ANALYTICAL INVESTIGATIONS OF BOILING HEAT TRANSFER IN SMOOTH/MICRO-FIN TUBES OF DIFFERENT REFRIGERANTS

[1] RAFEEQ AHAMAD.M.S, [2] MUDE MURALI MOHAN NAIK,
[1] PG Student, [2] Assistant Professor & Head,
[1, 2] Department of Mechanical Engineering,
[1,2]Annamacharya Institute of Technology & Sciences, KADAPA, AP, INDIA

Abstract: Air conditioner condensers are a heat exchanger device; AC condenser units are grouped according to how it rejects the heat to the medium (surround air). The primary component of a condenser is typically the condenser coil, through which the refrigerant flows. Since, the AC condenser coil contains refrigerant that absorbs heat from the surrounding air, the refrigerant temperature must be higher than the air. In this paper designed an air-cooled Condenser fins for an air conditioner. Presently the material used for coils is Copper and the material used for Fins is Copper or aluminium G Al Cu 4IMG 204 whose thermal conductivity is 110-150W/m K. the condenser fines design using computer aided software catia. We are optimizing the design parameters by changing the thickness of the fin for the same length without failing the load conditions. To validate the temperatures and other thermal quantities like flux and gradient, thermal analysis is done on the condenser fins by applying copper for coil and Fin materials G Al Cu 4IMG 204, Aluminium Alloy Al99 and Magnesium alloy. Heat flux, directional heat flux, convection, Thermal analysis is done in ansys. And also we are varying inside cooling fluid Hydrocarbon (HC) and Hydro chloro flouro carbon (HCFC). The best material and best fluid for the condenser of our design can be checked by comparing the results. Optimization is done by changing the thickness of the catia is a parametric 3D modelling software and ansys is analysis software.

***IndexTerms* - Micro fin/groove Tubes, Refrigerator, Heat, small diameter copper tubes, HVAC Cool, Air Conditioner, titanium, Copper, Aluminium.**

I. INTRODUCTION

Conventional resources of energy are depleting at an alarming rate, which makes future sustainable development of energy use very difficult. As a result, considerable emphasis has been placed on the development of various augmented heat transfer surfaces and devices. Heat transfer augmentation techniques are generally classified into three categories namely: active techniques, passive techniques and compound techniques. Passive heat transfer techniques (ex: tube inserts) do not require any direct input of external power. Hence many researchers preferred passive heat transfer enhancement techniques Micro fin tube is one of the passive heat transfer technique. Micro fin tubes which are also called as microgroove tubes meaning, micro means small diameter tube and fin or groove means enhancements in the form of groove or fin which are formed by cutting the internal thickness of tube. Because of fin or groove inside tubes, the boundary layers formation is reduced against the refrigerant flowing inside tube, surface area of contact of refrigerant along the tube material is increased because of small diameter of tube carrying refrigerant. Evaporator and condenser are the two heat exchangers where micro fin tubes are used in HVAC and refrigeration system. Due to two characteristics of reduced or non-boundary layer formation and increased tube surface area of contact with refrigerant flowing in it, the micro fin tubes are characterized by high heat transfer coefficients, low pressure drop penalty, less material consumption in manufacturing of condenser and evaporator in refrigeration/HVAC system and reduction of refrigerant charge in refrigeration/HVAC equipment. Due to these two excellent advantages Micro fin /groove tubes are widely used in residential HVAC industry and automobile cooling system.

II. LITERATURE REVIEW

G.B. Jiang[1], The refrigerants tested were R22, R134a, R407C and R410A while vapour quality ranges from 0.1 to 0.9, mass flux 50, 250, 450 kg m2 s 1 and heat flux of 5, 12.5, 20 kW m2 The saturation temperature is 5 C. For the smooth tube, the average heat transfer coefficients of R134a, R407C and R410A are 110.9%, 78.0% and 125.2% of those of R22 in test conditions respectively. For the micro-fin tube, the average heat transfer coefficients of R22, R134a, R407C and R410A are 1.86, 1.80, 1.69 and 1.78 times higher than those of the smooth tube. The pressure drop of R22, R407C and R410A for the smooth tube is similar to each other while the pressure drop of R134a is 1.7 times higher. The average pressure drop of R22, R134a, R407C and R410A for the micro-fin tube is 1.42, 1.30, 1.45 and 1.40 times higher when compared with that for the smooth one. Considering the effect of heat transfer enhancement and pressure drop augment, the efficiency index g1 which values the thermo-hydraulic performance at identical flow rate of R22, R134a, R407C and R410A in the micro-fin tube used is 1.31, 1.38, 1.17 and 1.27 respectively compared with the smooth tube.

S. Wellsandt [2] An experimental investigation of in-tube evaporation of R134a has been carried out for a 4 m long herringbone micro fin tube with an outer diameter of 9.53 mm. Measured local heat transfer coefficients and pressure losses are reported for evaporation temperatures between K0.7 and 10.1 8C and mass flow rates between 162 and 366 kg mK2 s K1 . Results from this work are compared to experimental results from literature as well as predicted values from some available helical micro fin correlations. Differences in heat transfer mechanisms between helical and herringbone micro fin tubes are discussed, as heat transfer coefficients in the investigated herringbone tube tend to peak at lower vapour qualities compared to helical micro fins. Correlations developed for helical micro fin tubes generally predict experimental values within G30% for vapour qualities below 50%. However, at higher qualities none of the correlations are able to reflect the early peak of heat transfer coefficients.

S. Mukul Ray [3] Review of Nucleate Pool Boiling Heat Transfer using Refrigerant, The pool boiling process occurs in the shell side of flooded evaporators and low pressure refrigerants are proposed for industry applications. Enhancement of heat transfer rate depends on different design of heating surface, type of refrigerant and operating parameters like heating surface roughness, surface orientation, operating pressure & temperature. Refrigerant plays a crucial role in the study of nucleate pool boiling heat transfer. Various inferences have been drawn based on the existing parameters by different researchers for enhancement of heat transfer rate.

In this paper a detailed [8] study has been carried out using different refrigerants on different surfaces to investigate the optimum value of heat transfer coefficients (HTC). The process could be further investigated using heat transfer enhancement particles such as Nano fluids and modification of the heating the pool boiling process occurs in the shell side of flooded evaporators and low pressure refrigerants are proposed for industry applications. Enhancement of heat transfer rate depends on different design of heating surface, type of refrigerant and operating parameters like heating surface roughness, surface orientation, operating pressure & temperature. Refrigerant plays a crucial role in the study of nucleate pool boiling heat transfer. Various inferences have been drawn based on the existing parameters by different researchers for enhancement of heat transfer rate.

III. 3D MODELING AND ANALYSIS OF MICRO FIN TUBES

A. MODELLING AND ANALYSIS

The reference for the modelling and analysis of micro fin tubes is taken from journal paper "G.B. Jiang a, J.T. Tan b, Q.X. Nian a, W.Q. Tao a, Experimental study of boiling heat transfer in smooth/micro-fin tubes of four refrigerants, International Journal of Heat and Mass Transfer 98 (2016) 631–642" specified as [1] in References chapter. The use of computational fluid dynamics (CFD) in the design and troubleshooting of HRSGs is now well established. However, the large ratio of scales between the overall flow path and the tube bundles themselves means that the bundles must be approximated using "porous media" models, with heat transfer and flow resistance simulated using lumped parameters. The parameters input into these models are taken from the open literature, proprietary data, and/or approximate analytical models. In the case of plain tubes, two-dimensional CFD models have been used to supplement this information. For the finned tubes used in HRSGs, however, 2D models will not suffice and 3D models can quickly become unwieldy.

This work was motivated by a desire to use computational methods to predict the onset of flow-induced vibration (FIV) in the leading superheater tube bundles of heat recovery steam generators (HRSG). These bundles are susceptible to vibration caused by turbulent buffeting as the flow from the gas turbine impinges upon the leading tubes and, to a lesser extent, familiar FIV mechanisms such as fluid-elastic whirl and vortex shedding.

B. FIN HEIGHT – 5mm

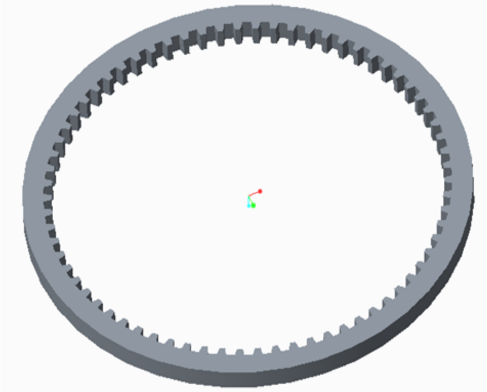


Fig. 1 3D of fin height – 5mm

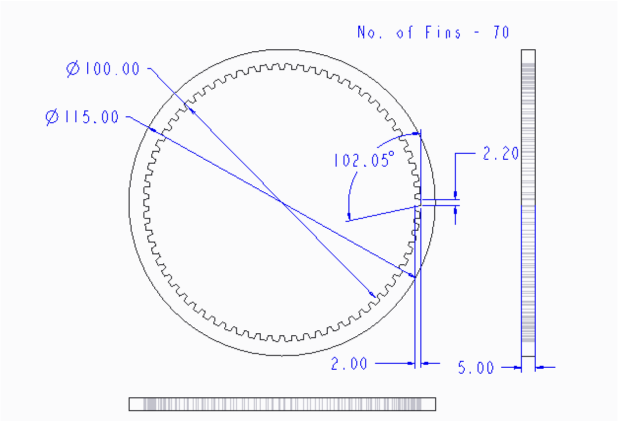


Fig. 2 2D Drawing of fin height – 5mm

C. FIN HEIGHT – 3mm

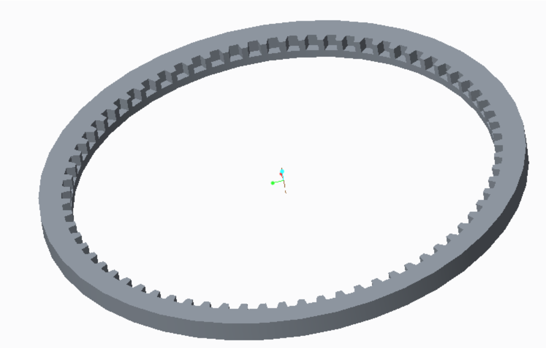


Fig. 3 3D of fin height – 3mm

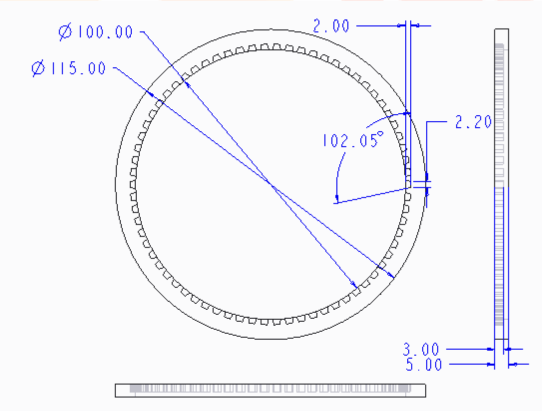


Fig. 4 2D Drawing of fin height – 3mm

IV. CFD ANALYSIS OF BOILING HEAT TRANSFER IN MICRO-FIN TUBES

CFD analysis is performed in fluent environment by applying the properties of different fluids to determine pressures, heat transfer coefficients and heat transfer rates.

A. FLUID PROPERTIES

R22
Density: 1409.2 kg/m^3
Cp: 1.090 kj/ (kg-k)
Thermal conductivity: 113.5 W/ (m-k)
Viscosity: 346.0 Pa’s
R134A
Density: 1376.7 Kg/m^3
Cp: 1.281 KJ/Kg-K
Thermal conductivity: 103.9 W/m-K
Viscosity: 384.2 Pa’s
R407C
Density: 1380.7 Kg/m^3
Cp: 0.787 KJ/Kg-K
Thermal conductivity: 127.9 W/m-K

Viscosity: 384.6 Pa’s

R410A

Density: 1349.7 Kg/m^3
Cp: 1.370 KJ/Kg-K
Thermal conductivity: 151.3 W/m-K
Viscosity: 346.4 Pa’s

B. FIN HEIGHT – 5mm

Save Pro-E Model as .iges format

→→Ansys → Workbench→ Select analysis system → Fluid Flow (Fluent) → double click
→→Select geometry → right click → import geometry → select browse →open part → ok

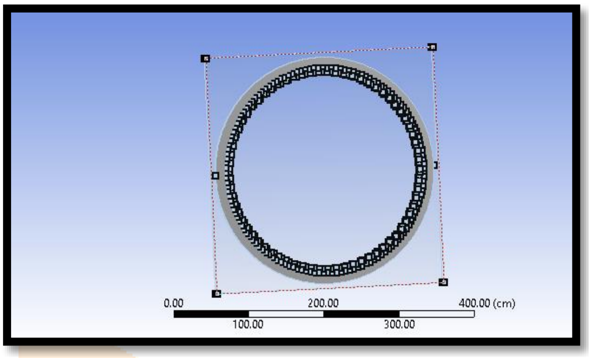


Fig. 5 imported geometry

→→ select mesh on work bench → right click →edit
Select mesh on left side part tree → right click → generate mesh →

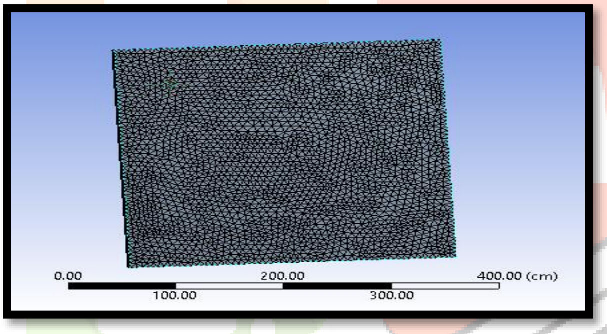


Fig. 6 meshing

C. FLUID - R22

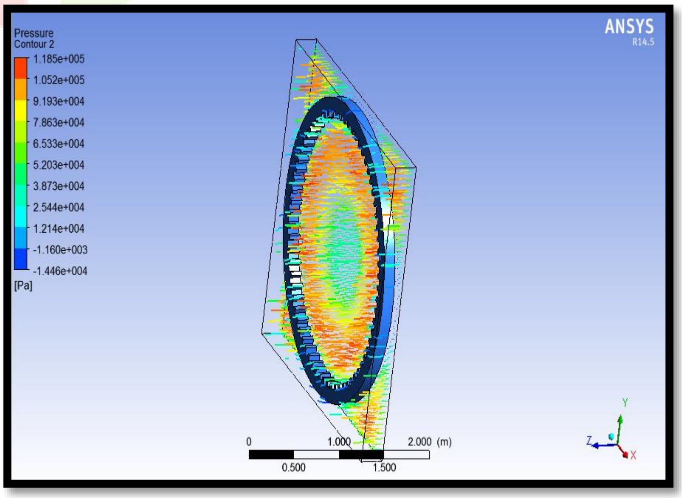


Fig. 7 pressure

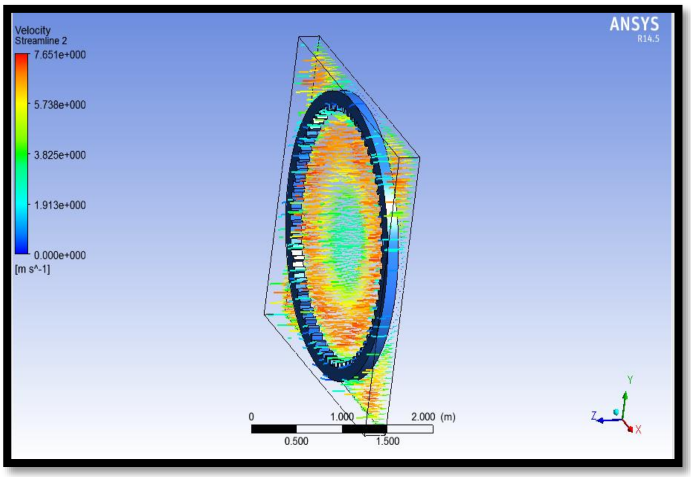
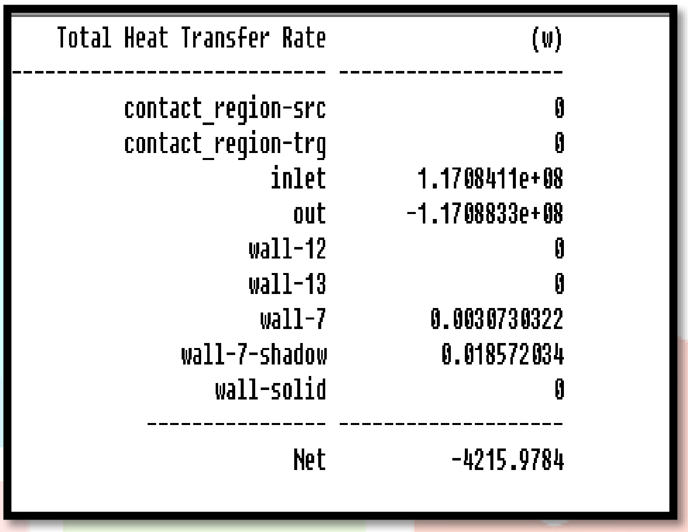


Fig. 8 velocity



```
  Total Heat Transfer Rate                      (w)
-------------------------------- --------------------
          contact_region-src                      0
          contact_region-trg                      0
                       inlet          1.1708411e+08
                         out         -1.1708833e+08
                     wall-12                      0
                     wall-13                      0
                      wall-7           0.0030730322
               wall-7-shadow            0.018572034
                  wall-solid                      0
               ---------------- --------------------
                         Net             -4215.9784
```

Fig. 9 total heat transfer rate

D FLUID - R134A

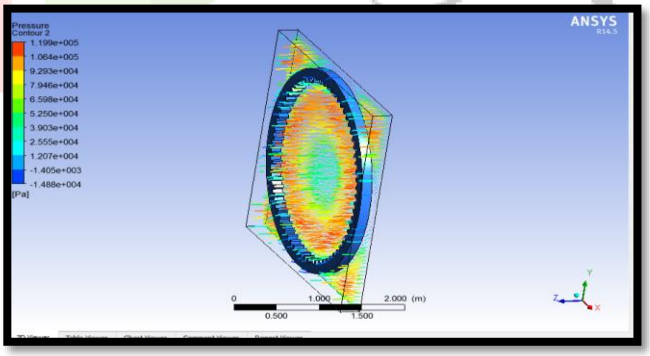


Fig. 10 Pressure

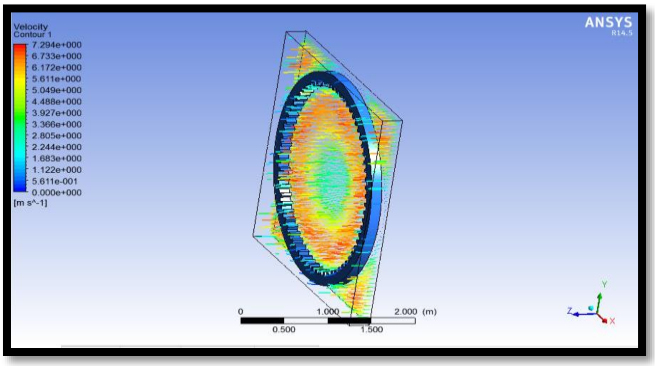


Fig. 11 velocity

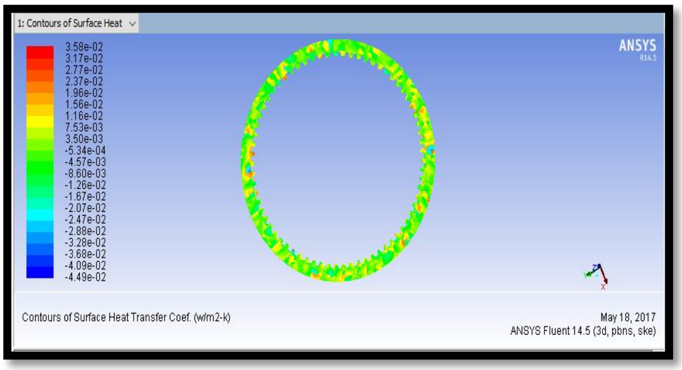
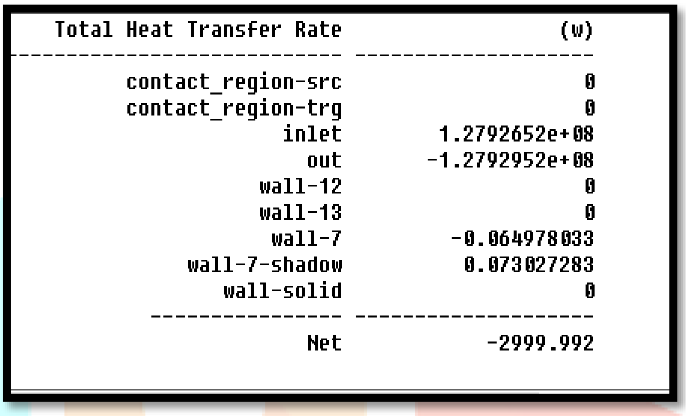


Fig. 12 heat transfer coefficient



```
     Total Heat Transfer Rate                    (w)
---------------------------- --------------------
           contact_region-src                    0
           contact_region-trg                    0
                        inlet        1.2792652e+08
                          out       -1.2792952e+08
                      wall-12                    0
                      wall-13                    0
                       wall-7         -0.064978033
                wall-7-shadow          0.073027283
                   wall-solid                    0
            ---------------- --------------------
                          Net            -2999.992
```

Fig. 13 total heat transfer rate

E. FLUID – R407C

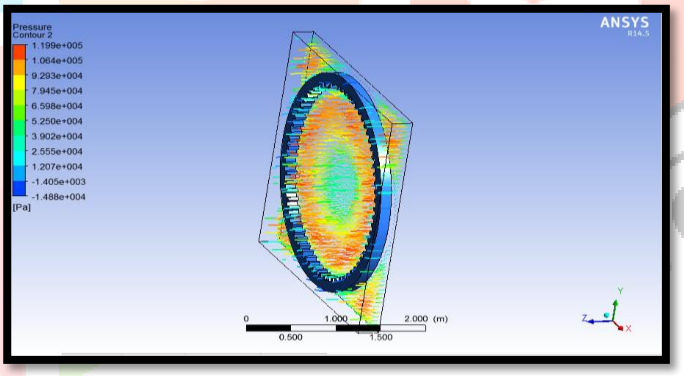


Fig. 14 pressure

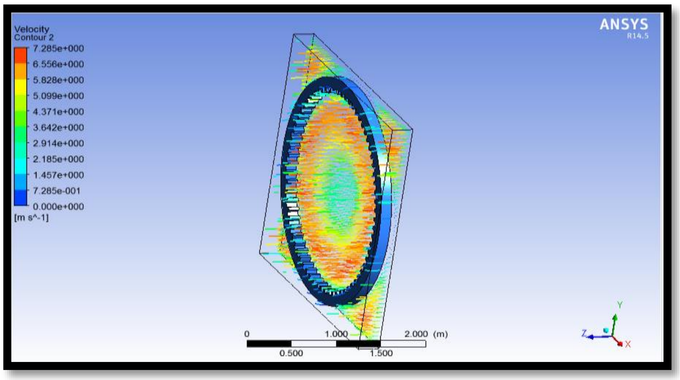


Fig. 15 velocity

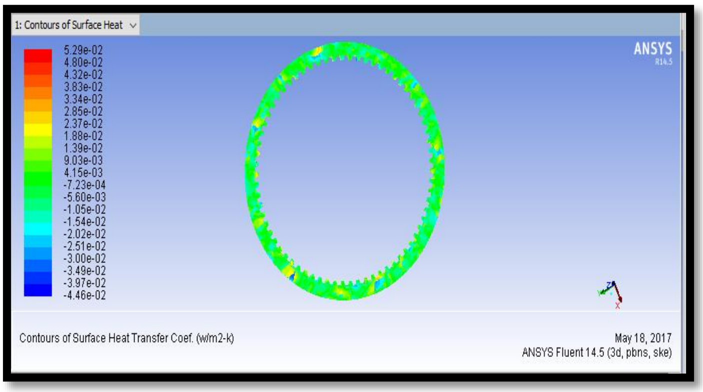
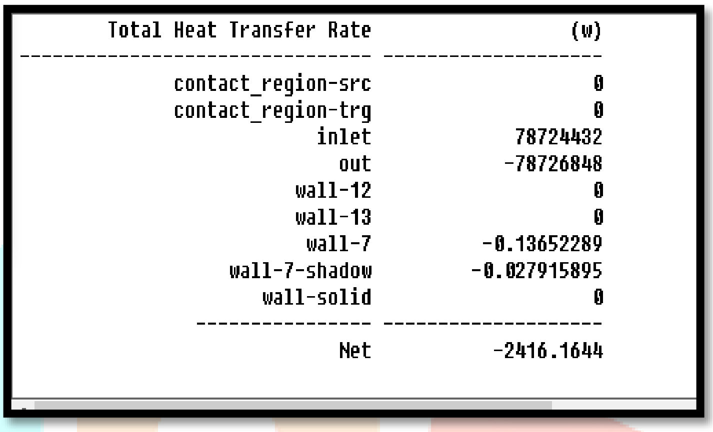


Fig. 16 heat transfer coefficient



```
             Total Heat Transfer Rate                  (w)
-------------------------------- --------------------
                contact_region-src                    0
                contact_region-trg                    0
                             inlet             78724432
                               out            -78726848
                           wall-12                    0
                           wall-13                    0
                            wall-7          -0.13652289
                     wall-7-shadow         -0.027915895
                        wall-solid                    0
                ---------------- --------------------
                               Net           -2416.1644
```

Fig. 17 total heat transfer rate

F. FLUID - R410A

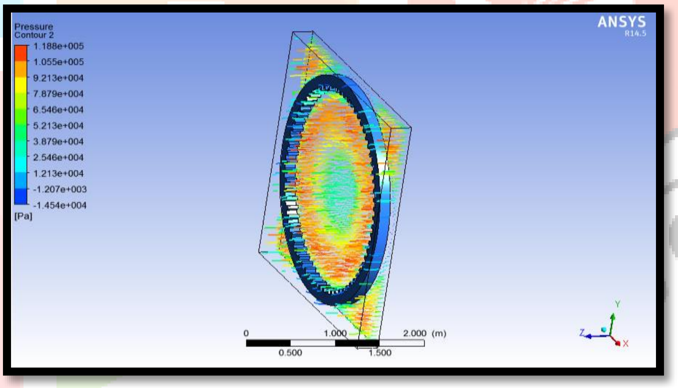


Fig. 18 pressure

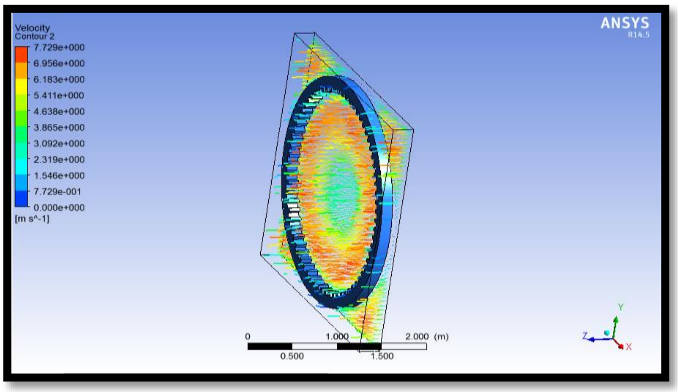


Fig. 19 velocity

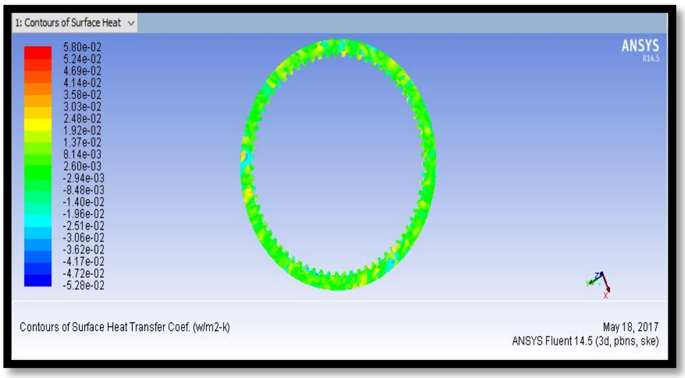
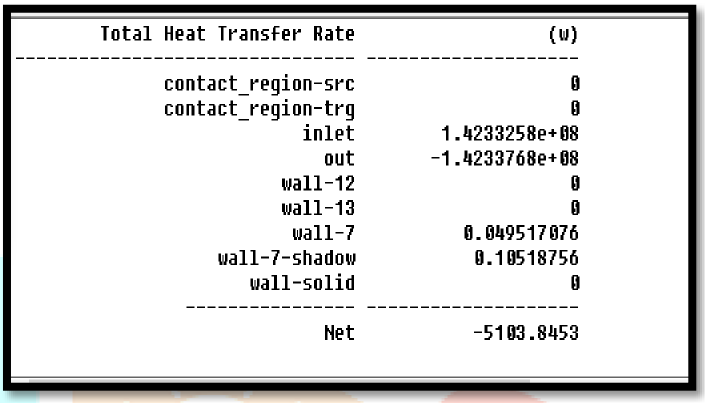


Fig. 20 heat transfer coefficient



```
            Total Heat Transfer Rate                   (w)
-------------------------------- --------------------
             contact_region-src                    0
             contact_region-trg                    0
                          inlet        1.4233258e+08
                            out       -1.4233768e+08
                        wall-12                    0
                        wall-13                    0
                         wall-7          0.049517076
                  wall-7-shadow           0.10518756
                     wall-solid                    0
                ---------------- --------------------
                            Net           -5103.8453
```

Fig. 21 total heat transfer rate

G. HEIGHT – 3mm

i.FLUID - R22

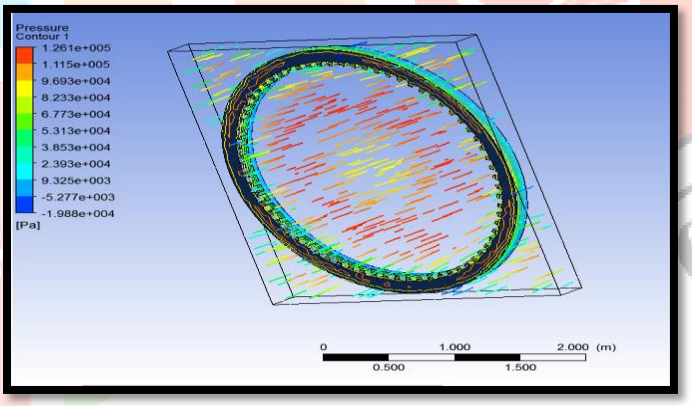


Fig. 22 pressure

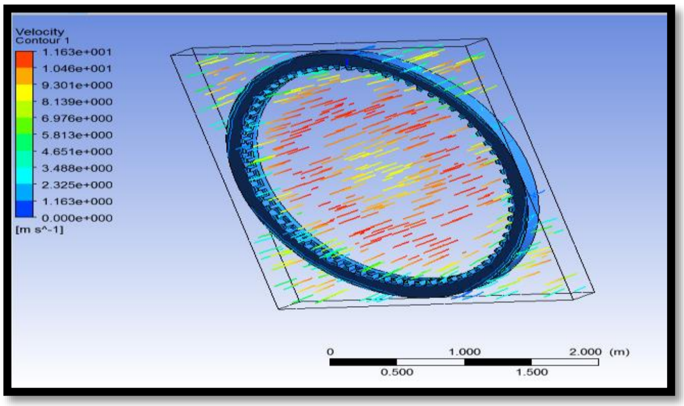
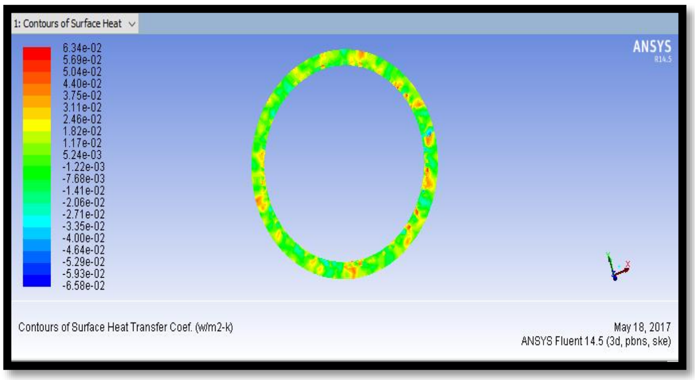


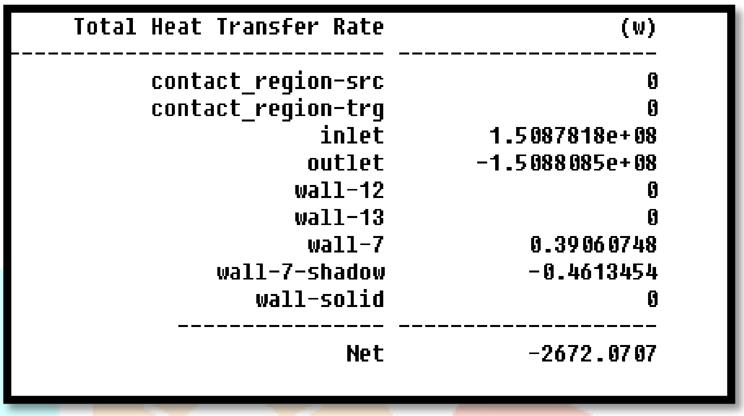
Fig. 23 velocity



Contours of Surface Heat Transfer Coef. (w/m2-k)

May 18, 2017
ANSYS Fluent 14.5 (3d, pbns, ske)

Fig. 24 heat transfer coefficient



```
     Total Heat Transfer Rate                        (w)
-------------------------------- --------------------
           contact_region-src                          0
           contact_region-trg                          0
                        inlet              1.5087818e+08
                       outlet             -1.5088085e+08
                      wall-12                          0
                      wall-13                          0
                       wall-7                 0.39060748
                wall-7-shadow                 -0.4613454
                   wall-solid                          0
             ---------------- --------------------
                          Net                 -2672.0707
```

Fig. 25 total heat transfer rate

H. FLUID - R134A

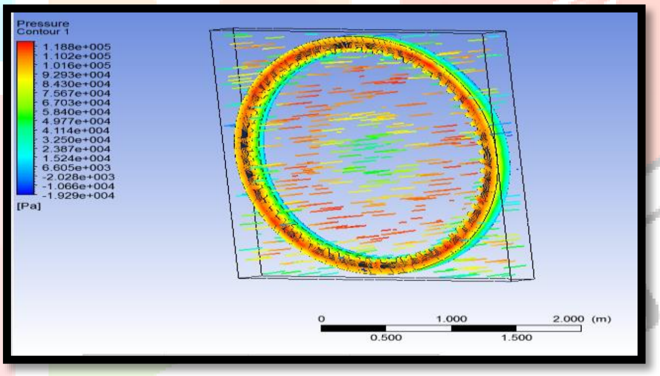


Fig. 26 Pressure

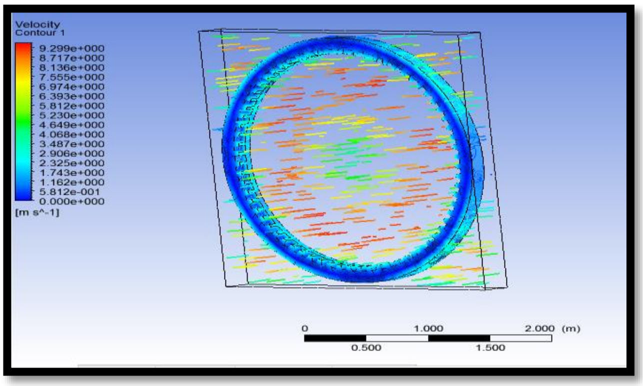


Fig. 27 Velocity

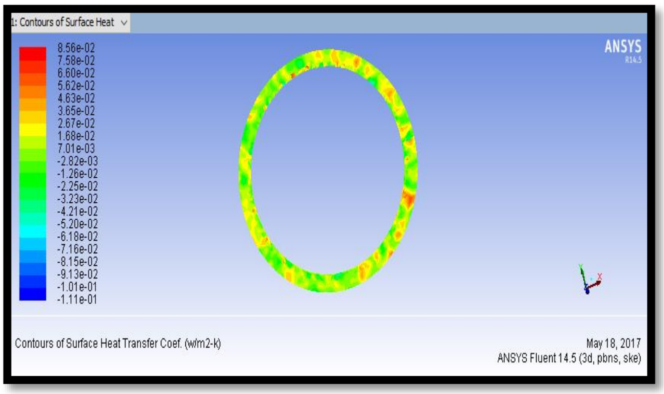
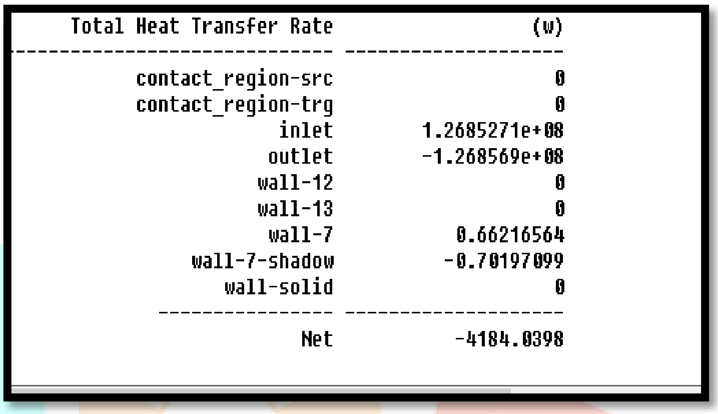


Fig. 28 Heat transfer coefficient



```
          Total Heat Transfer Rate                    (w)
-------------------------------- --------------------
              contact_region-src                    0
              contact_region-trg                    0
                           inlet        1.2685271e+08
                          outlet        -1.268569e+08
                         wall-12                    0
                         wall-13                    0
                          wall-7           0.66216564
                   wall-7-shadow          -0.70197099
                      wall-solid                    0
                ---------------- --------------------
                             Net           -4184.0398
```

