2D AND 3D FLOW ANALYSIS OF REFRIGERANT IN EVAPORATOR PART OF THREE F LUID VAPOUR ABSORPTION REFRIGERATION SYSTEM

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Abstract - *Among various new active cooling techniques, the vapour absorption refrigeration system stands different as it uses low grade energy like the exhaust of an internal combustion engine as energy source. Using vapour absorption refrigeration system for refrigeration purpose increases the efficiency of overall system, as no work absorbing devices are used and part of waste heat is recovered. Using three fluids, ammonia-water-hydrogen in VAR system increases its refrigeration effect compared to conventional two fluid VAR systems. Computational fluid dynamics technique is used to analyze the flow of refrigerant in the evaporator part of three fluids vapour absorption refrigeration system using FLUENT (ANAYS 14.5). The analysis is carried out based on the known experimental results. The evaporator part is analyzed to study the temperature distribution, velocity variation, enthalpy distribution, static pressure distribution and phase transformation. Analysis is carried out for 2D and 3D models, with varying mesh size for the 2D models.*

Key Words: *VCRS, VARS, FLUENT-solver software.*

1. INTRODUCTION

The common refrigeration units used in the automobiles for air conditioning purpose are vapour compression refrigeration systems (VCRS). The mechanical work required for running mechanical compressor in VCRS is taken from the shaft work. 4 to 5% of the shaft work is used for the working of the mechanical compressor, which in turn increases the fuel consumption of the engine. And also the refrigerants used in the vapour compression systems are not environmental friendly. All the above disadvantages of the VCR system has led to the idea of using vapour absorption refrigeration systems (VARS). In vapour absorption refrigeration system, mechanical compressor is replaced by the physio-chemical process called absorption. VAR system uses low waste heat energy like engine exhaust as the work input. Refrigerant used in the VAR system is mostly ammonia, which is environmental friendly. Using VARS instead of VCRS will increase the fuel efficiency as it does not use shaft energy. Three fluid vapour absorption refrigeration system is more efficient than the two fluid vapour absorption system, as it uses no mechanical parts. Instead it uses the third fluid, which acts as a carrier gas by varying partial pressure of refrigerant.

Three fluid vapour absorption refrigeration system is set up and run using single cylinder four stroke diesel engine exhaust. Based on the experimental results the flow of refrigerant in evaporator part is analyzed using FLUENT (ANSYS 14.5). Analysis is carried out to analyze the temperature distribution, velocity distribution, static pressure distribution and phase transformation occurring in the evaporator part. Evaporator part is the one, in which heat in the confined space is removed to maintain constant required temperature.

2. MODELLING OF EVAPORATOR PART

Evaporator part which is to be analyzed is modeled in UGNX9.0 software. 2D and 3D models were modeled according to the measured parameters. The 2D and 3D models designed for the flow analysis are as shown below.

