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CFD Analysis of VARS Component (Evaporator) on ANSYS Fluent

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Abstract - This work presents design and analysis of an ammonia water absorption refrigeration system using exhaust of an internal combustion engine as energy source. It belongs to vapor absorption refrigeration system capacity 1 tonne which will replace the conventional car's AC system. The design is based on basic concepts of thermodynamic principles. In design of evaporator of system is calculated on the basis of enthalpy parameters at different points in the system. The data is analyzed using the first and second laws of thermodynamic. After designing of the system modeling is done by using cad software solid edge and analysis is done by using ansys fluent. The system is working between the condenser pressure of 10.7 bar and evaporator pressure of 4.7 bar. Ammonia is used as the refrigerant in the system and water as absorbent in the physic-chemical process.

Key Words: Evaporator, solid edge, fea , cfd analysis, ansys fluent.

1.INTRODUCTION

Energy efficiency has been a major topic f discussion on natural resource preservation and costs reduction. Based on estimates of energy resources at medium and long terms it is vital to develop more efficient processes from energy and exergy standpoints. Environment preservation must also be considered through energy optimization studies. An important point to mention chlornized fluorocarbons (CFC's) by alternative refrigerants, according to the Montreal protocol, signed in 1987 by 46 countries and revised in 1990 to protect the ozone layer.

Other motivating factors are the continues optimization of the performance of internal combustion engine and increasing utilization of air conditioning in vehicles, as it reaches the status of essential need for modern life. Internal combustion engines are potential energy sources for absorption refrigerant systems, are potential energy sources for absorption refrigeration systems, as about one third of the energy availability in the combustion process is wasted through the exhoust gas. Thus use of exhaust gas in an absorption refrigeration system can increas the overall system efficiency.

The technology of absorption refrigeration has been used for cooling purposes for over a hundred years now. Even after the advent of various compact refrigerators they still continue to attract scientists and engineering enthusiasts as they provide means of regenerating the waste heat from plants, automobile, etc. into useful work.

Ammonia vapour is vigorously absorbed into water. So when low pressure ammonia vapour from the evaporator comes in the contact in the absorber with the weak solution coming from generator; it is readily absorbed, releasing the latent heat of of condensation. The water has tye property to absorb very large quantities of ammonia vapour and the solution thus formed, is known as aqua-ammonia.

The main difference between an compression and a absorption cycle is that the former needs mechanical energy as a driving source for the compressor and the latter needs thermal energy for the desorber and only a small amount (2% of the driving energy) of electricity for the liquid pump.

In some cases it is useful to build Absorption Refrigeration Plants (ARP) with several stages, foe instance when the temperature of driving energy is not high enough.

The absorption of ammonia in water lowers the pressure in the absorber which in turn draws more ammonia vapour from the evaporator and thus raises the temperature of solution. The absorber is cooled by the circulating water thus absorbing the heat of solution (Qa) and maintaining a constant temperature. The strong solution (rich in ammonia) thus formed in the absorber is pumped to the generator by the liquid pump. The pump increases the pressure of strong solution.

The strong solution of ammonia is heated inthe generator, where heat(Qg) is supplied from vehicle's exhaust heat.Since the boiling point of ammonia(-33°C) is less than that of water(100°C), the ammonia vapour is given off from the solution at high pressure, and the weak solution returns to the absorber through a pressure reducing valve. The ammonia vapour leaving the generator condenses in the condenser releasing the heat of condensation (Qc) to the surroundings or cooling water and is throttled by the expansion valve and then evaporates by absorbing the latent heat of vaporization (Qe) from the surroundings.

2 LITERATURE REVIEW

2.1 Background

A literature research on the subject of utilization of waste heat for refrigeration shows that most of the previous work has been limited to schemes that utilize automobile exhaust gases for air conditioning.

C.L Keating Jr. (U.S. patent no. 2667040); R.W. Kroger (US patent no. 3021690); S.G. Hause (U.S. patent no. 3142161) and T.G. McNamara (U.S. patent no.3661200) are typical examples of prior work in this area of endeavour. Since energy was until recently relatively inexpensive, very little effort was made to develop these patented devices.

2.2 Recent Works in Research

Following are some of the research papers we studied during the course of preparation of project.

