0.217	13.02	2.72	55.29
80	0.280	22.4	2.29	56.15
100	0.351	35	1.80	74.01
120	0.408	48.96	1.75	76.48

4.3 Result table 3

Flow Rate 3.7 m/s and At Below Atmospheric Temperature

V	I	Q in W	h in W/m^2 ^{0}C	χ in%
60	0.219	13.14	1.85	84.62
80	0.286	22.88	1.99	83.36
100	0.343	34.3	1.75	87.43
120	0.424	50.88	1.86	84.69

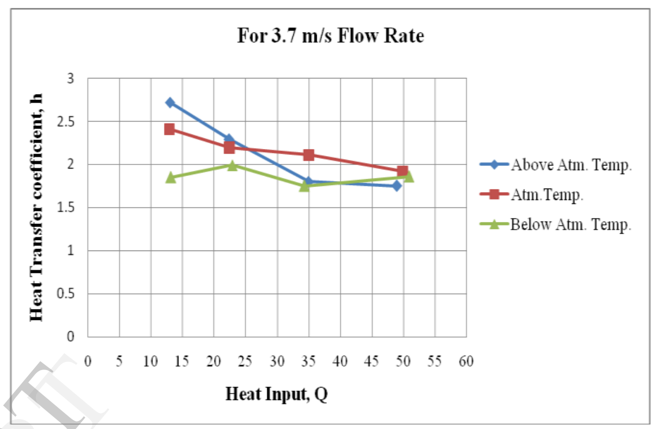


Figure 4: Graph of Heat input Vs heat transfer coefficient for 3.7 m/s flow rate

Figure shows that, for air flow rate of 3.7 m/s the heat transfer rate decreases as heat input increases. Also h is higher at above atmospheric temperature and lower at below atm. Temperature.

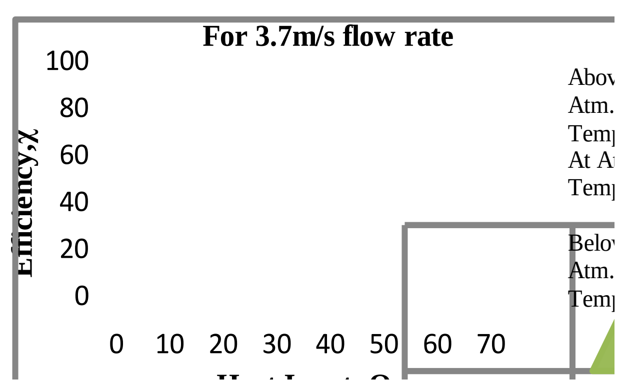
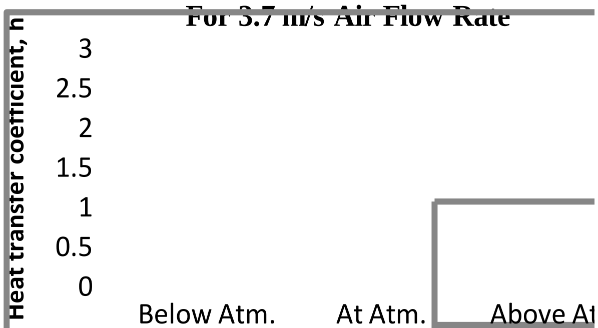


Figure 5: Graph of Heat input Vs efficiency for 3.7 m/s flow rate

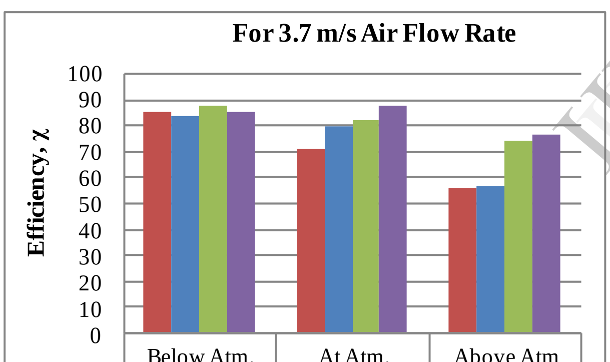
Figure shows that, for air flow rate of 3.7 m/s the efficiency increases as heat input increases. The efficiency increases as heat input increases. Also efficiency is higher at below atmospheric temperature and lower at above atm. Temperature.



	Below Atm.	At Atm.	Above Atm.
60V	1.85	2.41	2.72
80V	1.99	2.19	2.29
100V	1.75	2.11	1.8

Figure 6: Graph of heat transfer coefficient at different environmental conditions for 3.7 m/s flow rate

Figure shows that, for 3.7 air flow rate heat transfer coefficient is higher at above atm. Temperature and lower at below atm. Temperature. For 60 V input h is higher at above atmospheric temperature and lower at below atmospheric temperature. Similarly for increase in voltage same results are obtained.



	Below Atm.	At Atm.	Above Atm
60V	84.62	70.8	55.29
80V	83.36	79.13	56.15
100V	87.43	81.49	74.01
120V	84.69	87.53	76.48

Figure 7: Graph of efficiency at different environmental conditions for 3.7 m/s flow rate

Figure shows that, for 3.7 air flow rate efficiency is higher at below atm. Temperature and lower at above atm. Temperature. The efficiency is higher at below atmospheric temperature and lower at above atm. Temperature.

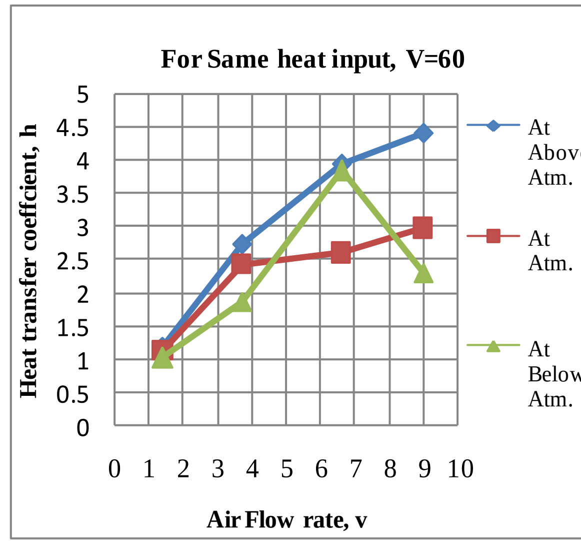


Figure 8: Graph of air flow rate Vs heat transfer coefficient for V=60

For same heat input (i.e. at V = 60) as flow rate increases heat transfer coefficient increases for different environmental conditions.