Fig. 29 Total heat transfer rate

I. FLUID - R407C

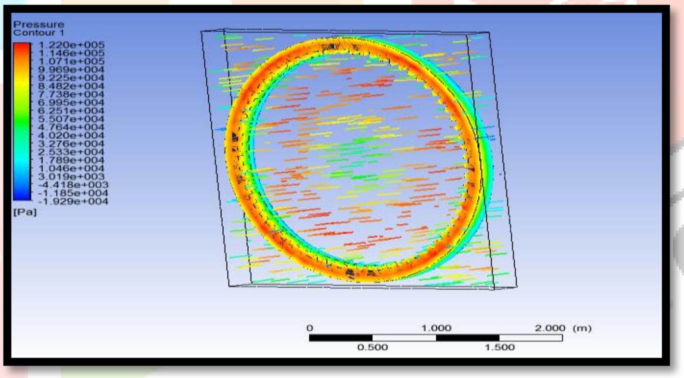


Fig. 30 pressure

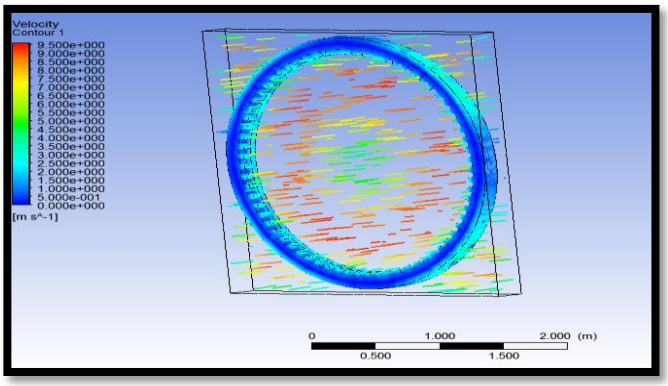


Fig. 31 velocity

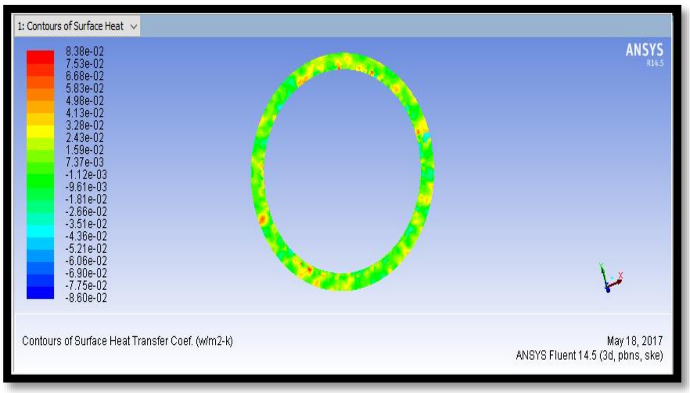
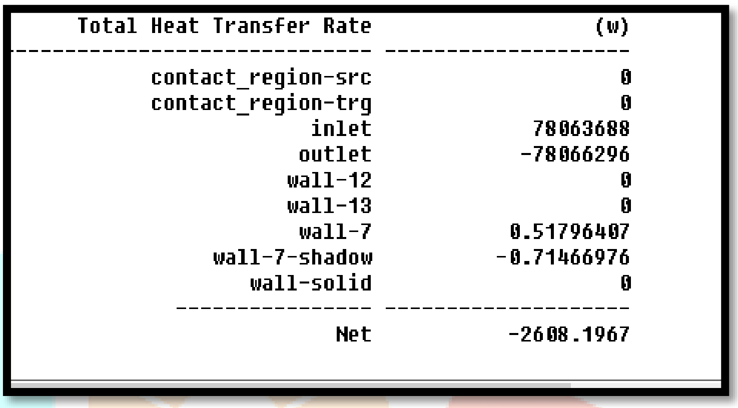


Fig. 32 heat transfer coefficient



```
         Total Heat Transfer Rate                    (w)
-------------------------------- --------------------
              contact_region-src                    0
              contact_region-trg                    0
                           inlet             78063688
                          outlet            -78066296
                         wall-12                    0
                         wall-13                    0
                          wall-7           0.51796407
                   wall-7-shadow          -0.71466976
                      wall-solid                    0
                ---------------- --------------------
                             Net           -2608.1967
```

Fig. 33 total heat transfer rate

J. FLUID - R410A

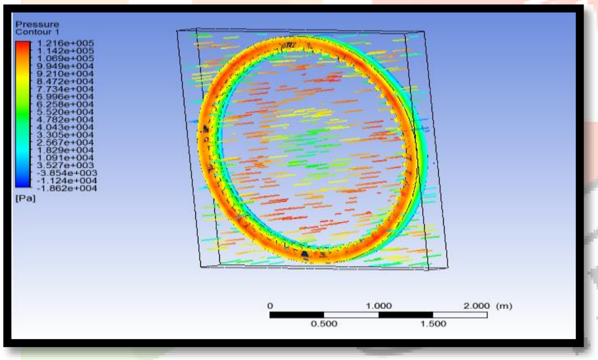


Fig. 34 pressure

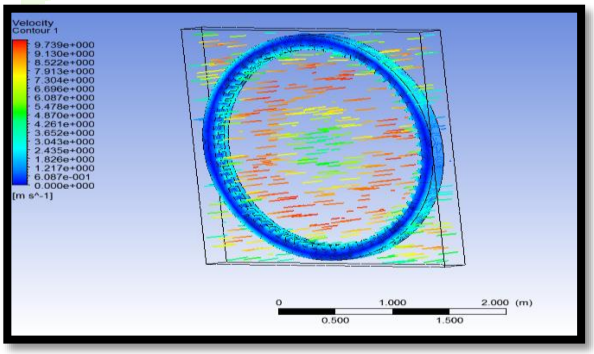


Fig. 35 velocity

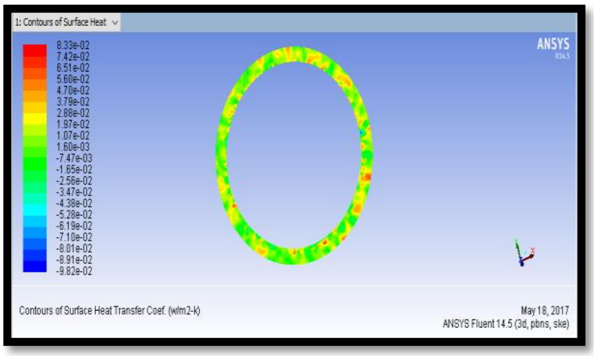
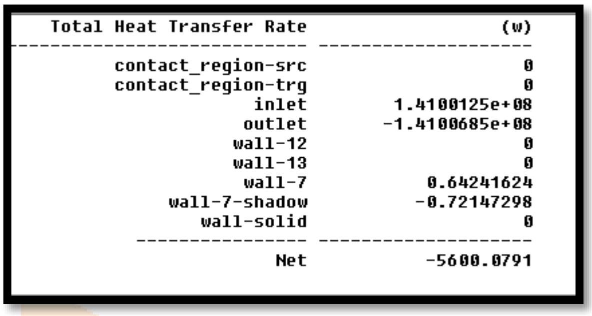


Fig. 36 Heat transfer coefficient



```
  Total Heat Transfer Rate                          (w)
---------------------------- --------------------
         contact_region-src                    0
         contact_region-trg                    0
                      inlet        1.4100125e+08
                     outlet       -1.4100685e+08
                    wall-12                    0
                    wall-13                    0
                     wall-7           0.64241624
              wall-7-shadow          -0.72147298
                 wall-solid                    0
           ----------------- --------------------
                        Net           -5600.0791
```

Fig. 37 total heat transfer rate

TABLE 1: Results of FIN HEIGHT – 5mm

	R22	**R134A**	**R407C**	**R410A**
Pressure(Pa)	1.185E+005	1.199E+005	1.199E+005	1.188E+005
Velocity(m/s)	7.651E+000	7.294E+000	7.285E+000	7.729E+000
Heat transfer coefficient(w/m^2 K)	4.70E-02	3.58E-02	5.29E-02	5.80E-02
Total heat transfer rate (W)	2672.0707	2999.992	2416.1644	5103.8453

TABLE 2: Results of FIN HEIGHT – 3mm

	R22	**R134A**	**R407C**	**R410A**
Pressure(Pa)	1.261E+005	1.188E+005	1.1220E+005	1.126E+005
Velocity(m/s)	1.163E+001	9.299E+000	9.500E+000	9.739E+000
Heat transfer coefficient(w/m^2 K)	6.34E-02	8.56E-02	8.38E-02	8.33E-02
Total heat transfer rate (W)	4215.9784	4184.0398	2608.1967	5600.0791

V. THERMAL ANALYSIS

A. FIN HEIGHT – 5mm

The heat transfer coefficient value for convention is taken of maximum value from CFD analysis (R410A – 5.8e^{-2} W/m^2 K)

i. MATERIAL - ALUMINUM ALLOY

Save Pro-E Model as .iges format.