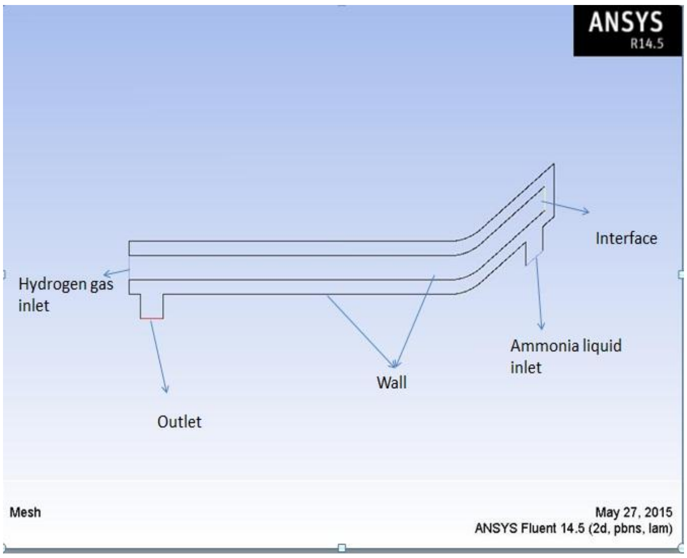

Fig 1- 2D Evaporator model

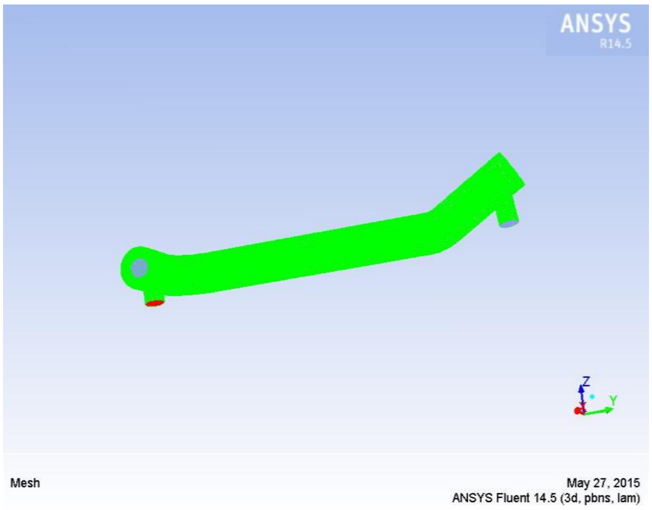

Fig 2- 3D Evaporator model

Above figures 1 and 2 shows 2D and 3D models of evaporator part. Boundary conditions were assigned and meshed in GAMBIT software, with varying mesh size for 2D model and single mesh size for 3D model.

3. EVAPORATOR PART

In the three fluid vapour absorption refrigeration system evaporator part is the one, in which the heat is removed from the confined space. Ammonia liquid is entering the evaporator at 258K after condensing in the condenser part. And hydrogen gas is entering the evaporator part at 309K from the absorber part due to density and pressure difference. The ammonia liquid mixes with the hydrogen gas, absorbs the heat and forms ammonia vapour. Ammonia vapour and hydrogen gas mixture at the outlet will be going to the absorber part again. The hydrogen gas circulates in between evaporator and absorber part. Initially evaporator part will be filled with the hydrogen gas, and then the ammonia liquid enters. The properties of the fluids entering the evaporator part are:

3.1 Properties of Ammonia liquid entering evaporator

Sl. No	Properties	Values
1	Density	660 kg/m^3
2	Absolute viscosity	$2.5047*10^4 Ns/m^2$
3	Kinematic viscosity	$0.3795*10^{-6}$ m^2/s
4	Prandtl number	2.080
5	Specific heat	4.5365 kJ/kgK
6	Thermal conductivity	0.5448 W/mk

Table 1- Ammonia liquid properties at -15^0C

3.2 Properties of Hydrogen gas entering evaporator

Sl no	Properties	Values
1	Density	0.08139 kg/ m^3
2	Absolute viscosity	$8.411*10^{-6}Ns/m^2$
3	Thermal conductivity	0.1672 W/mk
4	Specific heat	14283 kJ/kgK
5	Molecular weight	2.01594

Table 2- Properties of hydrogen gas at 309K

4 RESULTS AND DISCUSSION

4.1 Results of 2D evaporator model

4.1.1 Contours of hydrogen gas volume fraction at time zero

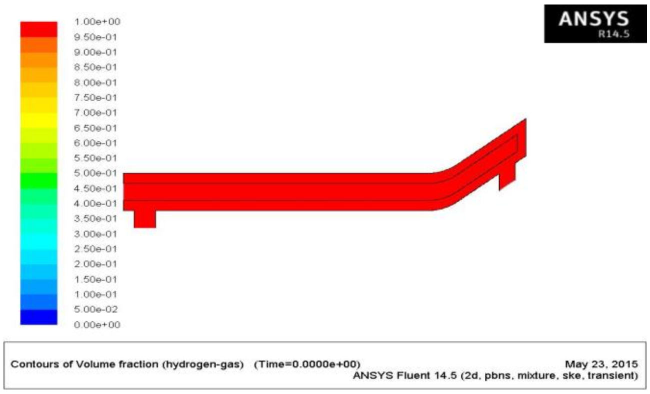

Fig 3- Hydrogen gas volume fraction at time zero

The figure 3 shows the results of hydrogen gas volume fraction at time zero. That is at the initial the evaporator is filled with the hydrogen gas. Ammonia liquid and ammonia vapour volume fraction is zero at the initial.

4.1.2 Contours of ammonia liquid volume fraction

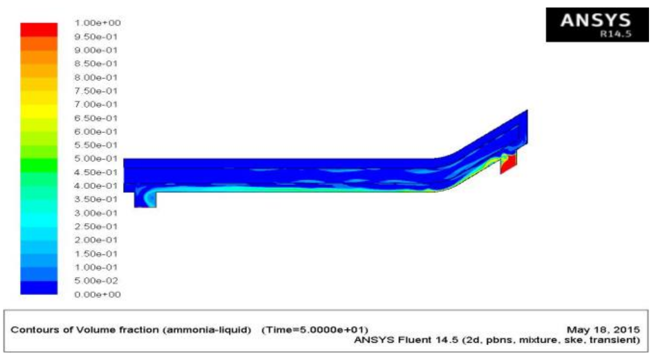

Fig 4- Ammonia liquid volume fraction

The figure 4 shows the results of volume fraction of ammonia liquid in the evaporator for 0.2 mesh spacing. Ammonia liquid is entering the evaporator at liquid state, absorbs the heat and leaves as ammonia vapour at the outlet. Volume fraction of ammonia liquid is 1 at inlet and nearly 0.05 at outlet.