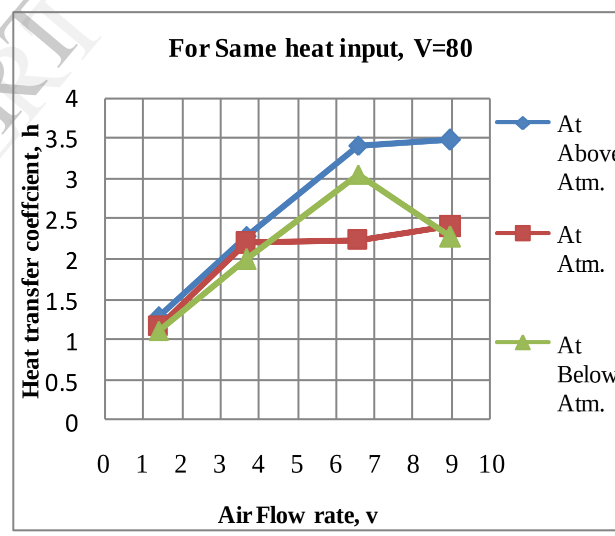


Figure 9: Graph of air flow rate Vs heat transfer coefficient for V=80

For same heat input (i.e. at V = 80) as flow rate increases heat transfer coefficient increases for different environmental conditions.

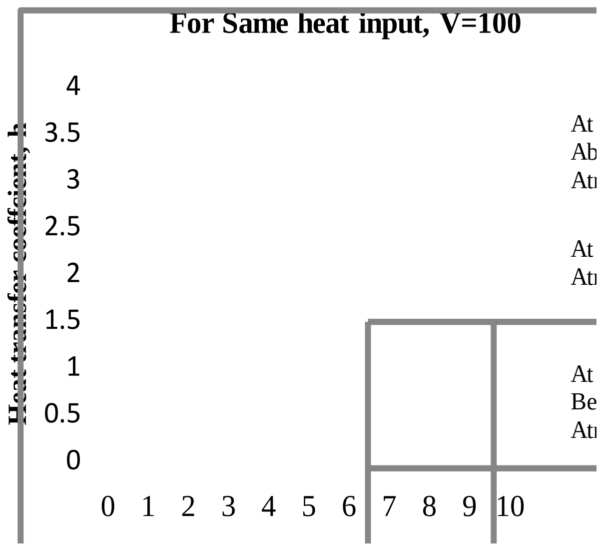


Figure 10: Graph of air flow rate Vs heat transfer coefficient for V=100

For same heat input (i.e. at V = 100) as flow rate increases heat transfer coefficient increases for different environmental conditions.

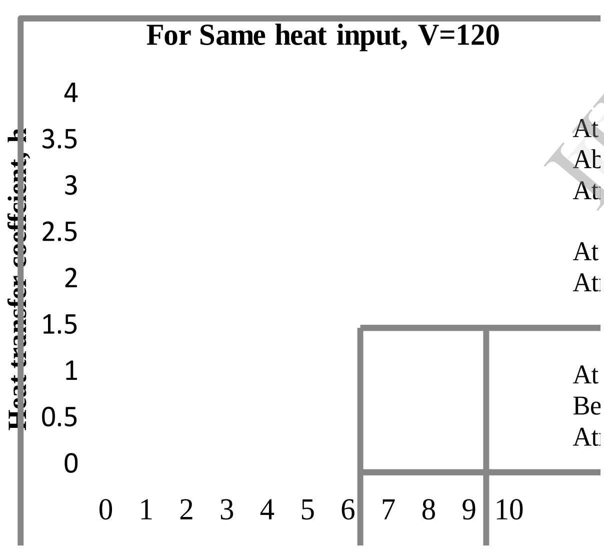


Figure 11: Graph of air flow rate Vs heat transfer coefficient for V=120

For same heat input (i.e. at V = 120) as flow rate increases heat transfer coefficient increases for different environmental conditions

5. "CFD results"

Case 1: 3.7 m/s flow rate at atm. temp. and V = 60

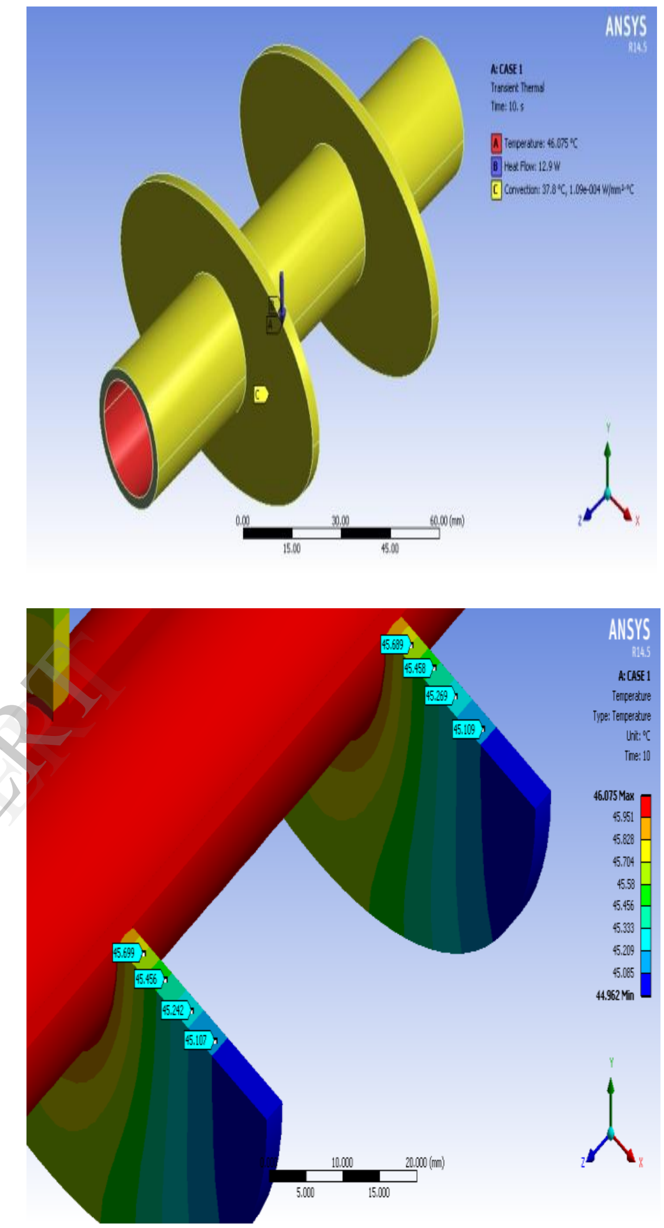


Figure 12: Boundry conditions with their respective results of case 1

Case 2: 3.7 m/s flow rate at atm. temp. and V = 80

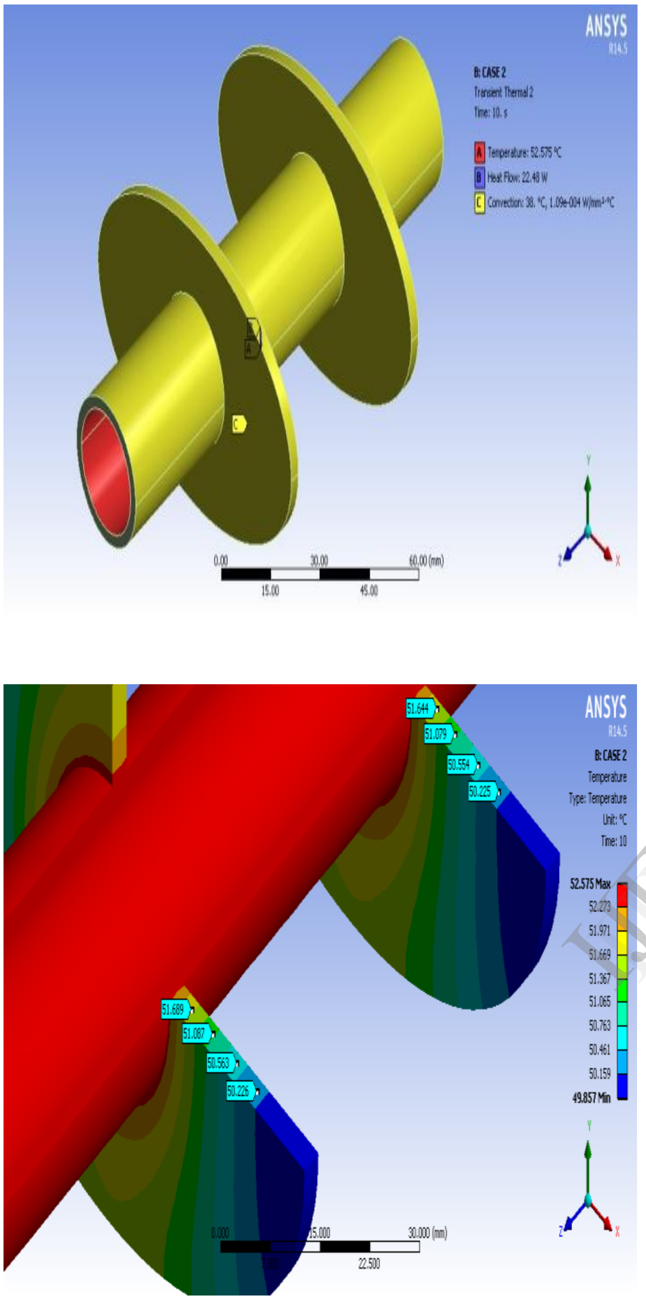


Figure 13: Boundry conditions with their respective results of case 2

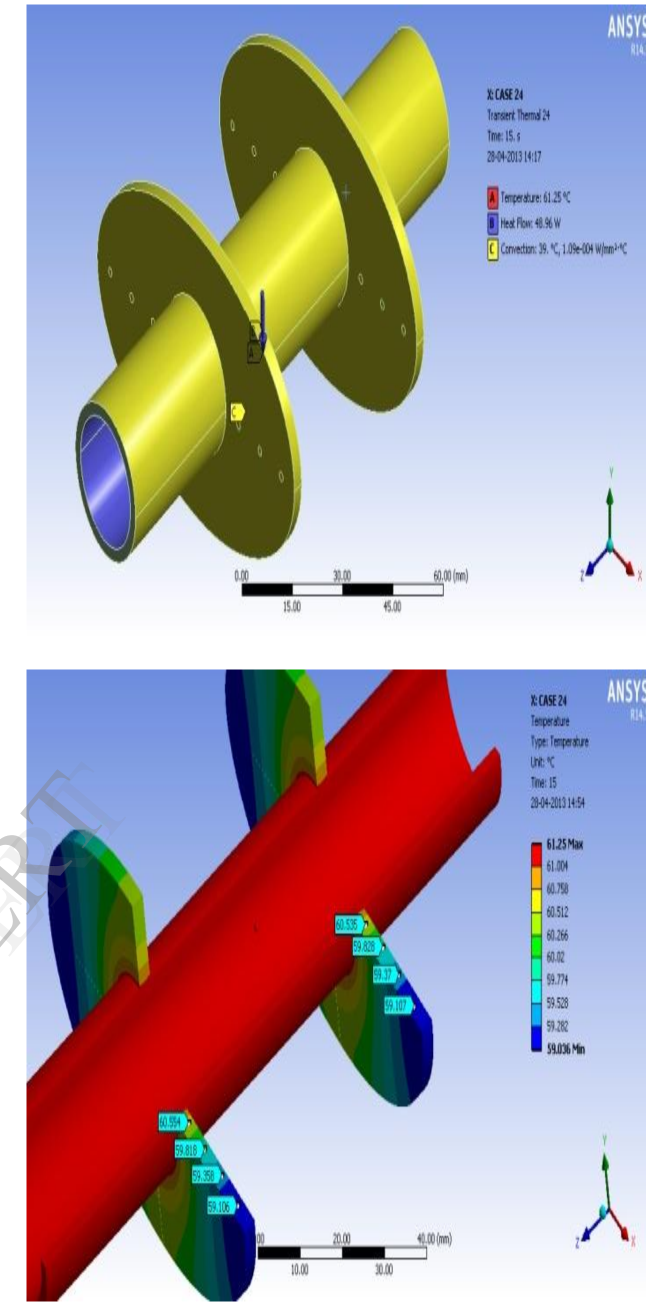


Figure 14: Boundry conditions with their respective results of case 3