Ansys 14.5 → workbench → select engineering data → edit material properties → return to project → select geometry → right click → import geometry → select required iges file → open

Select model → right click → edit→ other window will be open

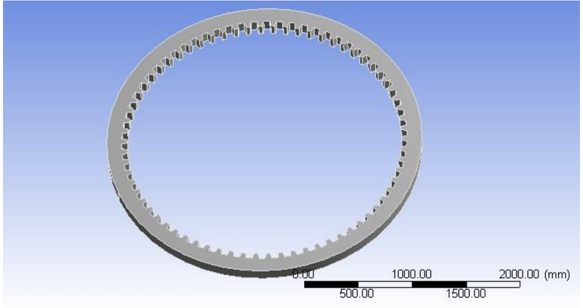


Fig. 38 Imported model

ii. Material properties of Aluminum alloy

Density – 2770 Kg/m^3

Thermal conductivity:144 W/m ^{0}C
Select mesh → right click → generate mesh → select sizing → change from course into fine → select again mesh → right click → generate mesh

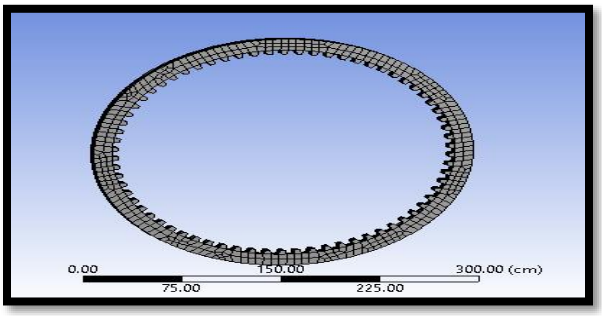


Fig. 39 Meshed model

Select study state thermal → right click → insert → temperature → select temperature applied area on component → enter temperature value → apply

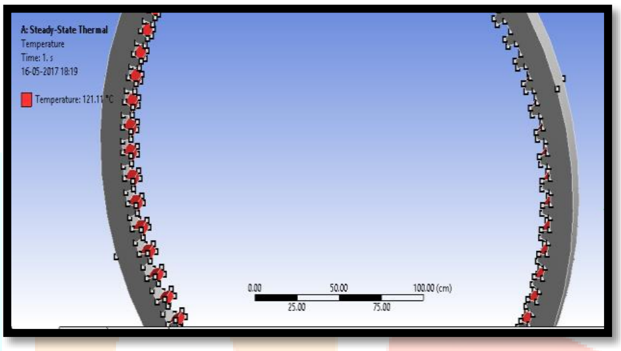


Fig. 40 Temperature applied on the fins

Select study state thermal → right click → insert → convection → select convection applied area → enter film coefficient value → apply

iii. Convection

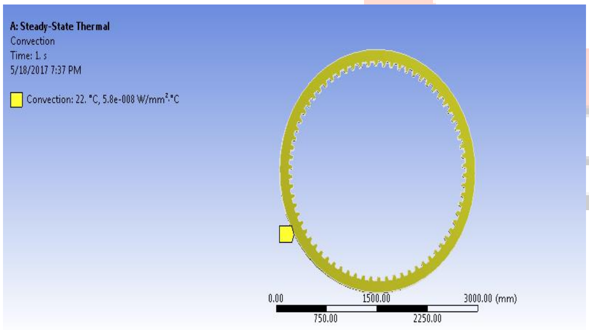


Fig. 41 Convection applied on the outer surface

Select Solution→ right click → insert → select temperature
Select solution → right click → insert → select heat flux
Select solution → right click → solve → take results

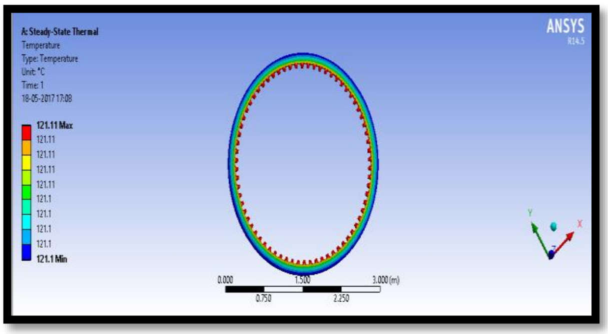


Fig.42 Temperature

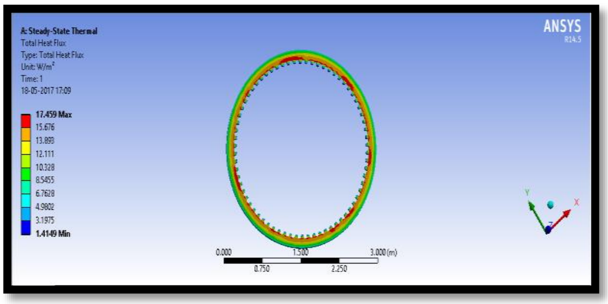


Fig. 43 Heat flux

iv. MATERIAL – COPPER ALLOY

Material properties of Copper

Density – 8300kg/m^3

Young’s modulus = 110000Mpa

Poission’s ratio = 0.34

Thermal conductivity:401 W/m ^{0}C

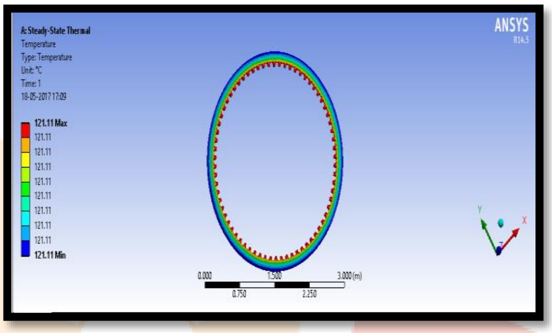


Fig. 44 Temperature

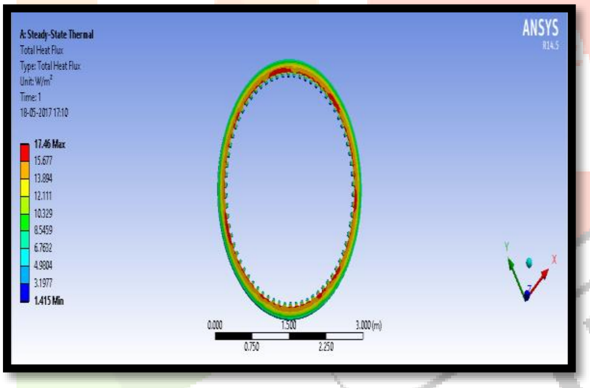


Fig. 45 Heat flux

v. MATERIAL – TITANIUM ALLOY

Material properties of Titanium alloy

Density – 4620 kg/m^3 , Young’s modulus = 96000Mpa , Poission’s ratio = 0.36, Thermal conductivity:21.9 W/m ^{0}C

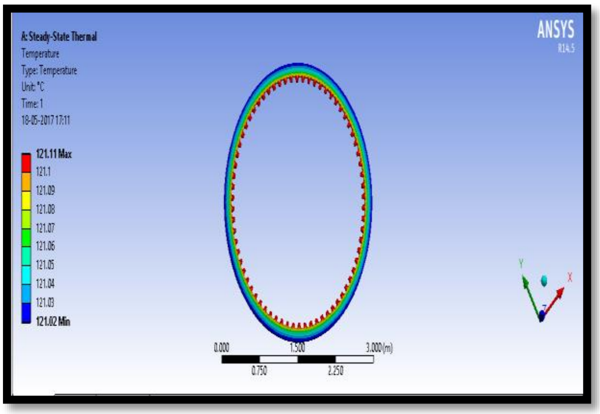


Fig. 46 Temperature

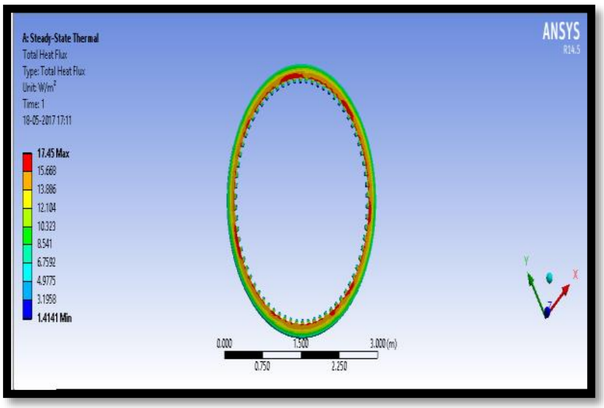


Fig. 47 Heat flux

B. FIN HEIGHT – 3mm

The heat transfer coefficient value for convention is taken of maximum value from CFD analysis (R134A – 8.56e^{-2} W/m^2 K)

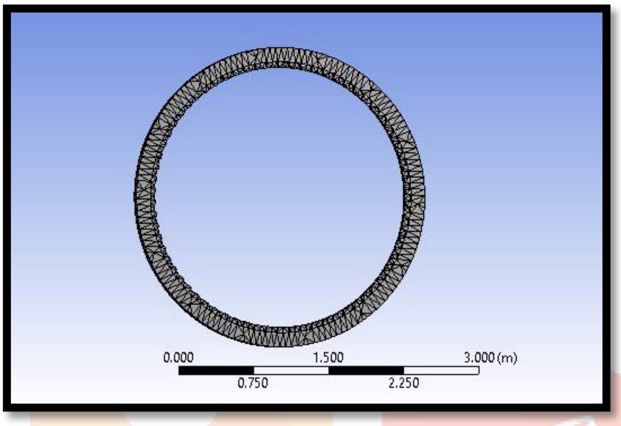


Fig. 48 Meshed model

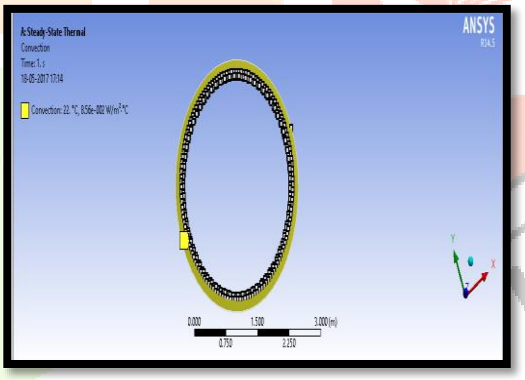


Fig. 49 Convection

i. MATERIAL – ALUMINUM ALLOY

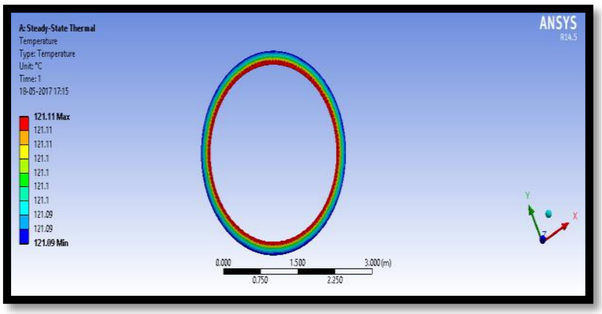


Fig. 50 Temperature

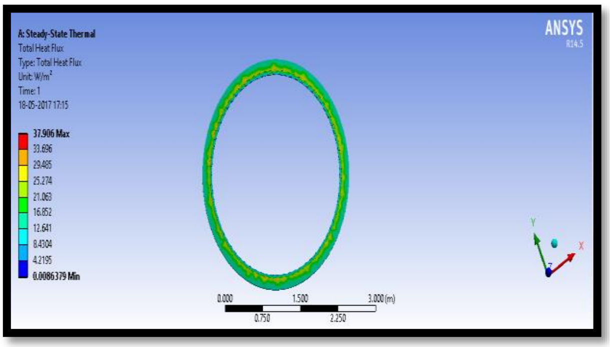


Fig. 51 Heat flux

ii. MATERIAL – COPPER ALLOY

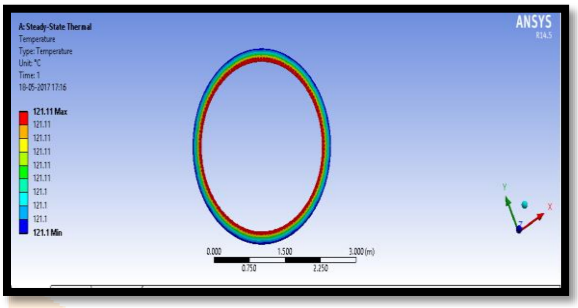


Fig. 52 Temperature

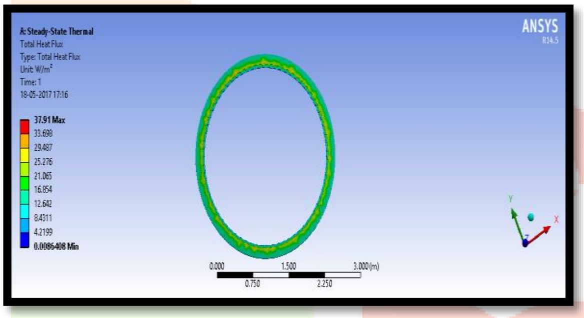


Fig. 53 Heat flux

iii. MATERIAL – TITANIUM ALLOY

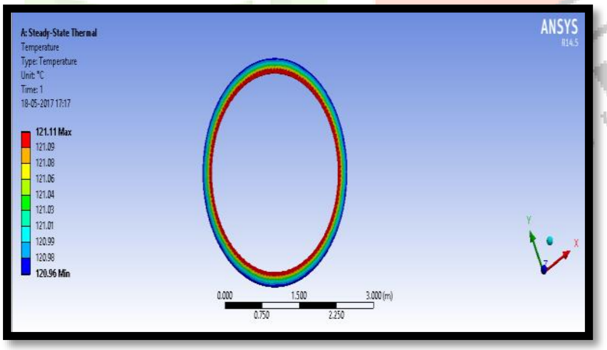


Fig. 54 Temperature

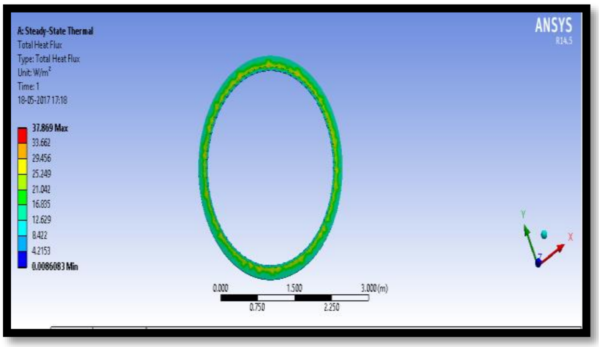


Fig. 55 Heat flux

TABLE 3: FIN HEIGHT – 5mm

PARAMETER	**ALUMINUM ALLOY**	**COPPER ALLOY**	**TITANIUM ALLOY**
TEMPERATURE(℃)	121.11	121.11	121.11
HEAT FLUX (W/m^2)	17.459	17.46	17.45

TABLE 4: FIN HEIGHT – 3mm

PARAMETER	**ALUMINUM ALLOY**	**COPPER ALLOY**	**TITANIUM ALLOY**
TEMPERATURE(℃)	121.11	121.11	121.11
HEAT FLUX (W/m^2)	37.906	37.91	37.869

VI. CONCLUSION

In this paper, analytical investigations are performed to determine boiling characteristics in micro-fin tubes for different refrigerants R22, R134a, R407C and R410A. The performance of the micro fin tubes is determined by changing fin heights 5mm and 3mm. CFD is performed on the micro fin tube to determine the heat transfer coefficients, pressure drop and heat transfer rates. By observing the results, the heat transfer coefficient for fin height 3mm is more by 34.89% when R22 is used, by 139.11% when R134A is used, by 58.41% when R407C is used and by 43.62% when R410A is used when compared with that of 5mm fin height. The heat transfer rate for fin height 3mm is more by 57.78% when R22 is used, by 39.47% when R134A is used, by 7.95% when R407C is used and by 9.72% when R410A is used when compared with that of 5mm fin height.

The pressure drop for fin height 3mm is more by 6.41% when R22 is used, less by 0.92% when R134A is used, less by 6.42% when R407C is used and less by 5.22% when R410A is used when compared with that of 5mm fin height. The performance of the micro fin tubes is also analysed by determining and comparing the thermal characteristics (heat flux) for different fin materials of aluminium, copper and titanium alloys respectively.

Thermal analysis is performed for different materials of micro fin tube of Aluminium alloy, Copper alloy and Titanium alloy. By observing the results, the heat flux for fin height 3mm is more by 52.01% when aluminium alloy is used, more by 27.49% when copper alloy is used and more by 30.40% when aluminium alloy is used when compared with that of 5mm fin height. When the comparison is made among different materials of aluminium alloy, copper alloy and titanium alloy, it is being noticed that copper alloy is more efficient.

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