4.1.3 Contours of hydrogen gas volume fraction

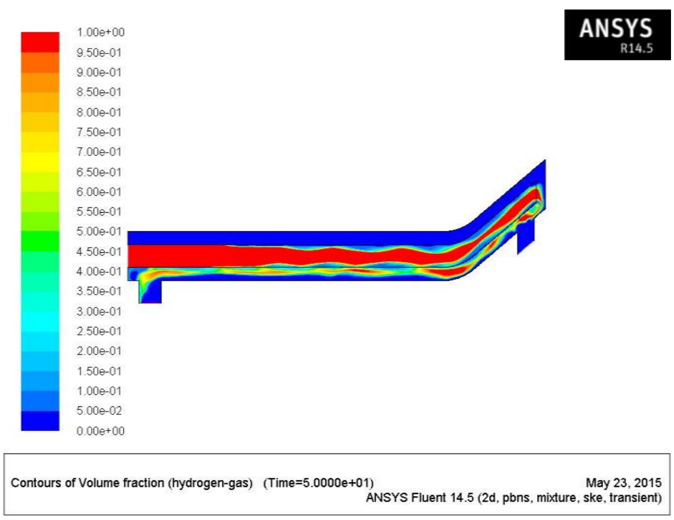

Fig 5- Hydrogen gas volume fraction

The figure 5 shows the results of hydrogen gas volume fraction in the evaporator. Volume fraction of hydrogen is 1 at the hydrogen inlet. The volume fraction of hydrogen gas decreases as it enters the outer tube flows to the outlet.

4.1.4 Contours of ammonia vapour volume fraction

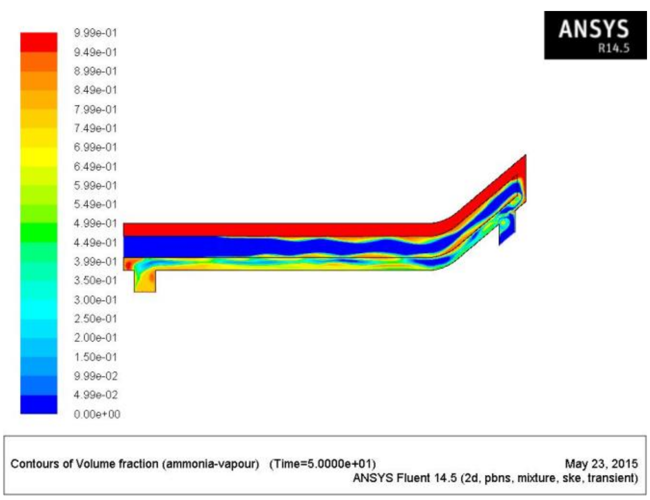

Fig 6- Ammonia vapour volume fraction

The figure 6 shows the results of ammonia vapour volume fraction. The result shows that the ammonia liquid is converted to ammonia vapour by absorbing heat as it flows in the evaporator. Volume fraction of ammonia liquid is 0.85 at the outlet.

4.1.5 Contours of temperature distribution

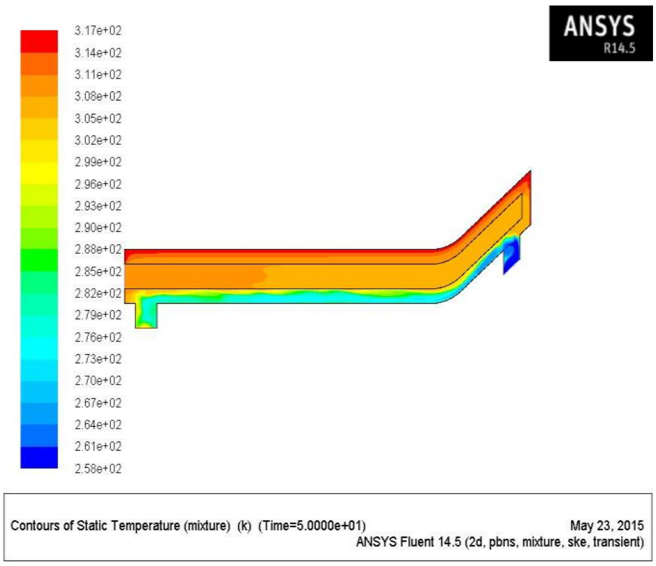

Fig 7- Temperature distribution

The figure 7 shows the results of temperature distribution in the evaporator for 0.2 mesh spacing. The maximum temperature of the ammonia vapours formed is 317K, which is almost near to the experimental value of 316K. Ammonia liquid is entering at 258K, and hydrogen gas is entering at 309K.