Case 3: 3.7 m/s flow rate at atm. temp. and V = 100

Case 4: 3.7 m/s flow rate at atm. temp. and V = 120

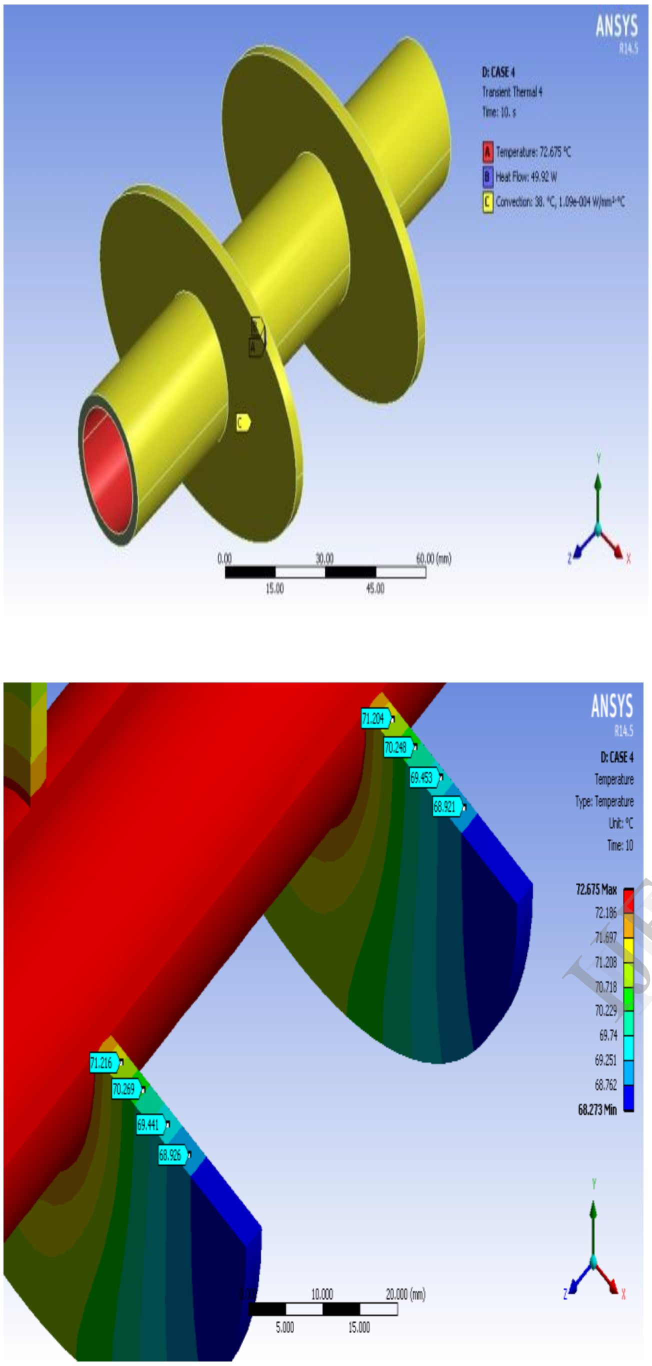


Figure 15: Boundry conditions with their respective results of case 4

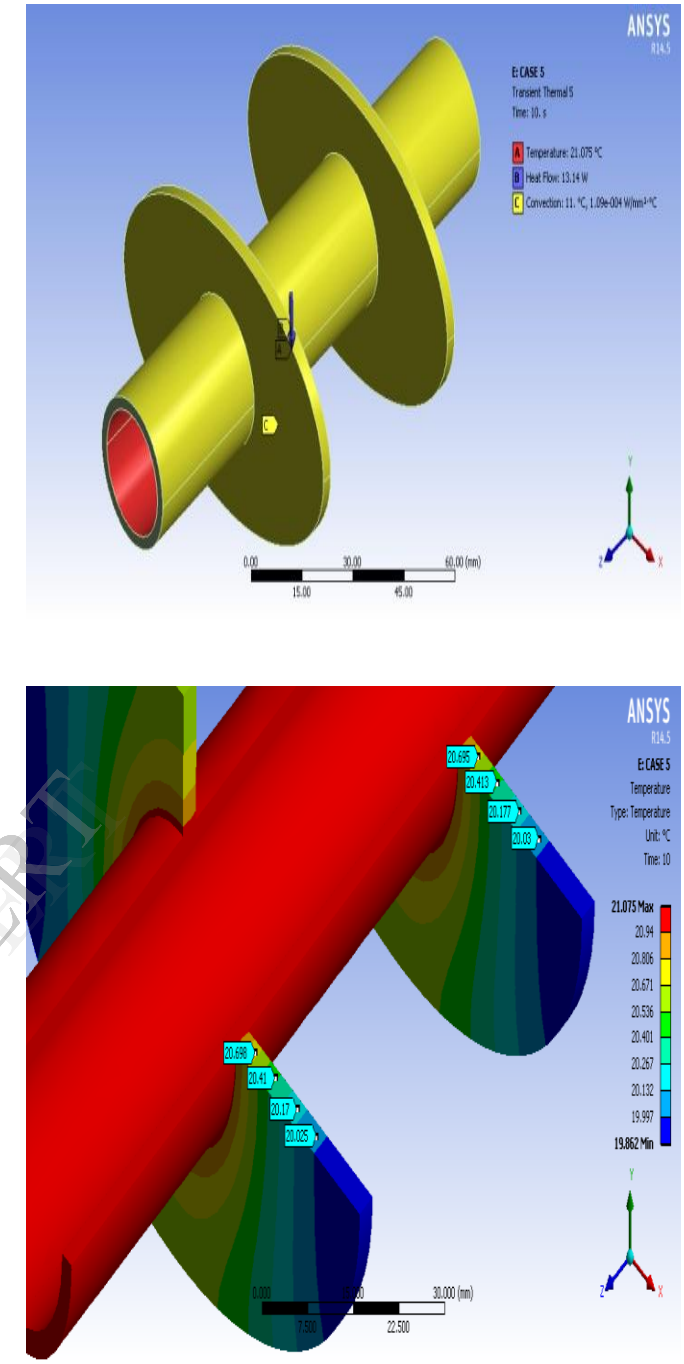


Figure 16: Boundry conditions with their respective results of case 5

Case 5: 3.7 m/s flow rate at below atm. temp. And V = 60

Case 6: 3.7 m/s flow rate at below atm. temp. And V = 80

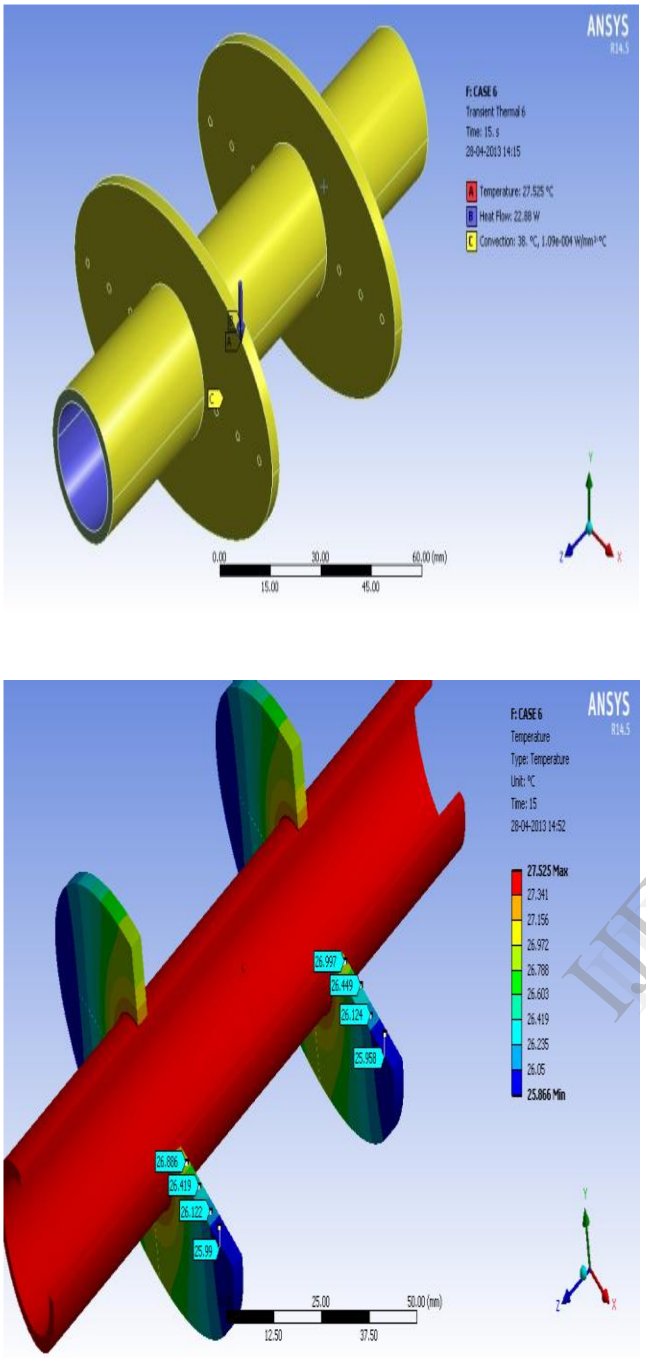


Figure 17: Boundry conditions with their respective results of case 6

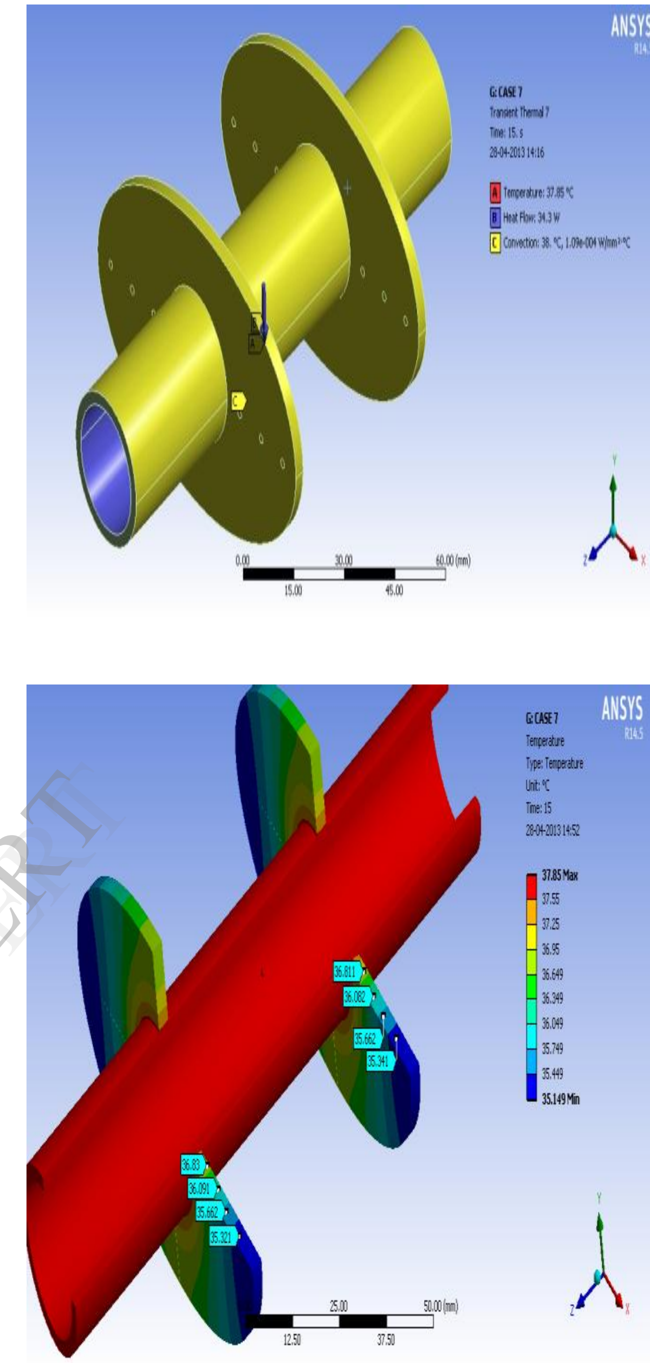


Figure 18: Boundry conditions with their respective results of case 7

Case 7: 3.7 m/s flow rate at below atm. temp. And V = 100

Case 8: 3.7 m/s flow rate at below atm. temp. And V = 120

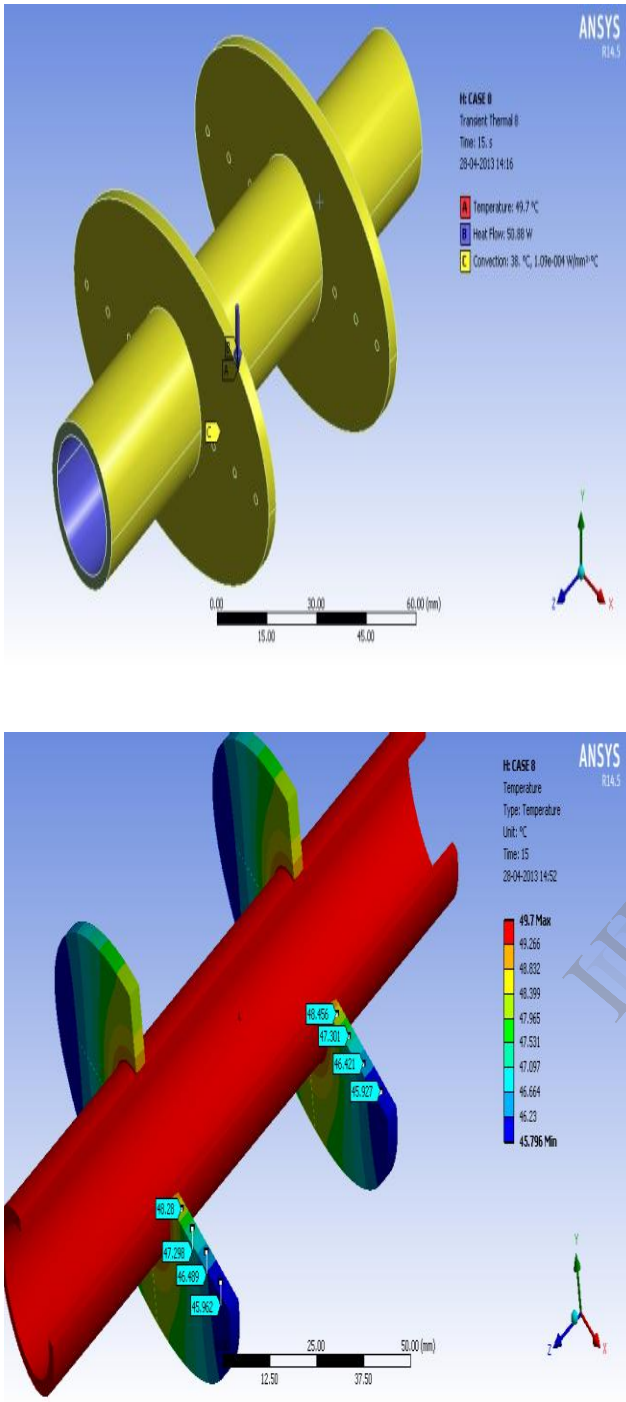


Figure 19: Boundry conditions with their respective results of case 8

