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Modeling & Analysis of a Compact Dynamic Model for Household Vapour Compression Refrigerated Systems

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Abstract— **The work of heat transport is traditionally driven by mechanical work, but can also be driven by heat, magnetism, electricity, laser, or other means. Vapor compression refrigeration system used in domestic refrigerators and air conditioners are typical examples of steady-state refrigeration systems. Steady-state refrigeration systems in which the cooling effect is continuous, the refrigerant flow is steady and in one direction. In this work a compact model of house hold refrigerator ismodeled in 3D modeling software Pro/ Engineer wild fire 5. The refrigeration system consists of Condenser, Evaporator, Compressor and expansion valve. The refrigerant used mostly nowadays is HFC-134a.**

Thermal analysis is done on the main parts of the refrigeration system using ANSYS-14. In this project work HFC-134a is replaced with HCFC, HFC-152A, and 404R. The commonly used material for condenser is copper, in this project work it is replaced with aluminum alloy 6061 and aluminum. Thermal analysis is done on the condenser, compressor and evaporator by changing the materials and refrigerants.

Index Terms— **Condenser, Refrigerant, Thermal gradient**

I. INTRODUCTION

A refrigerator (colloquially fridge) is a common household appliance that consists of a thermally insulated compartment and a heat pump (mechanical, electronic, or chemical) that transfers heat from the inside of the fridge to its external environment so that the inside of the fridge is cooled to a temperature below the ambient temperature of the room. Refrigeration is an vital food storage space practice in developed countries. Lower temperatures in a confine volume lower the replica rate of bacteria, so the refrigerator reduces the rate of spoilage.

A refrigerator maintains a temperature a small number of degrees above the freezing point of water. Most favorable temperature range for unpreserved food storage is 3 to 5 °C (37 to 41 °F). A similar instrument that maintains a temperature below the freezing point of water is called a freezer.

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The refrigerator replaced the icebox, which was a common household domestic device for approximately a century and a half prior. For this reason, a refrigerator is from time to time referred to as an icebox in American practice.

Refrigeration is the process of maintain temperature in a space lower than the environment. In this process heat is detached from the source at low temperature & terrified out to the source at higher temperature. Refrigeration is the process of heat transfer against the natural flow of heat. This is from far above the ground temperature to near to the ground temperature. This heat is passed by a fluid, usually Freon gas.

II. HOUSEHOLD REFRIGERATION

In both developed and developing economies Household refrigeration is a main stream. While some other product types do exist, the vast bulk of goods use single phase mains Power and a Refrigeration system (compressor, evaporator, and condenser) that uses the vapor compression cycle as a means of cooling an insulated dresser. Safe storage and preservation of food and drink for Human consumption is primary purpose in the household refrigeration products. For that temperature inside household refrigeration products should be controlled with in a particular Range – this is the most important energy checkup delivered by these devices. There are two fundamental models on the market: these are automatic defrost products (also called frost free which regularly used forced air) and manual defrost products (also called direct cooling Products) . There are a variety of sizes (from as little as 30 liters to as great as 800 liters) and a Range of product configurations (e.g. vertical Vs chest, single door/ two doors/ multi door, Freezer situated on summit/underneath/side). While there are not actually primary product design differences at a universal level, they are physically powerful local variations in occurrence of exact defrost types, sizes and configurations.

Household refrigeration is a universal service and there is important global trade. Refrigerators are one of the minority appliances that remain "on" constantly and as such put away a significant amount of electricity during regular utilize. Usually series from 100 to 1000 KWh or more per annum Electricity is consumed for refrigerators, depending on the design, size, features, efficiency and situation of use. Refrigerators are broadly synchronized for energy utilization around the globe under programs

III. COMPONENTS OF REFRIGERATOR

Refrigerators contain a variety of parts. Freon gas flow through these parts & undergoes number of phase transitions. The stream of this gas through a range of parts of the refrigeration system is called a refrigeration cycle.

1) **Compressor**: Compressor is the major part of the refrigeration system. The power required for transmitting heat

from low temperature space to high temperature space is given here. When Freon gas flows through a compressor it compressed highly i.e. pressure and its temperature also becomes very elevated. When it discharges the compressor, Freon gets modified into the gaseous state.

2) **Condenser**: via condenser all the heat the Freon has absorbed from the material at low temperature is rejected to the environment. For household refrigerators, the condenser frequently a copper coil is uncovered to the atmosphere. When Freon flow though this coil it gives up its heat incompletely to the atmospheric or surrounding air and its temperature decreases, but its pressure is constant. Water cooled condensers are used in case of the larger refrigerators.

3) **Expansion valve**: When the high pressure and low temperature Freon flow through expansion valve its pressure decreases rapidly and along with it its temperature also decreases rapidly and significantly. A thin copper tube is used as the expansion valve in the household refrigerator. Freon discharges through the expansion valve are in part in liquid state and in part in gaseous state.

4) **Evaporator**: The freezer section of the refrigerator is the evaporator which is in the type of various coils of copper or aluminum tubing. In evaporator the foods or the substances which are to be cooled originally at higher temperature are kept for cooling. When the low temperature and low pressure Freon flows through the evaporator, evaporator chills the space where we want to cool the food products and food items placed there. It receives the heat from the products to be chilled and so its temperature increases as does its pressure. It discharges the evaporator or freezer in the vapor state and then passes into the compressor where the cycle is going on.

The refrigeration cycle of the Freon keeps on repeating for an indefinite period till your refrigerator is operated. Since the Freon vapor is compressed in this cycle, it is also called as Vapor Compression Cycle.

IV. REFRIGERANTS

Haloalkane refrigerants family has the trade name of "Freon". These refrigerants manufactured by Dew Point and some other companies. Due to their greater stability and safety properties These refrigerants were such as energy labeling and/or Minimum Energy Performance Standards (MEPS) frequently used: they were nonflammable at atmospheric temperature and atmospheric pressure, nor clearly toxic as were the fluids they replaced, such as sulfur dioxide. Haloalkanes are also an order(s) of magnitude grater expensive than petroleum resultant flammable alkanes of same or improved cooling performance. Unluckily, chlorine- and fluorine-contained refrigerants reach the top of the atmosphere when they run away. In the stratosphere layer, CFCs break up due to UV radiation, producing their chlorine free particles. Through chain reactions these chlorine free radicals act as catalysts in the crash of ozone. One CFC particle can cause thousands of ozone particles to break down. It was caused to major damage to the ozone layer. This damage shields the Earth's surface from the Sun's strong UV radiation, and has been shown to causes to greater percentage of skin cancer. The remaining chlorine molecule working as a catalyst until and unless it forming binding with another particle, forming a constant molecule. CFC refrigerants in common but retreating usage consist of R-11 and R-12. Modified refrigerants with decreasing ozone depletion effect such as HCFCs (R-22, used in most homes today) and HFCs (R-134a, used in most cars) have replaced most CFC use. HCFCs in turn are being phased out under the Montreal Protocol and modified by hydro fluorocarbons (HFCs), such as R-410A, these refrigerants lack chlorine molecule. However, CFCs, HCFCs, and HFCs all have grater global warming potential.

Modified refrigerants are at present the subject of study, such as supercritical carbon dioxide, known as R-744. These have related efficiencies compared to existing CFC and HFC based compounds, and have many orders of magnitude lesser global warming potential.

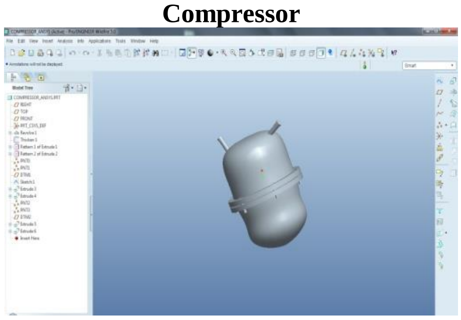
A simple vapor compression refrigeration system consists of the following equipments:

Compressor ii) Condenser iii) Expansion valve iv) Evaporator.

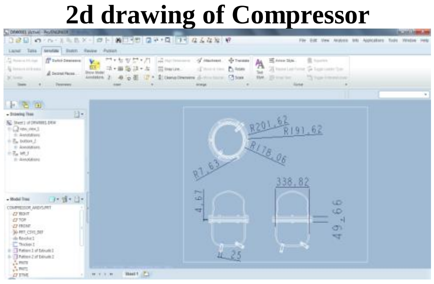
V. MODEL OF REFERIGERATION SYSTEM PARTS

Modeling is done using Pro-E as follows.

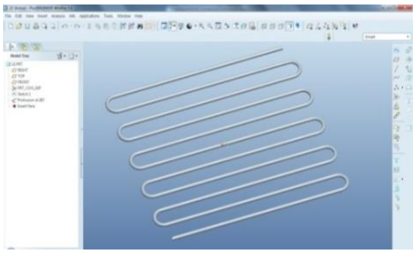
Compressor



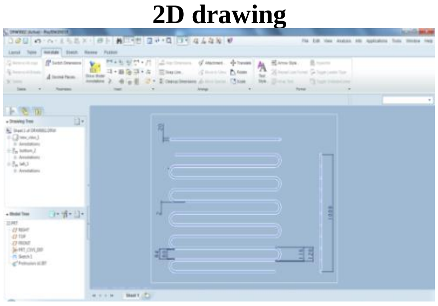
2d drawing of Compressor



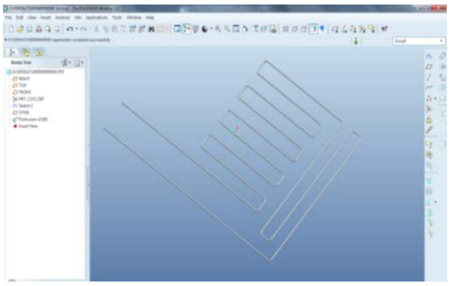
Condenser



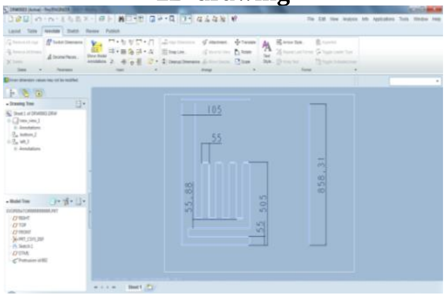
2D drawing



Evaporator



2D drawing



ANSYS finite element analysis software enables engineers to perform the following tasks.

1. Build computer models or transfer CAD models of structures, products, components or system.
2. Apply operating loads or other design performance conditions.
3. