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CFD Analysis of Air Cooled Condenser by Using Copper Tubes and Aluminum Fins

Mallikarjun[1], Anandkumar S Malipatil[2]

Abstract--In systems involving heat transfer, a condenser is a device or unit used to condense a substance from its gaseous to its liquid state, typically by cooling it. In so doing, the latent heat is given up by the substance, and will transfer to the condenser coolant. Condensers are typically heat exchangers which have various designs and come in many sizes ranging from rather small to very large industrial-scale units used in plant processes. Air cooled condensers are used in small units like household refrigerators, deep freezers, water coolers, window air-conditioners, split air-conditioners, small packaged air-conditioners etc. These are used in plants where the cooling load is small and the total quantity of the refrigerant in the refrigeration cycle is small. Air cooled condensers are also called coil condensers as they are usually made of copper or aluminum coil. Air cooled condensers occupy a comparatively larger space than water cooled condensers.

In this work heat transfer by convection in air cooled condensers is studied and improved. The assessment has been carried out on an air-cooled finned-tube condenser of a vapour compression cycle for air conditioning system. Heat transfer analysis and CFD analysis is done on the condenser to evaluate the better design and material. The materials considered for tube is copper and for fins are Aluminum alloys 1100, 6063 and Magnesium alloy for different refrigerants HCFC and 404R. CFD analysis is done at different velocities. Theoretical calculations are done to determine heat transfer rate.

Keywords: Air cooled condenser, Heat Flux, Mesh generation, Refrigerants HCFC & 404R, Static pressure

I. INTRODUCTION

A condenser or evaporator is a heat exchanger, allowing condensation, by means of giving off, or taking in heat respectively Refrigerant and air will be physically separated, at air conditioner condenser, and evaporator. Therefore, heat transfer occurs by means of conduction. Air-cooled condensers are increasing in popularity because of the absence of water piping, the consequent simplicity of operation and the freedom from any health risk associated with the use of spray water. One objection to their use is that the capacity of the refrigeration plant does not gradually reduce as the ambient dry-bulb rises but ceases suddenly when the high pressure cut-out operates. A partial solution is to arrange for some of the compressor to be unloaded when the condensing pressure rises, before it reaches the cut-out point. It is a good plan to select air-cooled condensers to operate in an ambient temperature two or three degree higher than the design value chosen for the rest of the air conditioning system. **M. M. Awad *et.al*** studied heat transfer by convection in air cooled condensers. **E.F. Gorzelnik** , indulged in the recovery of energy in the heat of compression from air conditioning, refrigeration, or heat-pump equipment in 1977 itself . **PSS. Srinivasan *et.al.*** discussed in studies on Waste Heat Recovery from an Air Conditioning Unit that the energy can be recovered and utilized without sacrificing comfort level in 2011. **P.Suresh Mohan Kumar** Confabulated that he used intercooler which increases the efficiency of Air Conditioning system in 2012. **Kaushik and Singh** Confabulated about 40 percent of heat is recovered using Canopus heat exchanger in 1995.

II. PROBLEM DEFINITION

The assessment has been carried out on an air-cooled finned-tube condenser of a vapor compression cycle for air conditioning system.

- The materials used for tube is copper and for fins are Aluminum Alloy 1100, Aluminum alloy 6063 and Magnesium. The refrigerants are HCFC, 404R.
- Cooling load calculations are done to determine the capacity of air conditioner required to cool the required room.
- Thermal flux calculations are done theoretically to compare the results with analytical results.
- 3D modeling is done in Pro/Engineer. The dimensions of the condenser are taken from the component itself using reverse engineering process.
- Heat transfer analysis is done on the condenser to evaluate the better design and material. Analysis is done in Ansys. The analysis is done to verify the heat transfer rate, temperature distribution.
- The better material for fin and better refrigerant are analyzed using heat transfer analysis.

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- CFD analysis is also done on the fin for two refrigerants HCFC and 404R at different fluid velocities 2.5m/s, 5m/s and 7.5m/s.

III. METHODOLOGY

In all of the approaches the procedure followed is.

During preprocessing the geometry (physical bounds) of the problem is defined.
The volume occupied by the fluid is divided into discrete cells (the mesh). The mesh may be uniform or non-uniform.
The physical modeling is defined – for example, the equations of motion + enthalpy + radiation + species conservation.
Boundary conditions are defined. This involves specifying the fluid behavior and properties at the boundaries of the problem. For transient problems, the initial conditions are also defined.
The simulation is started and the equations are solved iteratively as a steady-state or transient.
Finally a postprocessor is used for the analysis and visualization of the resulting solution.