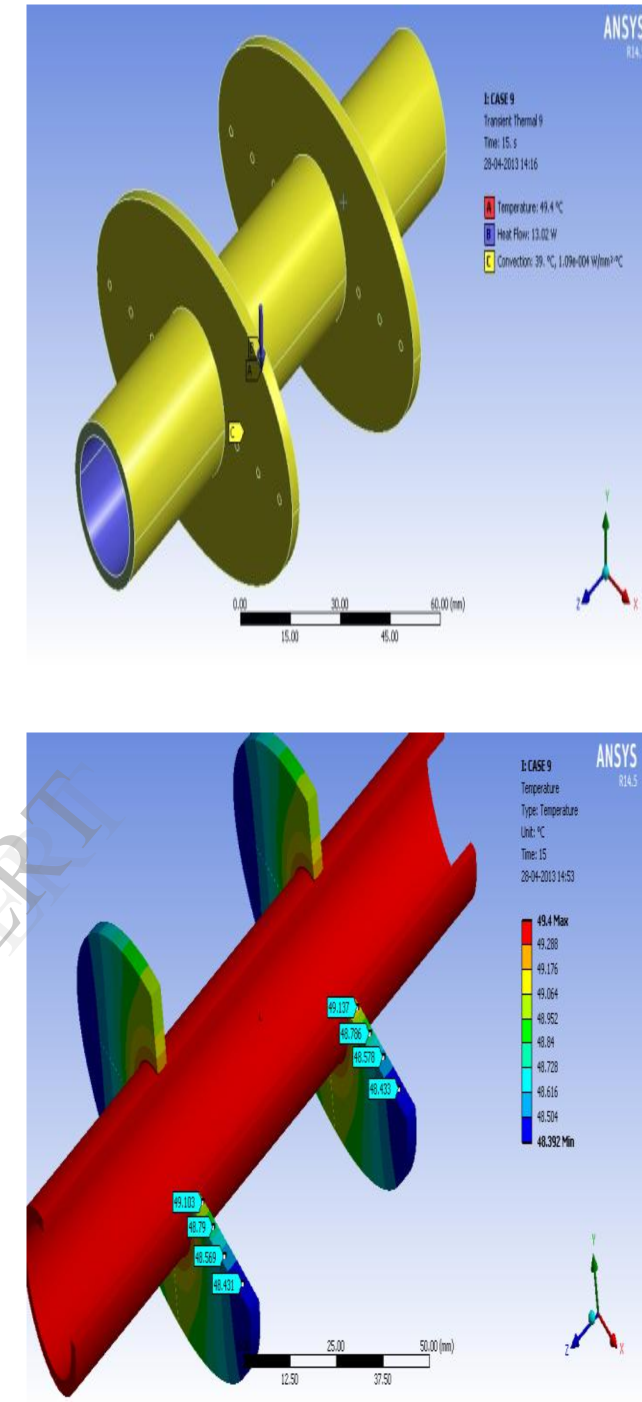


Figure 20: Boundry conditions with their respective results of case 9

Case 9: 3.7 m/s flow rate at above atm. temp. And V = 60

Case 10: 3.7 m/s flow rate at above atm. temp. And V = 80

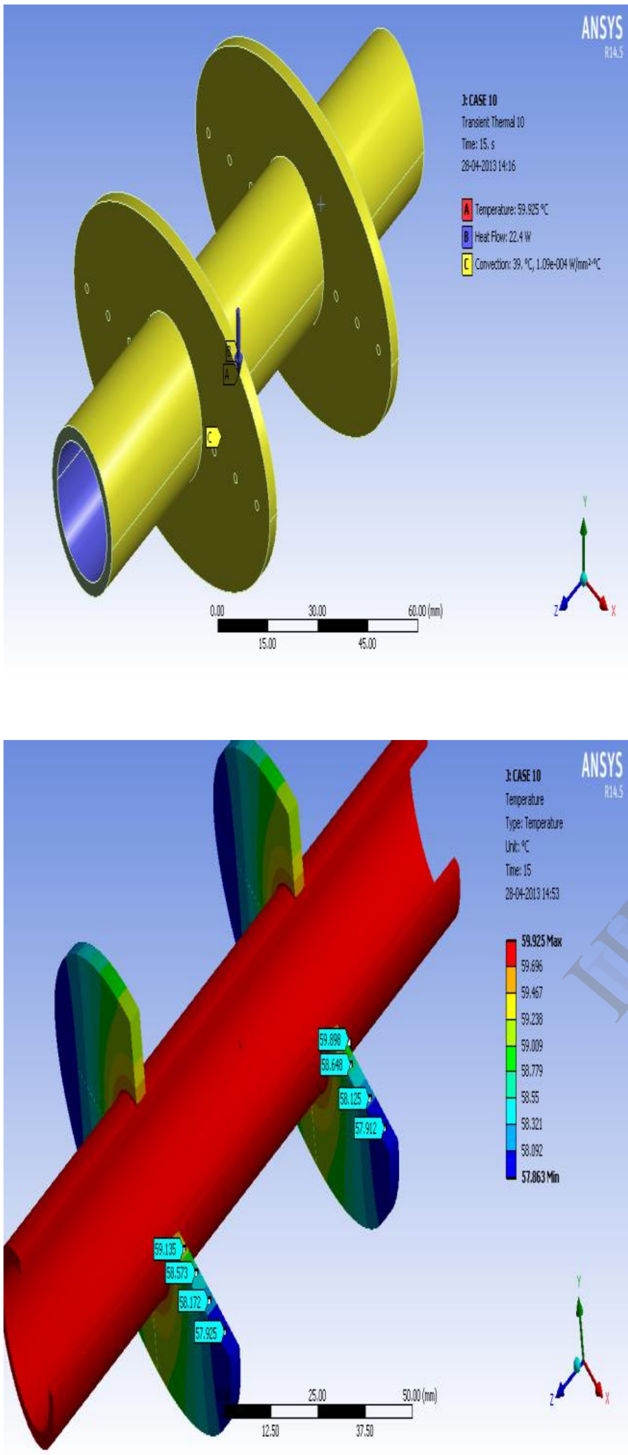


Figure 21: Boundry conditions with their respective results of case 10

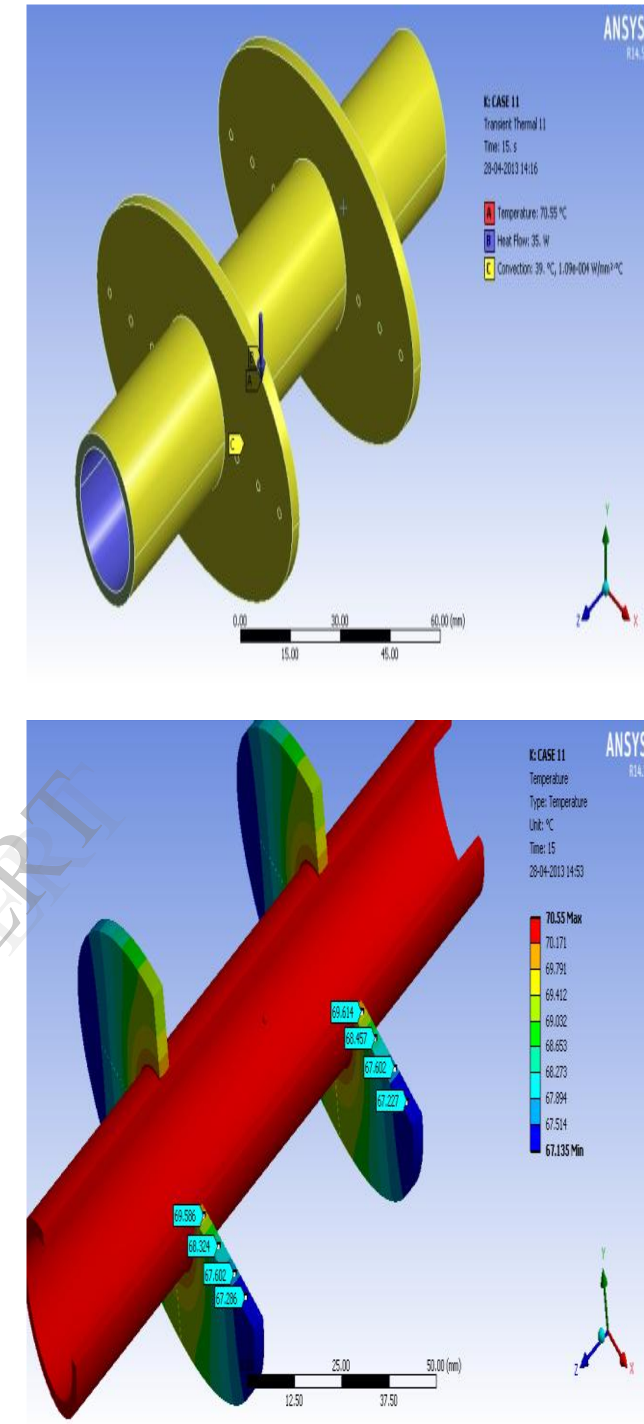


Figure 22: Boundry conditions with their respective results of case 11