- Analysis of Ammonia-Water Absorption Refrigeration System based on First law of Thermodynamics.
  By Satish Raghuvanshi and Govind Maheshwari
  IJERT ISBN 2219-5518 August-2011.
  Abstract
  The objective of this paper is to present emperical relationships fir evaluating the characteristics and performance of a single stage Ammonia-Water vapour absorption system. The necessary heat and mass transfer equations and appropriate equations describing the thermodynamic properties of working fluid at all thermodynamic states are evaluated. Finally the variations of various thermodynamic parameters are simulated and examined.

- Analysis of 3-TR aqua-ammonia absorption system
  By Arun Bangotra and Anshul Mahajan
  IJERT ISBN 2278-0181 October-2012
  Abstract
  This paper presents the design of aqua-ammonia VARS of capacity 3 tonne based on the basic concept of thermodynamic principles. In design all the area of all the major components of system is calculated on the basis of enthalpy parameters at different points in the system. The data is analysed using the first and second law of thermodynamics to determine the refrigerating effect, net heat required to run the system and coefficient of performance.

- Theoretical and experimental evaluation of a Vapour Absorption Refrigeration system.
  By V.D. Patel, A.J. Choudhari, R.D. Jilte
  IJERA ISSN 2248-9622 March 2012
  Abstract
  The VARS uses heat energy instead of mechanical energy in VCRS, in order to change the condition of refrigerant required for the operation of refrigeration cycle.This paper discuss about theoritical calculations of different components of system like evaporator, absorber,condensor and pump. A VARS of capacity 0.25 TR is developed and system was run to validate for reducing the temperature for free of cost operation.

3 METHODS

3.1 GEOMETRY

The Geometric dimensions of Evaporator unit are based on the results obtained from Analytical Solution.

3.1.1 Design Calculations

Evaporator is an equipment in which refrigerant vapourizes to generate desired cooling effect. It is also known as chiller. In our case it will be placed inside car cabin. Considering that the evaporator will be made of stainless steel tubes placed along the length of wheelbase.

Let air inlet temperature to evaporator, T_{H1} = 30°C

Let air outlet temperature to evaporator, T_{H2} = 5°C

$dT_1 = 30-2 = 28°C$

$dT_2 = 5-2 = 28°C$

LMTD, $T_M = dT_1-dT_2/\ln(dT_1/dT_2)$

$T_M = (28-3)/\ln(28/3) = 11.193°C$

From HMT Databook Domkundwar (Dhanpat Rai Co.) Table 9.1

Overall heat transfer coefficient(U) = 1000 W/m^2

Assuming correction factor(F) = 1

$Q_E = FUA_ET_M$

$3.517 \times 1000 = 1 \times 1000 \times A_E \times 11.193$

Area of Evaporator $A_E = 314200\ mm^2$

Considering the no. of evaporator tubes(n) = 5

Length of each tube(L) = 2000 mm

Diameter of tubes(D) = to be calculated

$A_E = n \times \pi \times D \times L$

$314200 = 5 \times \pi \times D \times 2000$

D = 10 mm

From Design Databook Mahadevan-Reddy(CBS Publishers) pg. 100, Eq.7.2(a)

Permissible pressure, $P = 2P_0/D \times (t-1.65) - 0.862$

where,

P_0 = Maximum Permissible pressure(MPa) for S.S = 65MPa

This stress value is acceptable till 340°C temperature.

D = outer diameter of pipe(mm) = 10 mm

P = working pressure(MPa) = 0.47MPa

Then the thickness of tube

$t = D/2P_0(P+0.862) + 1.65$

t = 1.75 mm

3.1.2 Effective Temperature Drop

The net drop in temperature in Actual Practice will be Somewhat lower than LMTD Temperature. Due to the fact that Evaporator is made up of long tubes in which the wall friction will kead to pressure drop, corresponding Decreased enthalpy values and decreased Temperature Drop.