IV. RESULT AND DISCUSSIONS

A. Thermal Analysis Of Condenser
File >import>IGES>ok>browse>select file>ok
Preferences>select thermal>ok
Postprocessor>materialproperties>material models
Used materials for condenser
Aluminum1100,Aluminum6063,Magnesium, Copper
Thermal analysis of condenser for HCFC refrigerant
Al 1100 for fins
Thermal conductivity=230w/mk, Specific heat=900J/Kg.k, Density=2705Kg/m^3
Copper for tubes
Thermal conductivity=390w/mk, Specific heat=390J/Kg.k , Density=8900Kg/m^3

B. Boundary conditions
Loads>apply>thermal>temperature>select temperature area>ok>enter-temperature value>313k>ok
The temperature is applied inside the tube of the condenser
Convection>onareas>selectconvection area>enter film coefficient value=0.0024w/m^{2}Loads>define Bulk temperature value=303k
The convection is applied on the fins
Solution>solve>current Ls>ok
General post processor>plot results>counter plot>nodal solution>dof solution>nodal temperature>ok

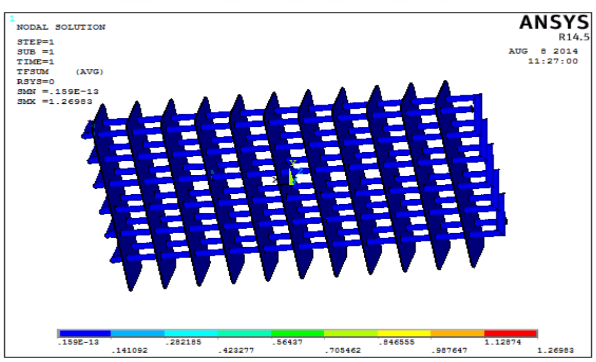

Figure 4.1: Heat flux

Thermal analysis of condenser for HCFC refrigerant
Al6063 for fins
Thermal conductivity=193w/mk, Specific heat=900J/Kg.k, Density=27000Kg/m^3

Copper for tubes

Thermal conductivity=390w/mk, Specific heat=390J/Kg.k, Density=8900Kg/m^3

Loads>define loads>apply>thermal>temperature>select temperature area>ok>enter temperature value>313k>ok

Convection>on areas>select convection area>enter film coefficient value=0.0024w/m^2

Bulk temperature value=303k

Solution>solve>current Ls>ok

General post processor>plot results>counter plot>nodal solution>DOF solution>nodal temperature>ok

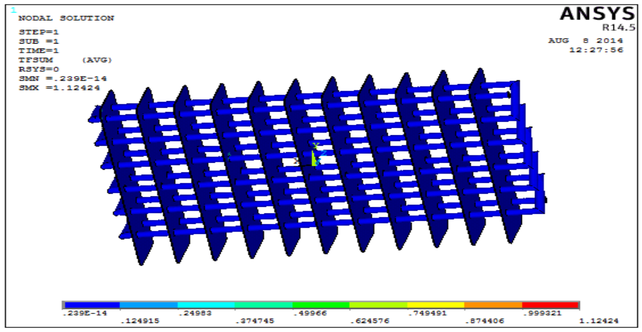

Figure 4.2: Heat flux

According to the contour plot, at fins the maximum rate of heat transfer (heat flux) area is 1.12424and at outer surface the minimum is 0.293e-14

Thermal analysis of condenser for HCFC refrigerant

Magnesium for fins

Thermal conductivity=160w/mk, Specific heat=1000J/Kg.k, Density=1700Kg/m^3

Copper for tubes

Thermal conductivity=390w/mk, Specific heat=390J/Kg.k, Density=8900Kg/m^3

Loads>define loads>apply>thermal>temperature>select temperature area>ok>enter temperature value>313k>ok

Convection>on areas>select convection area>enter film coefficient value=0.0024w/m^2

Bulk temperature value=303k

Solution>solve>current Ls>ok

General post processor>plot results>counter plot>nodal solution>dof solution>nodal temperature>ok

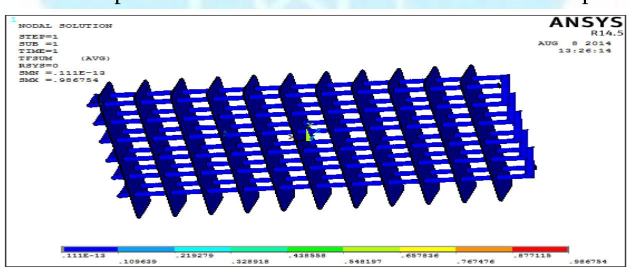

Figure 4.3: Heat flux

According to the contour plot, at fins the maximum rate of heat transfer (heat flux) area is 0.986754and at outer surface the minimum is 0.111e-13

Thermal analysis of condenser for 404R refrigerant

Al 1100 for fins

Thermal conductivity=230w/mk, Specific heat=900J/Kg.k, Density=2705Kg/m^3

Copper for tubes

Thermal conductivity=390w/mk**,** Specific heat=390J/Kg.k**,** Density=8900Kg/m^3

Loads>define loads>apply>thermal>temperature>select temperature area>ok>enter temperature value>313k>ok

Convection>on areas>select convection area>enter film coefficient value=900w/m^2

Bulk temperature value=303k

Solution>solve>current Ls>ok

General post processor>plot results>counter plot>nodal solution>dof solution>nodal temperature>ok

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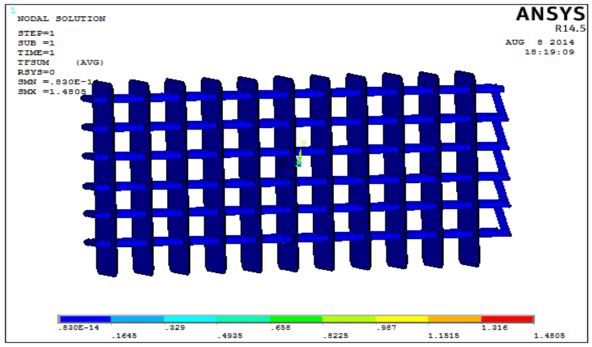

Figure 4.4: Heat flux

According to the contour plot, at fins the maximum rate of heat transfer (heat flux) area is 1.4805and at outer surface the minimum is 0.830e-14

C. Results Table For Thermal Analysis

REFRIGERANTS	MATERIALS	RESULTS		
		Nodal Temperature (K)	**Thermal Gradient (K/mm)**	**Heat flux (W/mm^2)**
HCFC	**Aluminum1100**	313	5.52101	1.26983
	Aluminum6063	313	5.82506	1.12424
	Magnesium	313	6.16722	0.986754
404R	**Aluminum1100**	313	6.43696	1.4805
	Aluminum6063	313	6.07077	1.28162
	Magnesium	313	6.94673	1.11148

In the above table, the nodal temperature, thermal gradient and thermal flux values are presented from thermal analysis results. From the results, thermal flux is more when Aluminum alloy 1100 is used for fin and refrigerant used is 404R. That is the heat transfer rate is more. Thermal gradient is also more that is the change in temperature over a distance is more.

D. Theoretical Thermal Flux Results

	Al ALLOY 1100	**Al ALLOY 6063**	**MAGNESIUM**
HCFC	2.64	2.44	2.21
R404	2.69	2.488	2.24

In the above table, thermal flux values are presented from theoretical calculations. From the results, thermal flux is more when Aluminum alloy 1100 is used for fin and refrigerant used is 404. That is the heat transfer rate is more.

CFD ANALYSIS OF FIN

REFRIGERANT - HCFC

VELOCITY - 2.5 m/s

Ansys → workbench→ select analysis system → fluid flow fluent → double click

→Select geometry → right click → import geometry → select browse →open part → ok

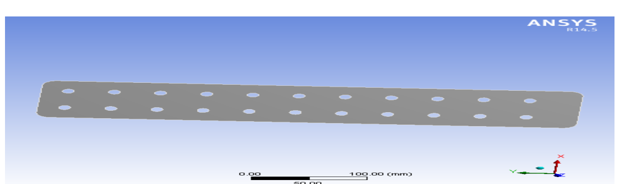

Figure 4.5: Import model

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

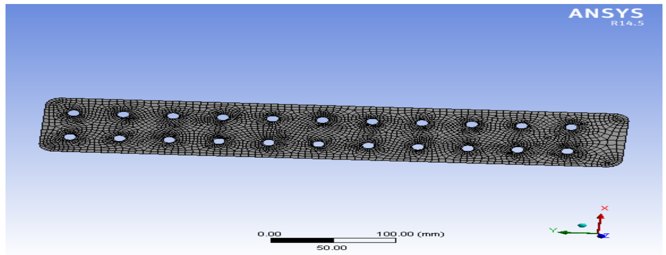

Figure 4.6: Meshed model

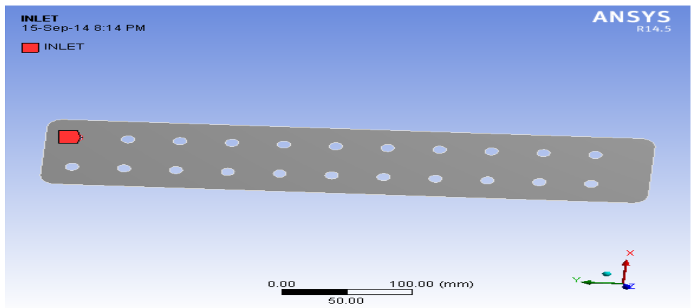

Figure 4.7: Refrigerant Inlet

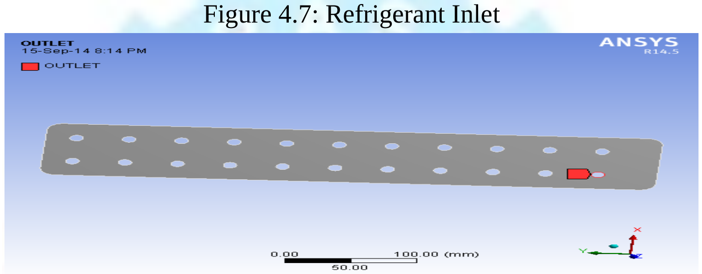

Figure 4.8: Refrigerant Outlet

Boundary conditions → Inlet → Edit
Velocity magnitude →2.5m/s
selectwall→wall→edit→heat transfer coefficient→243w/m^{2}k
Solution → Solution Initialization→ Hybrid Initialization →done
Run calculations → No of iterations = 10 → calculate → calculation complete
→→ Results → graphics and animations → contours → setup

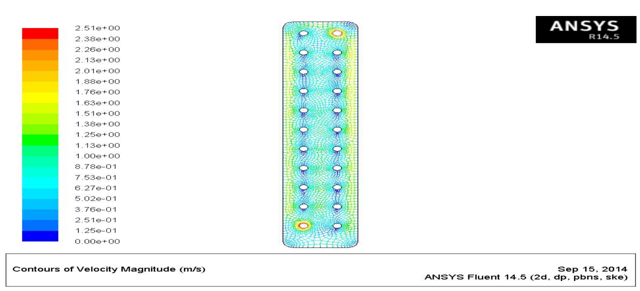

Figure 4.9: Velocity magnitude

According to the contour plot, the maximum velocity at inlet and outlet holes is 2.51e+00 m/s and the minimum at in between inlet and outlet holes is 1.25e-01 m/s

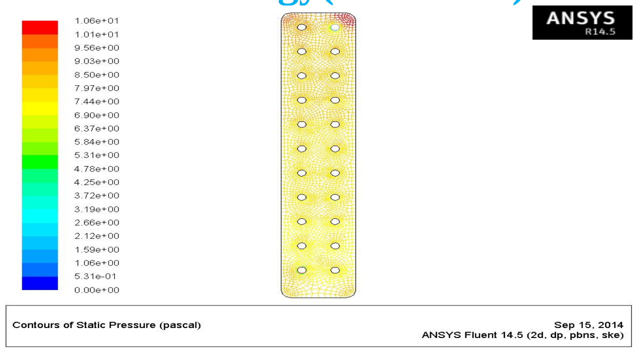

Figure 4.10: Static Pressure

According to the contour plot, the maximum static pressure at outlet hole beside corners is 1.06e+01pa and the minimum at inlet hole 5.31e-01pa

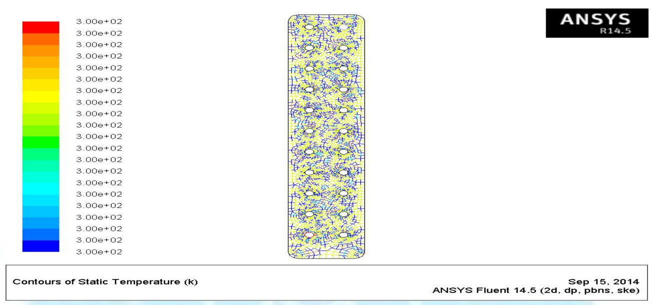

Figure4.11: Temperature

According to the contour plot, the maximum temperature at fin body is 3.00e+02 k

Mass flow report

"Flux Report"

Mass Flow Rate (kg/s)

inlet	0.09587553
interior-_trm_srf	-1.0707636
outlet	-0.095938734
wall-_trm_srf	0
Net	-6.3204351e-05 kg/sec.

The net mass flow rate of fin body is 6.3204351e-05 kg/sec

"Flux Report"

Total Heat Transfer Rate (w)

inlet	178.51022
outlet	-178.6279
wall-_trm_srf	3.5367242e-13
Net	-0.1176799 w

The net Total heat transfer rate of fin body is -0.117679 w.

VELOCITY 5m/s

Boundary conditions → Inlet → Edit

Velocity magnitude →5 m/s

Solution → Solution Initialization→ Hybrid Initialization →done

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Run calculations → No of iterations = 10 → calculate → calculation complete →→ Results → graphics and animations → contours → setup

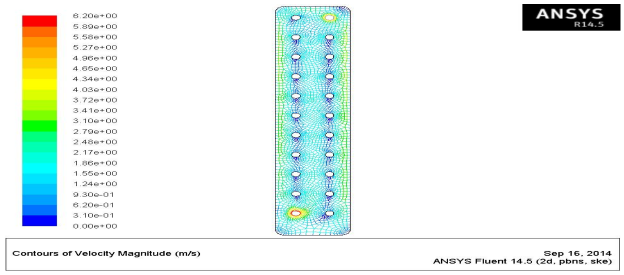

Figure 4.12: Velocity Magnitude

According to the contour plot, the maximum velocity at inlet and outlet holes is 6.20e+00 m/s and the minimum at in between inlet and outlet holes is 3.10e-01m/s

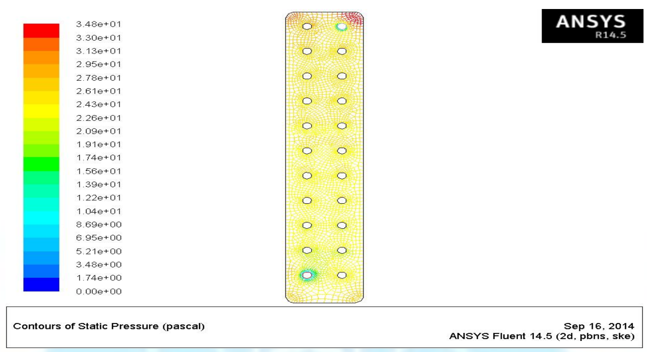

Figure 4.13: Static pressure

According to the contour plot, the maximum static pressure at outlet hole beside corners is 3.48e+01pa and the minimum at inlet hole 1.74e+00pa