Case 11: 3.7 m/s flow rate at above atm. temp. And V = 100

Case 12: 3.7 m/s flow rate at above atm. temp. And V = 120

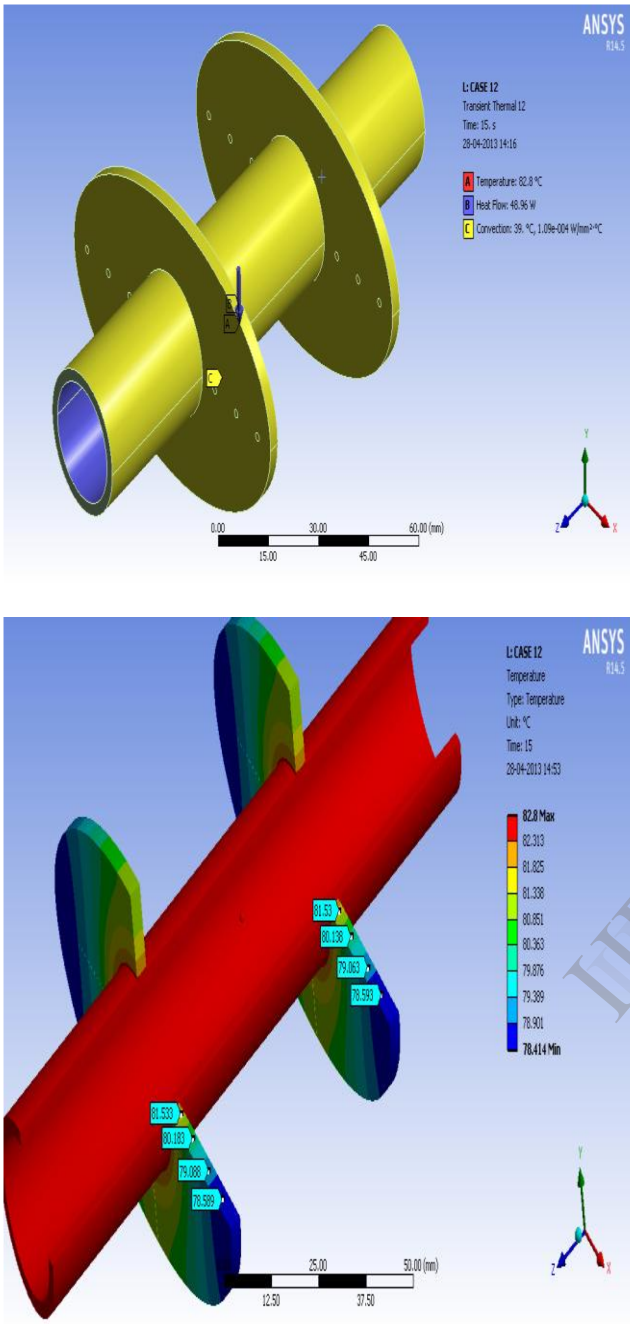


Figure 23: Boundry conditions with their respective results of case 12

6. "Conclusions"

i. At air flow rate of 3.7 m/s the heat transfer rate decreases as heat input increases. Also h is higher at above atmospheric temperature and lower at below atm. Temperature.