Darcy-Weisbach Equation is given by

$h_f = f_D l v^2/2gD$

From the Moody's Chart;

Indicative Roughness For Steel : ε = 0.2mm

Relative Roughness = ε/D = 0.02

The value of Darcy friction factor corresponding to this relative Roughness is

$f_D = 0.048$

Therefore head loss, $h_f = 0.048 \text{x} 2 \text{x} (6.2)^2/2 \text{x} 9.81 \text{x} 0.01$

$h_f = 18.8m$

Pressure Drop, $\Delta P = \rho g h_f = g h_f / \upsilon$

Specific Volume at that saturated Temperature = 0.0015728 m^3/kg

Thus, ΔP = 117.314 kPa

Now, Original pressure = 476.227 kPa; $h_{fg} = 1607.5$ kJ/kg

And, Reduced pressure = 358.913 kPa; $h_{fg} = 1599.8$ kJ/kg

Therefore Effective temperature drop, $\Delta T = \theta_M - (\Delta h/C_p)$

Thus, ΔT = 11.193 - (7.7/1.66) = 6.55°C

3.1.3 Results

- Tube Length : 2000mm
- Tube Internal Diameter : 10mm
- Tube Thickness : 1.75mm
- Tube External Diameter : 13.5mm
- Heat Flow = -3.517kW
- Effective temperature Drop = 6.55°C

3.2 MODELLING

3.2.1 SOLIDEDGE

Solidedge is used for modelling of evaporator.

3.2.2 Evaporator Assembly

The Evaporator will be made like a shell-tube heat exchanger where fluid domains will be added for work in Ansys. Baffle plates are not added for the simplicity of Desugn. However if added they can increase heat transfer.

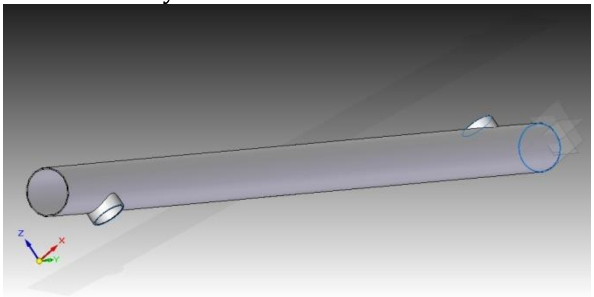


Fig-shell geometry as viewed in solidedge (a) end view (b) front view (c) 3Dview

ASSEMBLED GEOMETRY

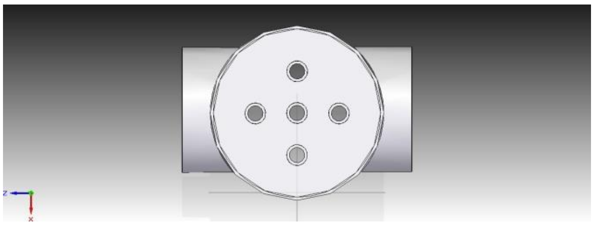


Fig -assembly as viewed in solid edge end view

3.3 ANALYSIS

3.3.1 FEA

Finite element analysis (FEA) is a computerized method for predicting how a product reacts to real-world forces, vibration, heat, fluid flow, and other physical effects. Finite element analysis shows whether a product will break, wear out, or work the way it was designed. It is called analysis, but in the product development process, it is used to predict what is going to happen when the product is used.

3.3.2 CFD

Computational fluid dynamics (CFD) is a branch of fluid mechanics that uses numerical analysis and data structures to solve and analyze problems that involve fluid flows. Computers are used to perform the calculations required to simulate the interaction of liquids and gases with surfaces defined by boundary conditions with high-speed supercomputers, better solutions can be achieved. Ongoing research yields software that improves the accuracy and speed of complex simulation scenarios such as transonic or turbulent flows.

3.3.3 Ansys Fluent

ANSYS Fluent is a state-of-the-art computer program for modeling fluid flow, heat transfer, and chemical reactions in complex geometries.

3.3.3.1 ANSYS DESIGN MODELLER

(a) Summary

The Model being saved into in .IGES file at Solid Edge provides the freedom to run it in Ansys Workbench. Thus the Model is imported into Design Modeller where various named selections, interfaces and Fluid Domains are added. Domains are

1. R-in Refrigerant in
2. R- out Refrigerant out
3. A-in Air in
4. A-out Air out
5. Refrigerant domain
6. Air domain
7. Tube
8. Shell
9. Interface 3
10. Interface 4