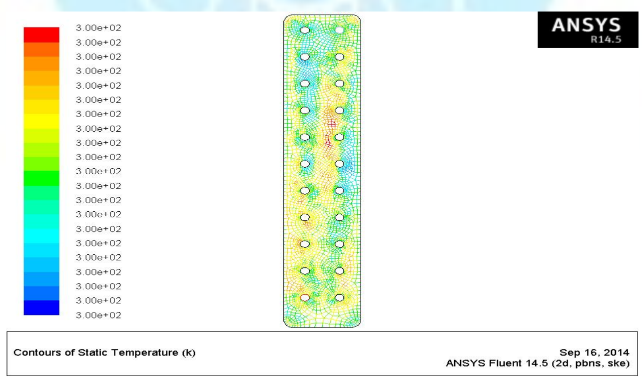

Figure 4.14: Temperature

According to the contour plot, the maximum temperature at fin body is 3.00e+02 k

Mass flow rate

"Flux Report"

Mass Flow Rate	(kg/s)
inlet	0.191751
interior-_trm_srf	-1.537853
outlet	-0.1914832
wall-_trm_srf	0

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---------------- --------------------
Net 0.00026780367 kg/sec

The net mass flow rate of fin body is 0.000267803kg/sec
"Flux Report"

Total Heat Transfer Rate	(w)
inlet	357.02032
outlet	-356.51999
wall-_trm_srf	-0.0013494033

---------------- --------------------
Net 0.49898629 w

The net Total heat transfer rate of fin body is 0.49898629w

VELOCITY 7.5m/s
Boundary conditions → Inlet → Edit
Velocity magnitude → 7.5m/s
Solution → Solution Initialization→ Hybrid Initialization →done
Run calculations → No of iterations = 10 → calculate → calculation complete
→→ Results → graphics and animations → contours → setup

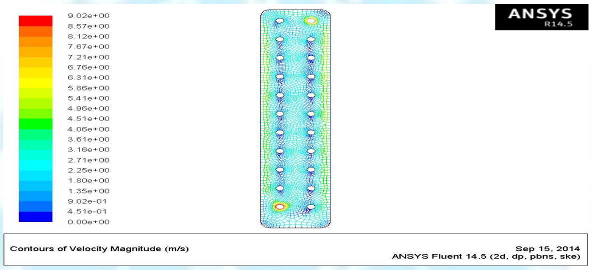

Figure 4.15: Velocity Magnitude

According to the contour plot, the maximum velocity at inlet and outlet holes is 9.02e+00 m/s and the minimum at in between inlet and outlet holes is 4.51e-01 m/s

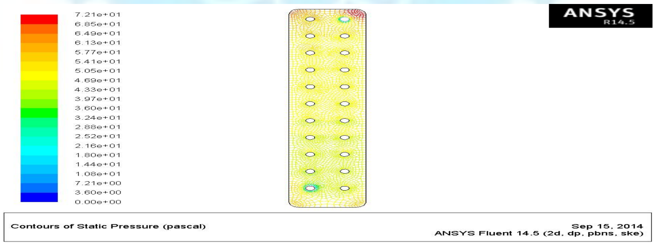

Figure 4.16: Static pressure

According to the contour plot, the maximum static pressure at outlet hole beside corners is 7.21e+01pa and the minimum at inlet hole 3.60e+00pa

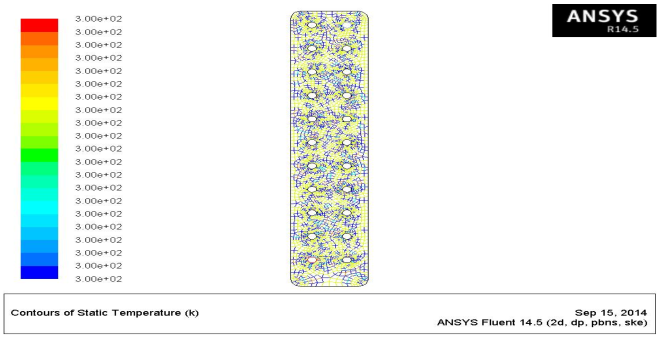

Figure 4.17: Temperature

According to the contour plot, the maximum temperature at fin body is 3.00e+02 k

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Mass flow report

"Flux Report"

Mass Flow Rate	(kg/s)
inlet	0.28762659
interior-_trm_srf	-3.1008352
outlet	-0.28777994
wall-_trm_srf	0
Net	-0.00015335041kg/sec

The net mass flow rate of a fin body -0.0001533504 kg/sec

"Flux Report"

Total Heat Transfer Rate	(w)
inlet	535.53065
outlet	-535.81617
wall-_trm_srf	-7.3948658e-13
Net	-0.28552244 w

REFRIGERANT - 404R

VELOCITY - 2.5m/s

Boundary conditions → Inlet → Edit

Velocity magnitude → 2.5m/s

Solution → Solution Initialization→ Hybrid Initialization →done

Run calculations → No of iterations = 10 → calculate → calculation complete

→→ Results → graphics and animations → contours → setup

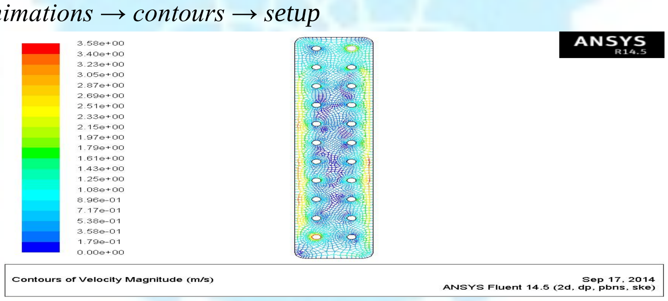

Figure 4.18: Velocity Magnitude

According to the contour plot, the maximum velocity at inlet and outlet holes is 3.58e+00 m/s and the minimum at in between inlet and outlet holes is 1.79e-01 m/s

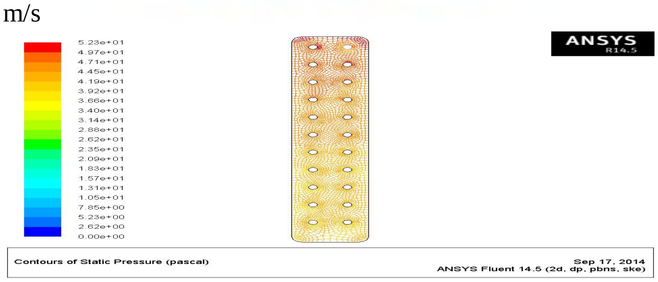

Figure 4.19: Static pressure

According to the contour plot, the maximum static pressure at outlet hole beside corners is 5.23+01pa and the minimum at inlet hole 2.62e+00pa

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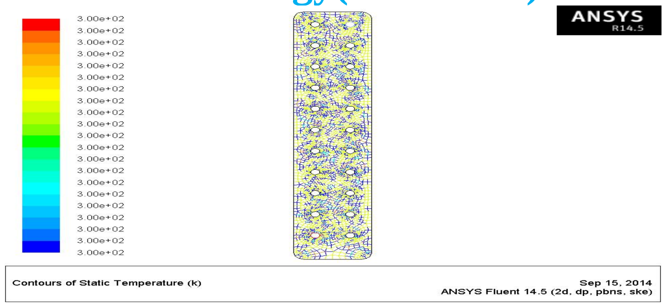

Figure 4.20: Temperature

According to the contour plot, the maximum temperature at fin body is 3.00e+02

Mass flow rate

```
            "Flux Report"
          Mass Flow Rate            (kg/s)
------------------------------- --------------------------------
inlet                                       0.19175106
interior-_trm_srf                           -2.0165849
outlet                                      -0.19167539


wall-_trm_srf                      0
---------------- -------------------------------------------------
                    Net      7.5668995e-05kg/sec
```

The net mass flow rate of fin body is 7.5668995e-05 kg/sec

```
  "Flux Report"
Total Heat Transfer Rate             (w)
------------------------------- --------------------
inlet                          178.51022
outlet                         -188.34201
wall-_trm_srf                  -3.1452141e-13
-------------------------- -----------------------------
                    Net        -0.98317916   w
```

The net Total heat transfer rate of fin body is-9.831796 w

VELOCITY- 5(m/s)

Boundary conditions → Inlet → Edit

Velocity magnitude →5m/s

Solution → Solution Initialization→ Hybrid Initialization →done

Run calculations → No of iterations = 10 → calculate → calculation complete

→→ Results → graphics and animations → contours → setup

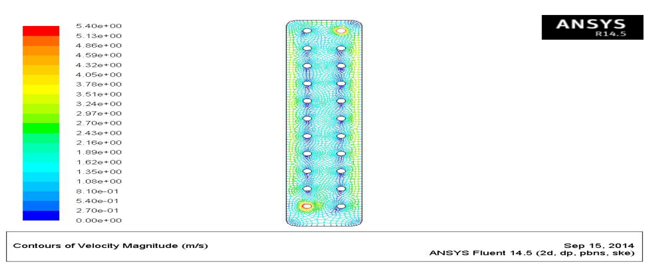

Figure 4.21: Velocity Magnitude

According to the contour plot, the maximum velocity at inlet and outlet holes is 5.40e+00 m/s and the minimum at in between inlet and outlet holes is 2.70e-01m/s

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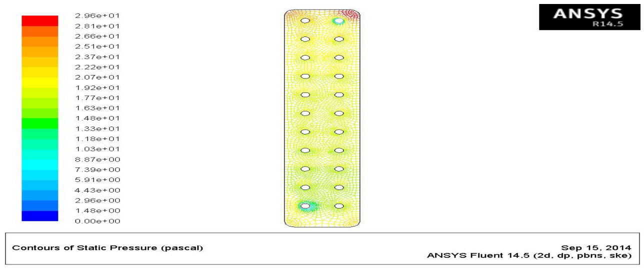

Figure4.22: Static pressure

According to the contour plot, the maximum static pressure at outlet hole beside corners is 2.96e+01pa and the minimum at inlet hole 1.48e+00pa

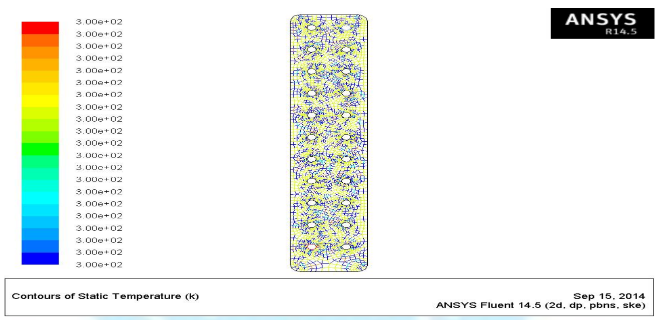

Figure 4.23: Temperature

According to the contour plot, the maximum temperature at fin body is 3.00e+02 k

Mass flow rate

"Flux Report"

Mass Flow Rate (kg/s)

-------------------------------- --------------------

inlet 0.09587553

interior-_trm_srf -0.73212272

outlet -0.10115606

wall-_trm_srf 0

---------------- --

Net -0.00052805282 kg/s

The net mass flow rate of fin body is -0.0052805282 kg/sec

"Flux Report

Total Heat Transfer Rate (w)

-------------------------------- --------------------

inlet 357.02043

outlet -356.87954

wall-_trm_srf 1.5402225e-14

---------------- --------------------

Net 0.14088776w

The net Total heat transfer rate of fin body is 0.14088776w

VELOCITY - 7.5m/s

Boundary conditions → Inlet → Edit

Velocity magnitude → 7.5m/s

Solution → Solution Initialization→ Hybrid Initialization →done

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Run calculations → No of iterations = 10 → calculate → calculation complete →→ Results → graphics and animations → contours → setup

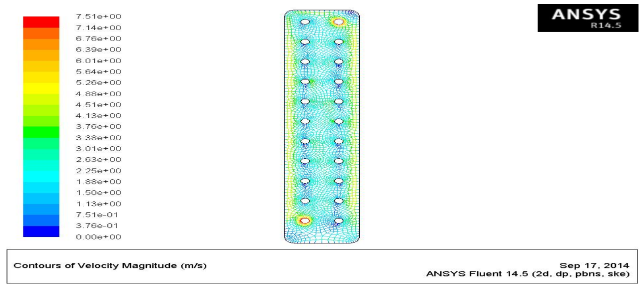

Figure 4.24: Velocity Magnitude

According to the contour plot, the maximum velocity at inlet and outlet holes is 7.51e+00 m/s and the minimum at in between inlet and outlet holes is 3.76e-01pa

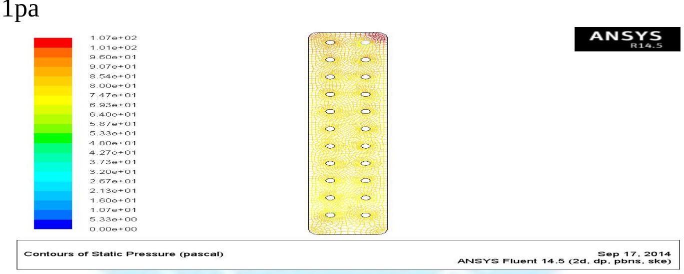

Figure 4.25: Static pressure

According to the contour plot, the maximum static pressure at outlet hole beside corners is 1.07e+02pa and the minimum at inlet hole 5.33e+00pa

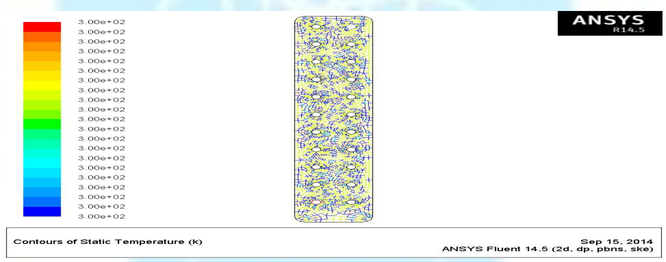

Figure 4.26: Temperature

According to the contour plot, the maximum temperature at fin body is 3.00e+02 k

Mass flow report

"Flux Report"

Mass Flow Rate	(kg/s)
inlet	0.28762659
interior-_trm_srf	-3.0067173
outlet	-0.28706232
wall-_trm_srf	0
Net	0.00056426693 kg/s

The net mass flow rate of fin body is 0.00056426693 kg/sec

"Flux Report"

Total Heat Transfer Rate (w)
------------------------------- --------------------
inlet 535.53065
outlet -534.48004
wall-_trm_srf 1.0814626e-12
---------------- --------------------
Net 1.0506061 w

The net Total heat transfer rate of fin body is 1.0506061 w.

RESULTS TABLE FOR CFD ANALYSIS

		Velocity Magnitude (m/s)	Static pressure (Pascal)	Temperature (K)	Mass Flow Rate (Kg/s)	Heat Transfer Rate (W)
Hcfc	2.5m/s	2.51e+00	1.06e+01	3.00e+02	6.3204351e-05	0.1176799
	5 m/s	6.20e+00	3.48e+01	3.00e+02	0.00026780367	0.49898629
	7.5 m/s	9.02e+00	7.21e+01	3.00e+02	0.00015335049	0.28552244

Results Table for CFD Analysis with HCFC Refrigerant

		Velocity Magnitude (m/s)	Static pressure (Pascal)	Temperature (K)	Mass Flow Rate (Kg/s)	Heat Transfer Rate (W)
404R	2.5 m/s	3.58e+00	5.23e+01	3.00e+02	7.5668995e-05	0.98317916
	5 m/s	5.40e+00	2.96e+01	3.00e+02	0.00052805282	0.14088776
	7.5 m/s	7.51e+00	1.70e+02	3.00e+02	0.000562426693	1.0506061

Results Table for CFD Analysis with 404R Refrigerant

V. CONCLUSIONS

In this work, an ac condenser is designed and optimized for better material, refrigerant and to improve the heat transfer rate.

- By observing the thermal analysis results, using fin material Aluminum alloy 1100, thermal flux is more than other two materials. So by using Aluminum alloy 1100, the heat transfer rate increases. And also by taking refrigerant R404 is better.
- Thermal flux is also calculated theoretically, by observing the results, using fin material Aluminum alloy 1100 and refrigerant R404 has more heat transfer rate.
- CFD analysis is also done on the fin for two refrigerants HCFC and 404R at different fluid velocities 2.5m/s, 5m/s and 7.5m/s. By observing the analysis results, the velocity magnitude, mass flow rate and heat transfer rate is more when 404R is used, so using 404R increases the efficiency of the condenser but the pressure is less.
- Increasing inlet velocity from 2.5m/s to 5m/s, yields no advantage but by increasing to 7.5m/s yields better results.

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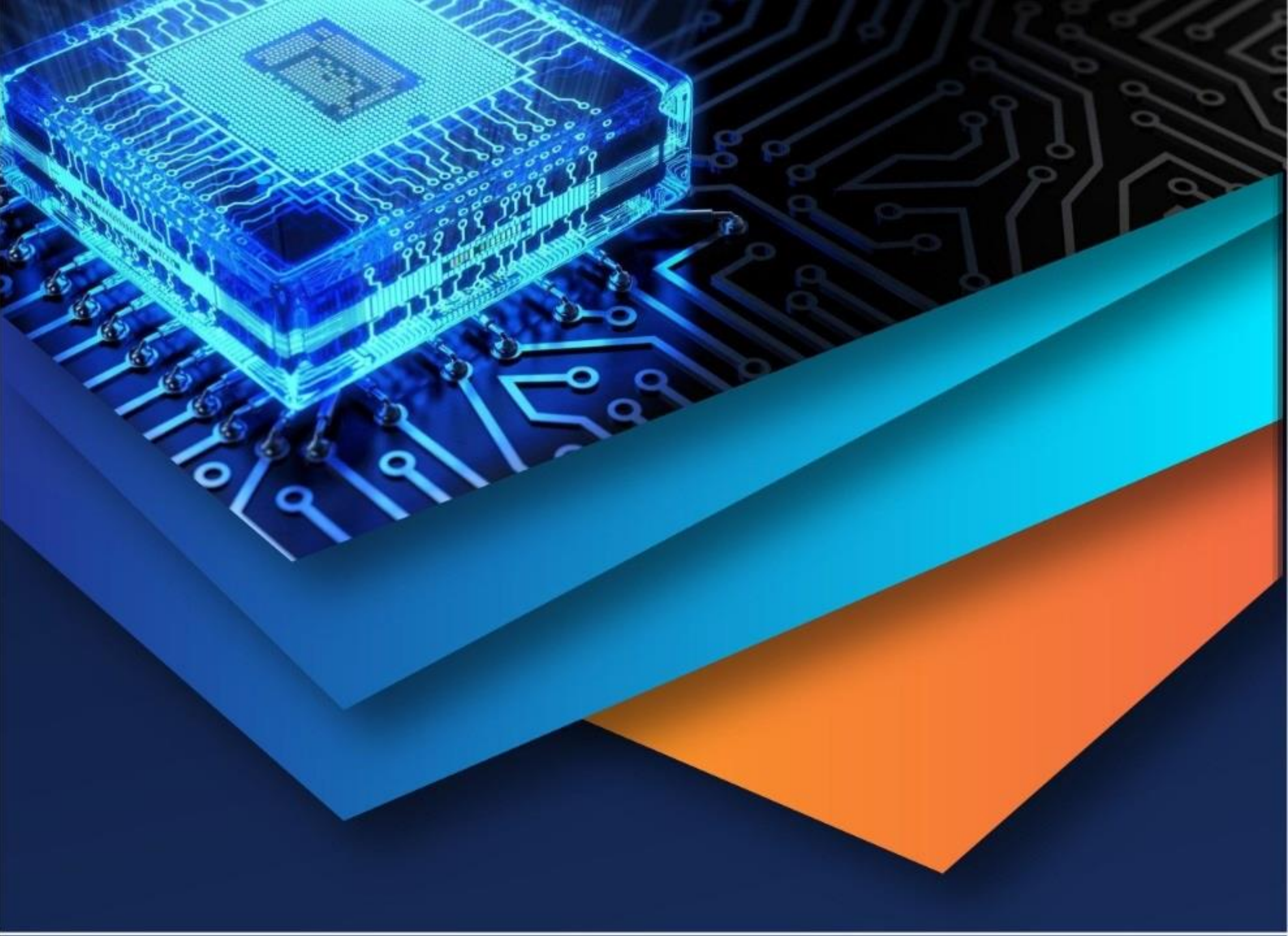

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