ii. At air flow rate of 3.7 m/s the efficiency increases as heat input increases. The efficiency increases as heat input increases. Also efficiency is higher at below atmospheric temperature and lower at above atm. Temperature.

iii. At 3.7 air flow rate heat transfer coefficient is higher at above atm. Temperature and lower at below atm. Temperature. For 60 V input h is higher at above atmospheric temperature and lower at below atmospheric temperature

iv. At 3.7 air flow rate efficiency is higher at below atm. Temperature and lower at above atm. Temperature. The efficiency is higher at below atmospheric temperature and lower at above atm. Temperature.

v. For same heat input (i.e. at V = 60) as flow rate increases heat transfer coefficient increases for different environmental conditions.

vi. For same heat input (i.e. at V = 80) as flow rate increases heat transfer coefficient increases for different environmental conditions.

vii. For same heat input (i.e. at V = 100) as flow rate increases heat transfer coefficient increases for different environmental conditions.

viii. For same heat input (i.e. at V = 120) as flow rate increases heat transfer coefficient increases for different environmental conditions.

ix. For 3.7 m/s flow rate at atm. temp. and V = 60, V=80, V=100 and V=120, CFD results shows that the temperature is gradually decreasing on major axis of elliptical fin

x. Experimental results show that the temperatures at middle of fin indicate slight increase in temp. That is because of combined effect of convection and conduction.

xi. CFD results are verified with experimental results for all cases.

7. "Future scope"

i. Heat transfer rate can be increased by providing a notch on major axis of elliptical fin. The heat transfer rate will vary for different ratio of major to minor axis. There probably would be different other shapes and sizes for which the rate of heat transfer would be maximum. In the future work, the size of notch may also be considered. The same methodology of experimental investigation and computational analysis can be used further for different types of notches and fins.

ii. The environmental conditions affect the heat transfer so experimentation can be done at different humid conditions.

iii. The distance between two fins is also taken into account.

iv. At different atmospheric conditions heat transfer coefficient & efficiency can be analyzed with different aspect ratio of elliptical fin.

8. "References"

[1] Nagarani and k. maysilsamy "Experimental heat transfer analysis on annular circular and elliptical fins" International Journal of Engineering Science and Technology Vol. 2(7) 2010, pp 2289-2845

[2] W. A. Khan, "The Role of Fin Geometry in Heat Sink Performance", Journal of Electronic Packaging DECEMBER 2006, Vol. 128 / 325Vol. 128, DECEMBER 2006 Copyright © 2006 by ASME Transactions of the ASME

[3] Pulkit Agraawal, Mayur Shirkhande and p. Shinivasan "Heat transfer simulation by CFD from fins of an air cooled Motorcycle engine under varying climatic condition" Proceeding of world congress on engineering, 2011, vol III WCE-2011, July 6-8, 2011, London.

[4] Christopher L. Chapman, and Seri Lee, "Thermal Performance Of An Elliptical Pin Fin Heat Sink" 0-7803-18S2-8/W/$3 .00 01984 IEEE Tenth IEEE SEMI-THERMP

[5] Monoj Baruah1, Anupam Dewan Department of Mechanical Engineering, Indian Institute of Technology Guwahati, and P. Mahanta1 Department of Applied Mechanics, Indian Institute of Technology Delhi, in CFD Letters Vol. 3 (2) – June 2011

[6] Denpong Soodphakdee, Masud Behnia, and David Watabe Copeland, "A Comparison of Fin Geometries for Heat sinks in Laminar Forced Convection: Part I - Round, Elliptical, and Plate Fins in Staggered and In-Line Configurations" The International Journal of Microcircuits and Electronic Packaging, Volume 24, Number 1, First Quarter, 2001 (ISSN 1063-1674)

[7] Chien-Nan Lin, "A two-dimensional fin efficiency analysis of combined heat and mass transfer in elliptic fins", International Journal of Heat and Mass Transfer 45 (2002) 3839–3847

[8] O˘ Guz Uzol _, Cengiz Camci, "Elliptical Pin Fins As An Alternative To Circular Pin Fins For Gas Turbine Blade Cooling Applications turbo machinery" Heat Transfer Laboratory Department of Aerospace Engineering Pennsylvania State University University Park, Pa 16802

[9] S.H. Barhatte1, M. R. Chopade, V. N. Kapatkar, "Experimental And Computational Analysis And Optimization For Heat Transfer Through Fins With Different Types Of Notch", Journal Of Engineering Research And Studies E-Issn 0976-7916 Jers/Vol.Ii/ Issue I/January-March 2011/133-138

[10] Antonio Acosta, Antonio campo "Approximate analytic temperature distribution and efficiency for annular fins of uniform thickness", May 2008.

[11] Prasanta ku. Das "Heat conduction through heat exchanger tubes of non-circular cross section", Journal of Heat transfer vol .130, January 2008.

[12] B.Kundu, P.K.Das, "Performance analysis and optimization of elliptic fins circumscribing a circular tube", International journal of Heat and Mass Transfer 50 (2007)173-180.

[13] Chine-Nan lin, Jiin-yuh jang "A two dimensional fin efficiency analysis of combined heat & mass transfer in elliptic fins". International journal of heat and mass transfer 45(2002.)3839-3847.

[14] Ahmet N.Ereslan ,Turgut Tokdemir, "Thermo elastic response of a fin exhibiting elliptic thickness profile" international journal of thermal science 47(2008)274-281.

[15] Mi sandar Mon, Ulrich Gross "Numerical study of fin spacing effects in annular finned tube heat exchanger", International Journal of Heat and Mass Transfer 47 (2004)

[16] Han Taw Chen, Wei-Lun Hsu, Estimation of heat transfer co efficient on the fin of annular finned tube heat exchangers in natural convection for various fin spacing's, International Journal of Heat & Mass Transfer (2007) 1750-1761.

[17] Wei-Lun Hsu, "Estimation of heat transfer co efficient on the fin of annular finned tube heat exchangers in natural convection for various fin spacing's", International Journal of Heat & Mass Transfer (2007) 1750-1761

[18] Anil Kumar Rao1, Dr. B. B Saxena2, Prof Ravindra Kirar, "CFD Analysis Of Elliptical Pin Fin Heat Sink" International Journal of Engineering Research & Technology (IJERT) Vol. 2 Issue 3, March - 2013 ISSN: 2278-0181

[19]Sunil Hireholi, K.S. Shashishekhar, George. S. Milton, "Experimental And Theoretical Study Of Heat Transfer By Natural Convection Of A Heat Sink Used For Cooling Of Electronic Chip", International Journal Of Engineering Inventions E-Issn: 2278-7461, P-Issn: 2319-6491 Volume 2, Issue 2 (January 2013) Pp: 01-09