4.1.6 Vectors of velocity distribution

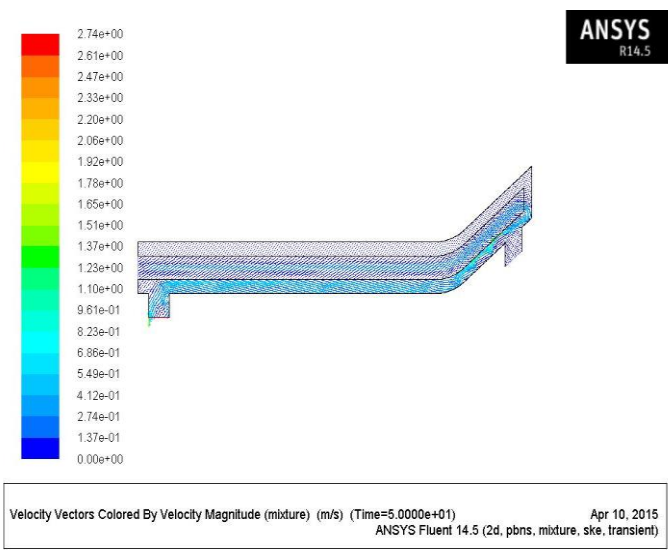

Fig 8- Velocity vectors

The figure 8 shows the results of velocity distribution in the evaporator for 0.2 mesh spacing. Velocity of ammonia vapour and hydrogen gas mixture at the outlet is around 0.55 m/s. Hydrogen gas is entering at the velocity of 0.1 m/s, and ammonia liquid is entering at the velocity of 0.02 m/s.

4.1.7 Temperature distribution

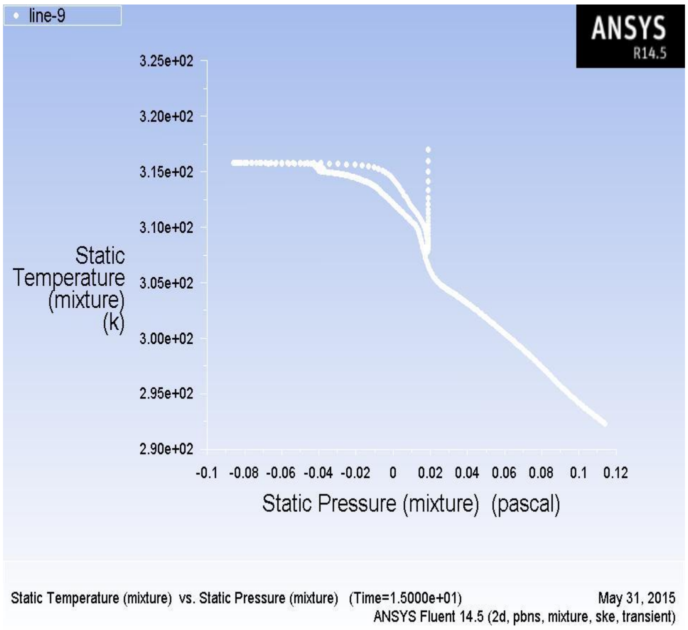

Fig 9- Temperature distribution

4.1.8 Static pressure distribution

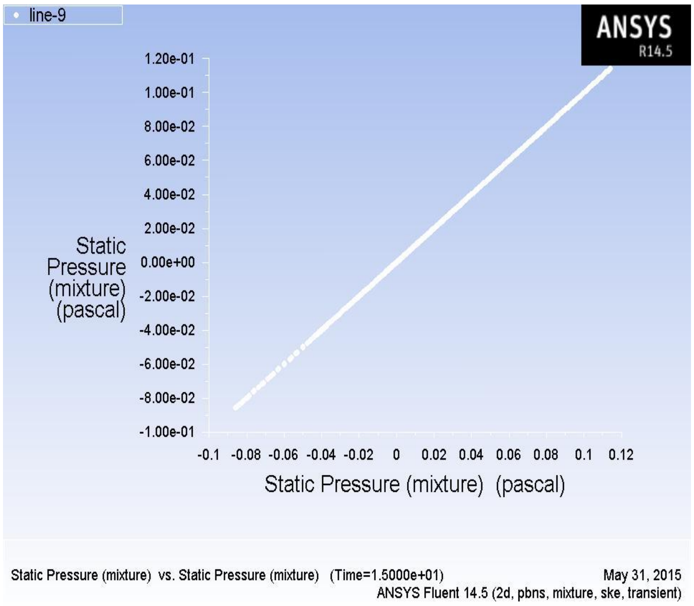

Fig 10- Static temperature distribution

The figure 9 shows the graph of temperature distribution in the evaporator part. Maximum temperature attained is 317K. Lowest temperature is 258K which is the temperature of ammonia liquid entering the evaporator. The temperature is increasing as the ammonia liquid entering absorbs the heat in the evaporator. Figure 10 shows the graph of static pressure distribution in the evaporator. Static pressure is decreasing towards the outlet as the ammonia liquid and ammonia vapour mixes with the hydrogen gas.