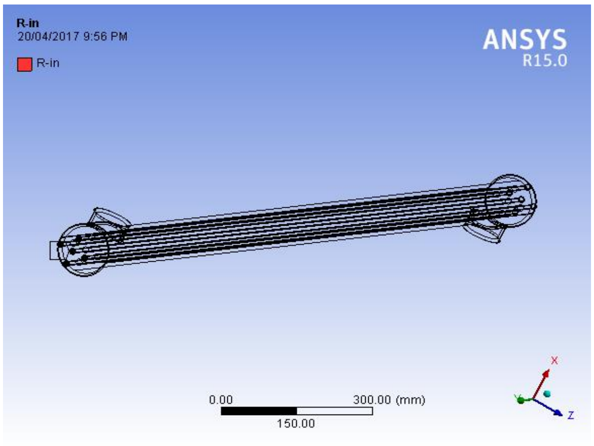


Fig- Inlet surface for refrigerator

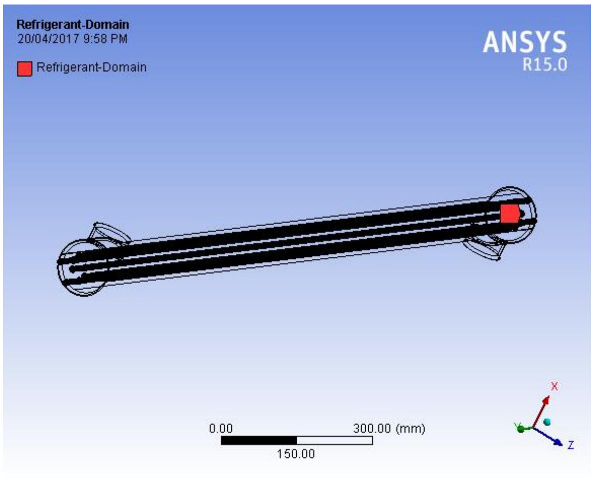


Fig- Refrigerant Domain

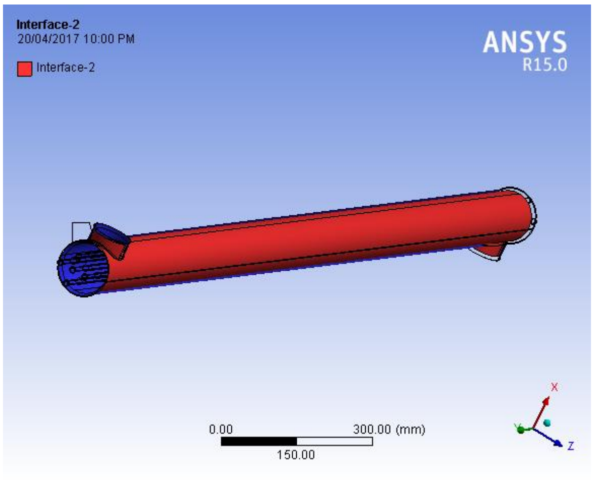


Fig- Air shell interface

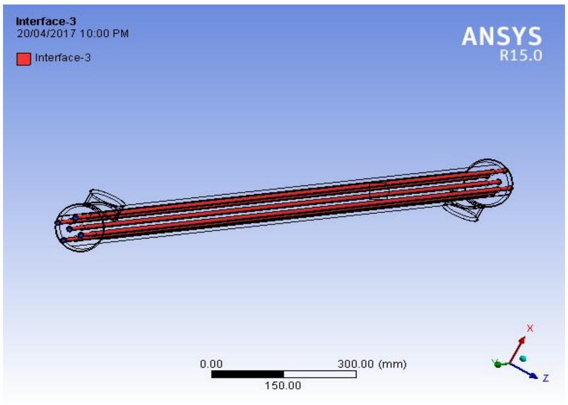


Fig-Refrigerant-tube interface

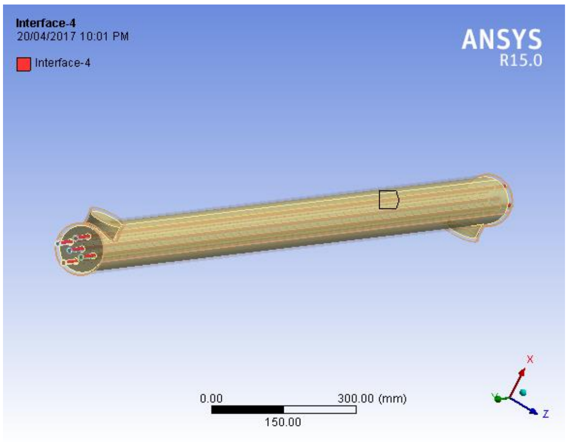


Fig-Tube-air interface

3.3.3.2 ANSYS MESHING

Summary

The Geometry being defined properly is then sent for Meshing.
In Our Case Mesh Size was Coarse and Smoothing Medium.

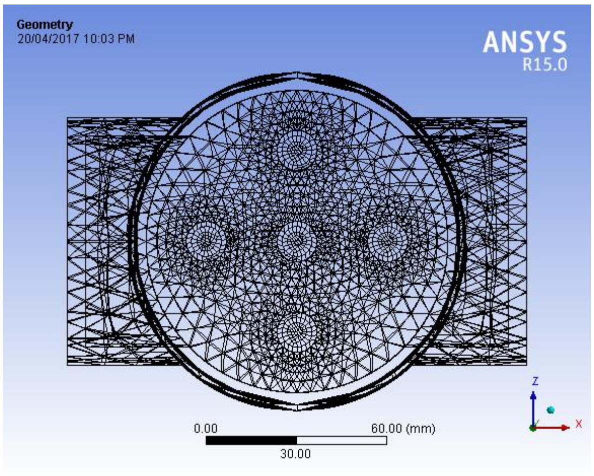


Fig- End view

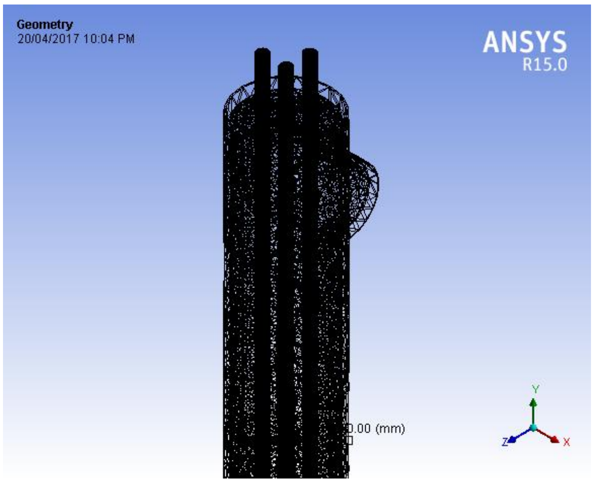


Fig- Isometric view

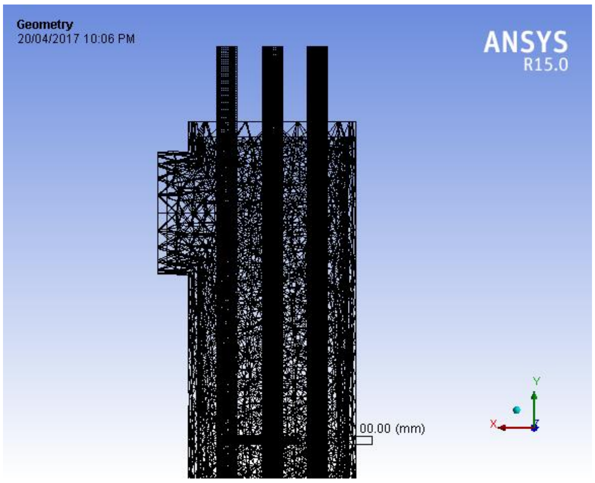


Fig-Rotated front view

3.3.3.3 ANSYS SETUP

(a) Introduction

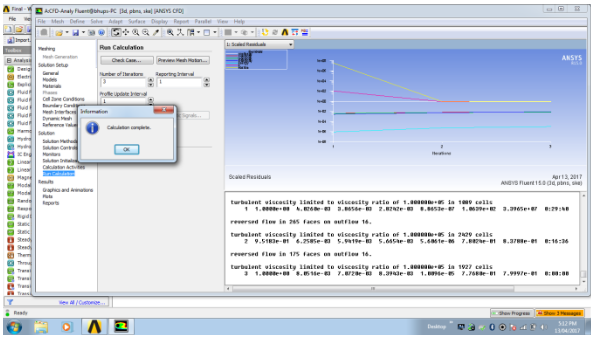
The Meshed Geometry is Imported in Ansys Fluent Setup. Here Various Boundary Conditions, Models, Materials, etc. are specified.Then the Setup is ready for Solver.

Setup Conditions

- Precision : Single Precision
- Processing : Serial
- Solver
    - Type : Pressure Based
    - Velocity Formulation : Absolute
    - Time : Steady
    - Gravity : ON; Y= -9.81 m/s^2
- Models
    - Energy Equation : ON
    - Viscous Model : k-epsilon 2 eq^n (Standard)
- Materials
    - Solid
        - Steel
    - Liquid
        - Liquid Ammonia
        - Air
- Cell Zone Conditions
    - Air-Domain : Fluid : Air
    - Refrigerant-Domain : Fluid : Liquid Ammonia
    - Tubes : Solid : Steel
    - Shell : Solid : Steel
- Mesh Interfaces
    - Air-Tube Interface
    - Air-Shell Interface
    - Tube-Refrigerant Interface
- Boundary Conditions
    - Air Inlet
        - Temperature : 303K
        - Velocity : 0.0 m/s
    - Refrigerant Inlet
        - Mass Flow Rate : 3.046 x 10^{-3} kg/s
        - Temperature : 275K
        - Pressure : 4.7 Bar
    - Refrigerant Outlet
        - Temperature : 275K
        - Pressure : 4.7 Bar
    - Wall Tube
        - (Neglecting Conduction Losses and taking Overall Heat Transfer Coefficient as Convective Coefficient) Convective Heat Transfer Coefficient : 1000W/m^{2}K
        - Heat Flux : -11200W/m^2 (Q = -3.517 kW)
        - Tube Thickness : 1.75mm

3.3.3.4 ANSYS SOLVER

- Solution Initialization : Hybrid Initialization
- Patch Zones
- Run Calculation : Automatic Export
- Create > File Type > CFD Post Compatible
- Quantities
    - Static Pressure
    - Total Pressure
    - Absolute Velocity (X,Y,Z)
    - Relative Velocity
    - Temperature
    - Heat Flux
    - Turbulent Energy Dissipation
- Time Stepping Method : Fixed
- Number of Iterations : 10



```
turbulent viscosity limited to viscosity ratio of 1.000000e+05 in 1089 cells
    1  1.0000e+00  4.0260e-03  3.8656e-03  2.8242e-03  8.8653e-07  1.0639e+02  3.3965e+07  0:29:40

reversed flow in 265 faces on outflow 16.

turbulent viscosity limited to viscosity ratio of 1.000000e+05 in 2429 cells
    2  9.5183e-01  6.2585e-03  5.9419e-03  5.6654e-03  5.6061e-06  7.8024e-01  8.3788e-01  0:16:36

reversed flow in 175 faces on outflow 16.

turbulent viscosity limited to viscosity ratio of 1.000000e+05 in 1927 cells
    3  1.0000e+00  8.0516e-03  7.0720e-03  8.3943e-03  1.0096e-05  7.7680e-01  7.9997e-01  0:00:00
```

Fig- Successful completion of calculation

ANSYS CFD POST-PROCESSING

(A) Volume Rendering

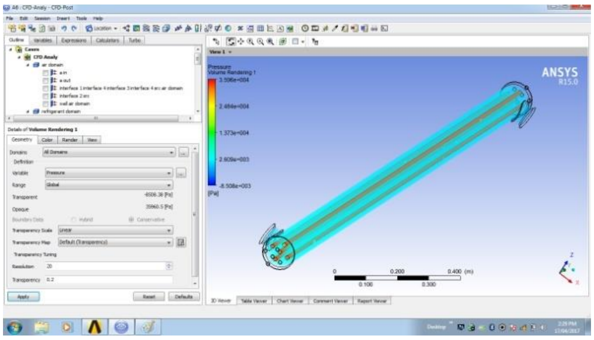


Fig- Pressure

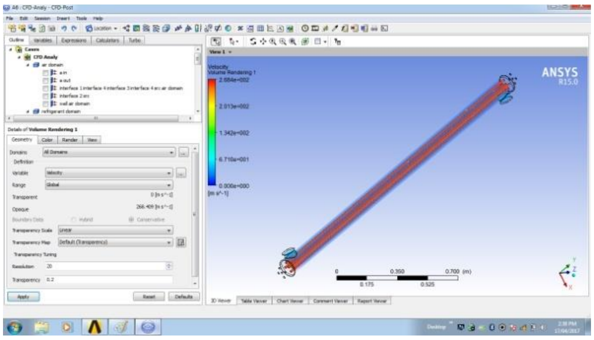


Fig- Velocity

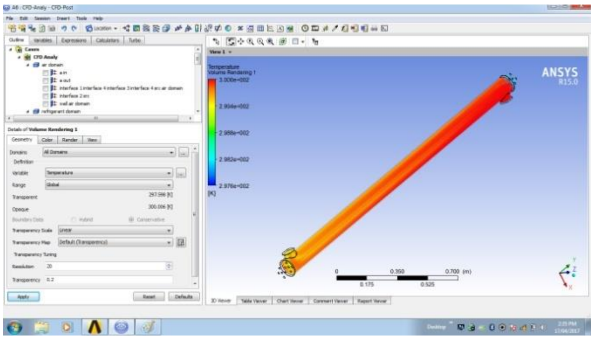


Fig-Temperature

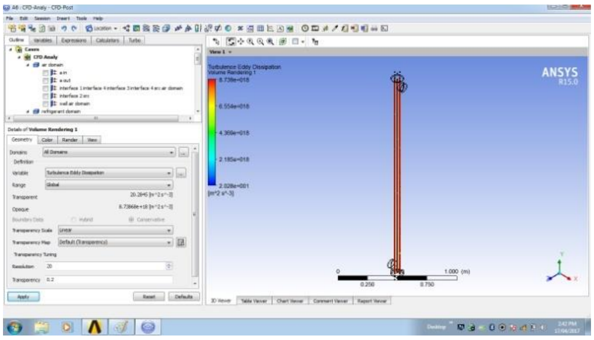


Fig- turbulence eddy dissipation

(B) Contour

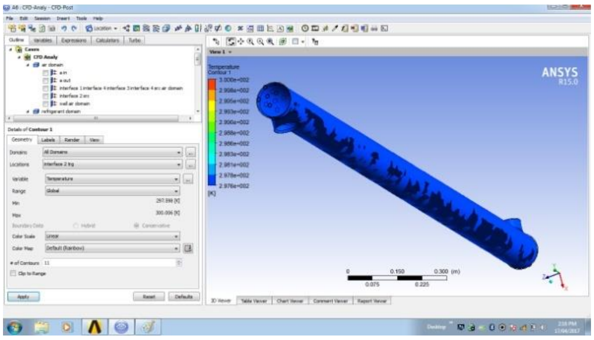


Fig-Air shell interface temperature

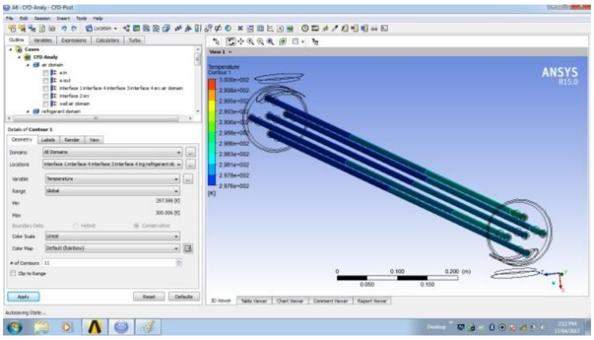


Fig-Refrigerant domain temperature

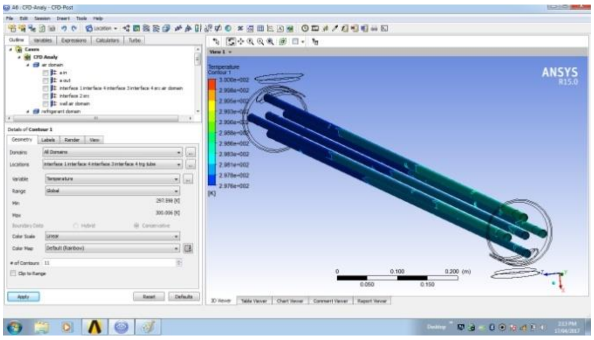


Fig-air tube interface domain temperature

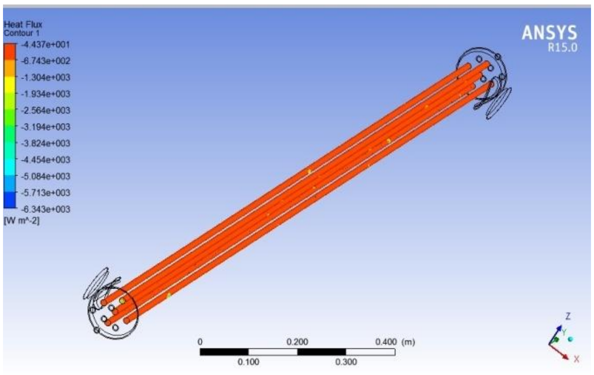


Fig-Tube air interface heat flux

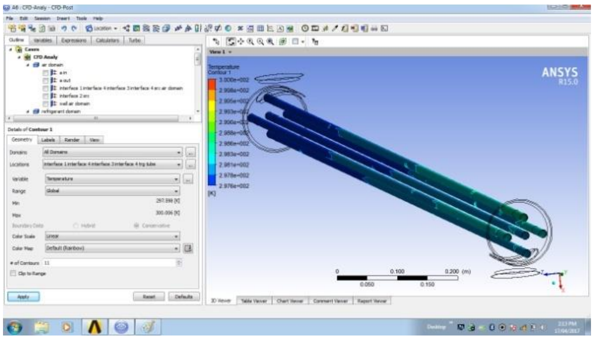


Fig-Air tube interface temperature

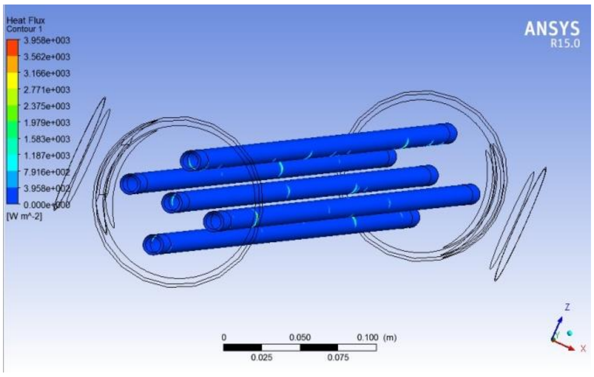


Fig-Refrigerant tube interface heat flux

(C) Plots

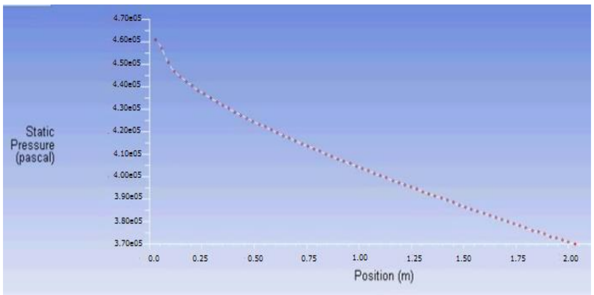


Fig-Pressure plot

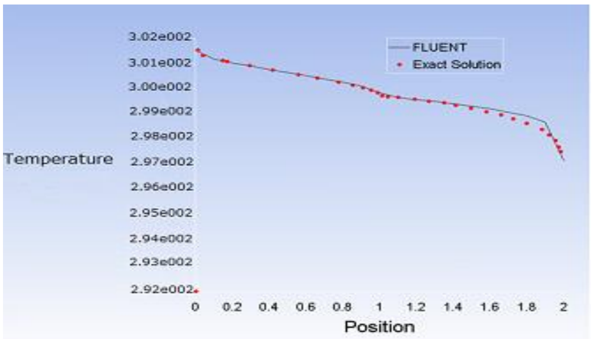


Fig-Temperature plot

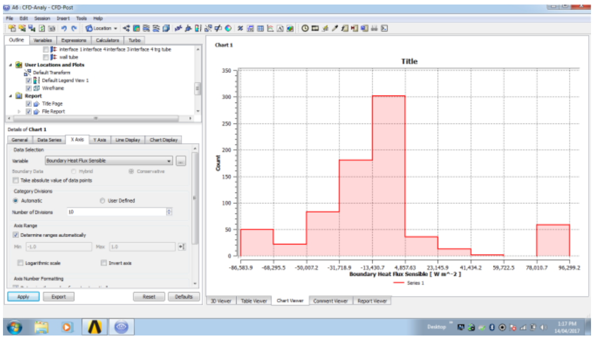


Fig -heat flux vs count histogram

4 RESULTS AND DISCUSSION

As per the Software results the temperature near air domain outlet is found to be 297K , so the drop is found to be around 6°C which is near to the temperature drop in the analytical solution(6.55°C).Thus it can be concluded that the evaporator design gives expected performance in CFD Analysis.

5 CONCLUSION

The analysis gives outlet Temperature which is in desired limit as shown in table.

Table 1 Comparison of Experimental Results and CFD Analysis Results

Description	Experimental	CFD analysis	% Deviation
Temperature in K	296.45	297	18.6

The deviation in results is due to perfectness of CFD analysis and uncertainty of experiments.

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