4.2 Results of 3D evaporator model

4.2.1 Contours of hydrogen gas volume fraction

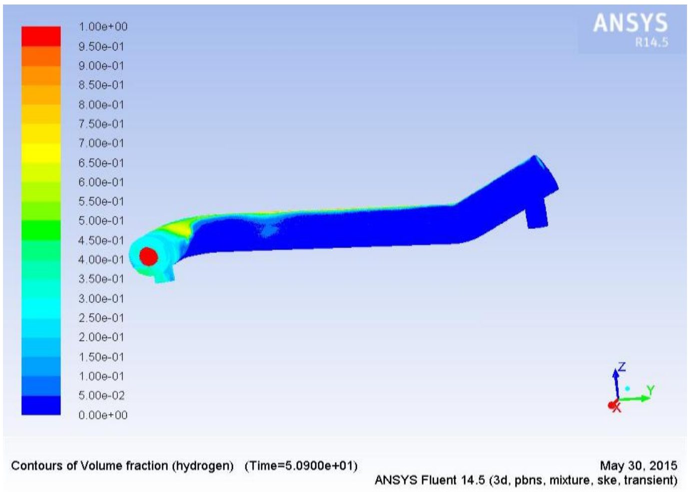

Fig 11- Contours of hydrogen gas volume fraction

The figure 11 shows the contours of volume fraction of hydrogen gas in the evaporator part. Volume fraction of hydrogen gas in the inner tube is one. In the outer tube the volume fraction of hydrogen gas is lower as it mixes with the ammonia vapour.

4.2.2 Contours of ammonia liquid volume fraction

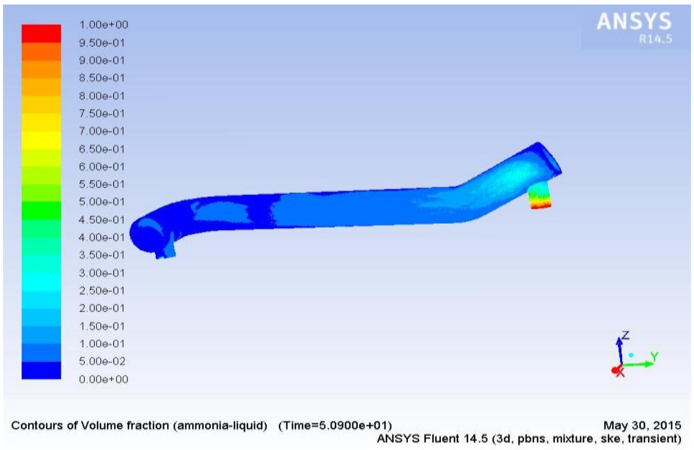

Fig 12- Contours of ammonia liquid volume fraction

The figure 12 shows the volume fraction of ammonia liquid in the evaporator. The volume fraction is one at the ammonia liquid inlet. Volume fraction of ammonia liquid decreases as the ammonia liquid absorbs heat and forms ammonia vapour. Contours show that almost all the liquid entering the evaporator is converted into vapours.

4.2.3 Contours of ammonia vapour volume fraction

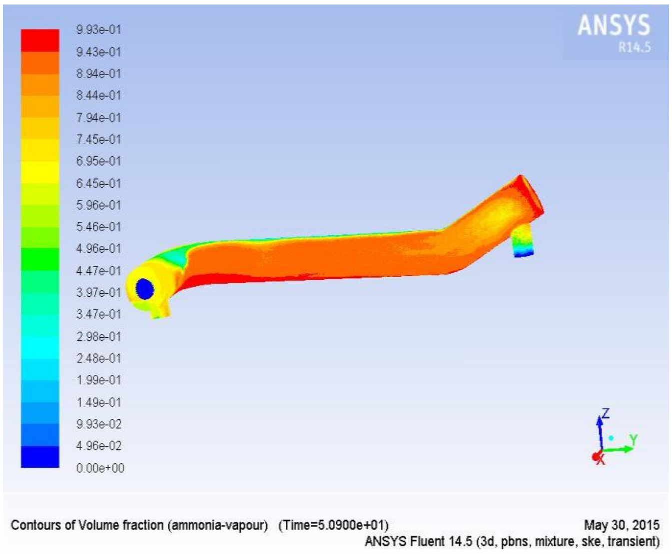

Fig 13- Contours of ammonia vapour volume fraction

The figure 13 shows the contours volume fraction of ammonia vapour. Ammonia liquid entering the evaporator absorbs the heat and forms ammonia vapour. The contours show that the volume fraction of ammonia vapours increases towards the outlet.

4.2.4 Contours of temperature distribution

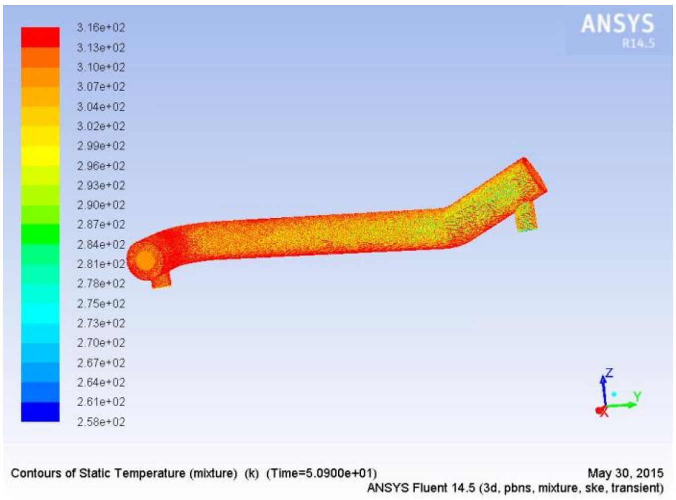

Fig 14- Contours of temperature distribution

The figure 14 shows the temperature distribution in the evaporator. The maximum temperature is 316K, which is matching with the experimental results. The ammonia vapours forming are absorbing the heat and attaining the maximum temperature. Near the tube wall the temperature is maximum.

4.2.5 Contours of static pressure distribution

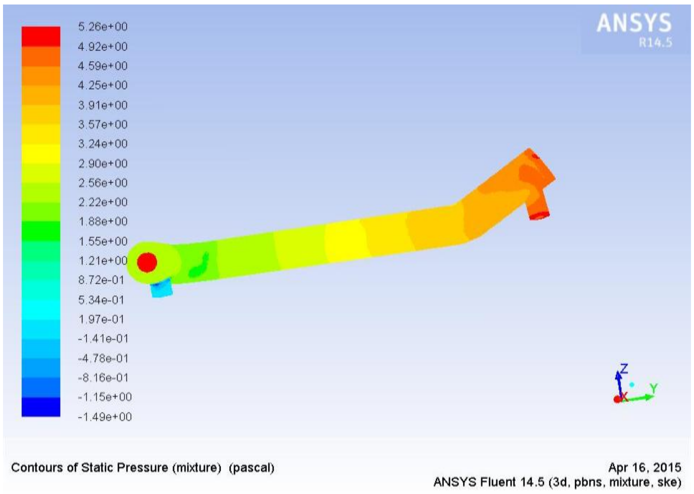

Fig 15- Static pressure distribution

The figure 15 shows the results of static pressure distribution. The static pressure is decreasing towards the outlet of the evaporator. As the ammonia liquid entering the evaporator mixes with the hydrogen gas, the static pressure is decreasing

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4.3 Results of 3D evaporator model at mid plane

4.3.1 Contours of hydrogen gas at time zero

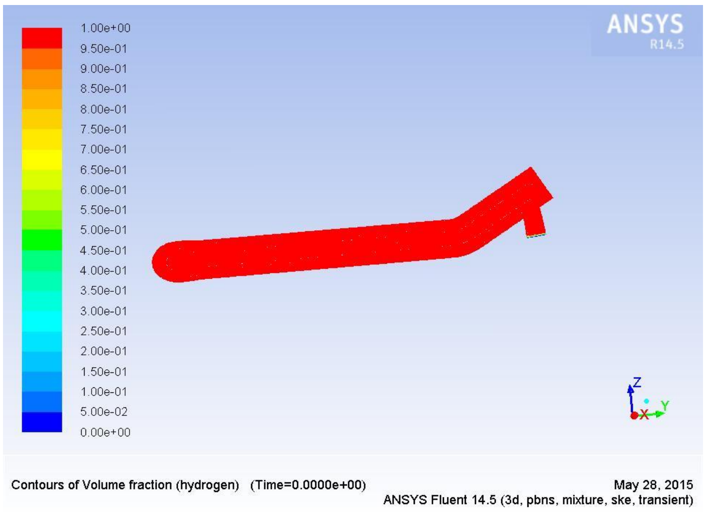

Fig 16- Hydrogen gas volume fraction at time zero

The figure 16 shows the results of hydrogen gas volume fraction at time zero. The problem is initialized with hydrogen gas being filled in the evaporator. Then the ammonia liquid is entering at the ammonia inlet.

4.3.2 Contours of ammonia vapour volume fraction at mid plane

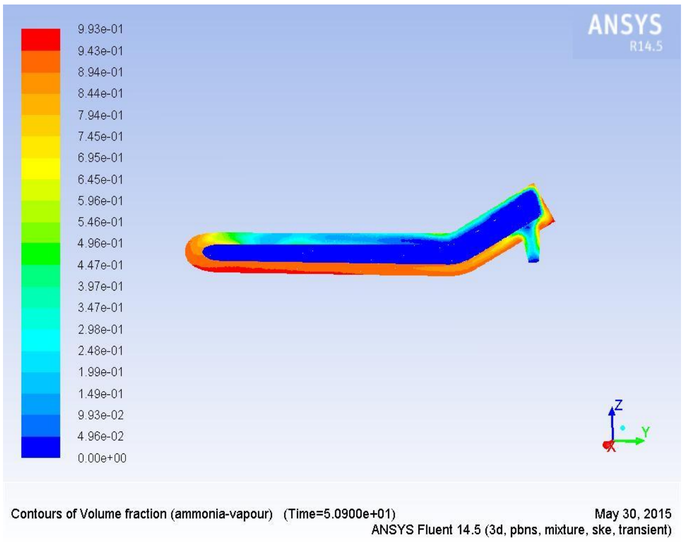

Fig 17- Contours of ammonia vapour volume fraction

The figure 17 shows the contours of ammonia vapour volume fraction. Ammonia liquid entering is absorbing the heat and forms ammonia vapours. Volume fraction of ammonia vapours is increasing towards the outlet.

4.3.3 Contours of ammonia liquid volume fraction

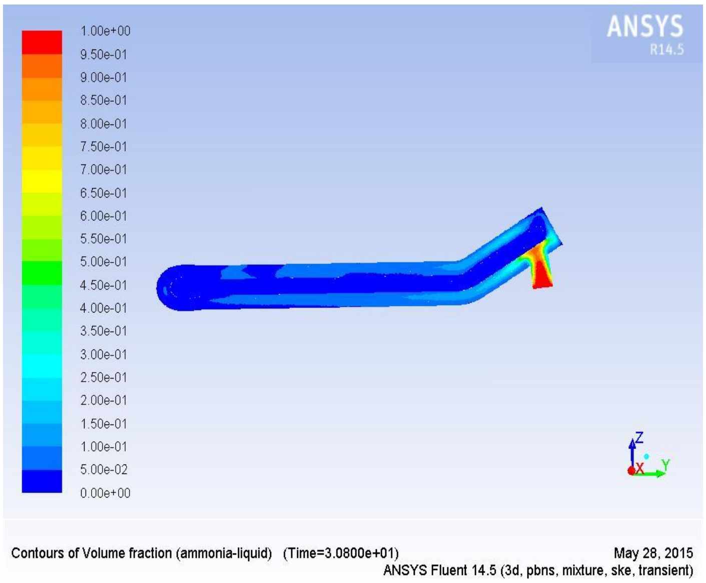

Fig 18- Contours of ammonia liquid volume fraction

The figure 18 shows the results of ammonia liquid volume fraction. The contours show that the volume fraction of the ammonia liquid is decreasing towards the outlet of the evaporator. The ammonia liquid is forming ammonia vapours as it absorbs the heat in the evaporator.

4.3.4 Contours of temperature distribution

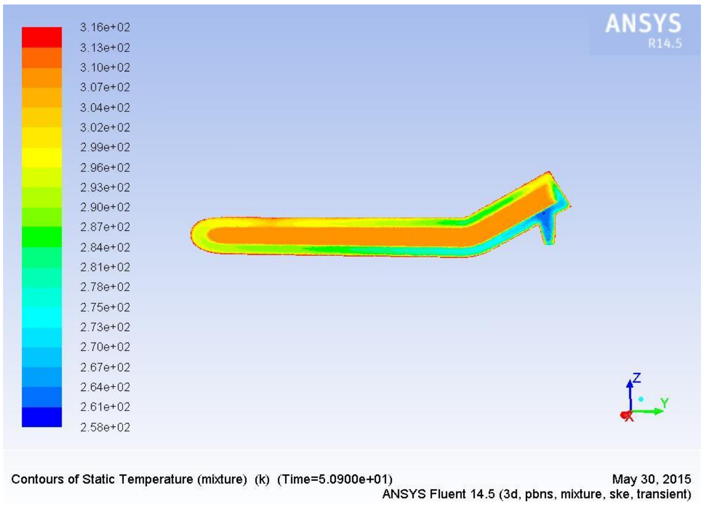

Fig 19- Temperature distribution

The figure 19 shows the results of temperature distribution in the mid plane of evaporator. The ammonia liquid is entering at 258K and hydrogen gas is entering at 309K. The maximum temperature is 316K. The ammonia vapours forming are obtaining the maximum temperature.

4.3.5 Contours of velocity distribution

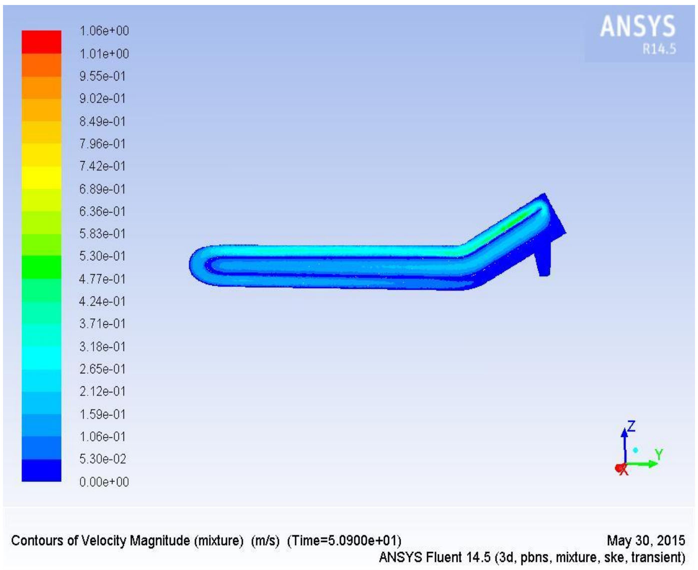

Fig 20- Velocity distribution

The figure 20 shows the velocity distribution contours. The velocity is increasing towards the outlet of the evaporator. Ammonia liquid is entering the evaporator at 0.02 m/s and hydrogen gas is entering at 0.1 m/s. As the ammonia vapours are forming the velocity increases due to density difference. The maximum velocity attained is 1.06m/s.

5. CONCLUSIONS

The analysis of the flow of refrigerant in the evaporator part of the three fluid vapour absorption refrigeration system has led us to the better understanding of the system. The evaporation process taking place in the evaporator is captured through the flow analysis using FLUENT(ANSYS 14.5). The velocity distribution in the evaporator is analysed, and the results show that the velocity is increasing when the ammonia liquid is vaporized. Also the distribution of the temperature in the evaporator part is analysed. The better results were shown in the 3D model compared to 2D model analysis. The analysis of the 3D model takes longer time, but the results are more accurate when compared to 2D model analysis. The velocity distribution, static pressure distribution, phase transformation and temperature distribution were analysed in the evaporator part.

REFERENCES

[1] Andre Aleixo Manzela et.al "Using engine exhaust gas as energy source for an absorption refrigeration system", Applied Energy 87 (2010) 1141-1148.

[2] **Pongsid Srikiran et.al** "A review of absorption refrigeration technologies", Renewable and Sustainable Energy Reviews 5 (2001) 343-372.

[3] **I. Horuz et.al** "Experimental investigation of a vapour absorption refrigeration system", International journal of refrigeration 27 (2004) 10-16.

[4] **Shah Alam et.al** "A proposed model for utilizing exhaust heat to run automobile air conditioner", The second International conference on "Sustainable Energy and Environment (SEE 2006).

[5] **C P Arora** " Refrigeration and Air conditioning", Tata McGraw-Hill publications.

[6] **Srinivas Garimelli et.al** "Waste heat driven absorption/vapour-compression cascade refrigeration system for megawatt scale, high flux, low temperature cooling", International journal of refrigeration 34 (2011) 1176-1785.

[7] **Jaime Sieres et.al** "Evaluation of the column components for the vapour enrichment and system performance in small power NH_3-H_2O absorption refrigeration system", International journal of refrigeration 29 (2006) 579-588.

[8] **N A Darwish et.al** "Performance analysis and evaluation of a commercial absorption refrigeration water ammonia (ARWA) sustem", International journal of refrigeration 31 (2008) 1214-1223.

[9] **Paul Kalinowski et.al** "Application of waste heat powered absorption refrigeration system to the LNG recovery process", International journal of refrigeration 32 (2009) 687-694.

[10] **Sumit K Swarankar et.al** "Performance of a vapour absorption refrigeration system operating with ionic liquid ammonia combination with water as cosolvent", Applied thermal engineering xxx (2014) 1-8.

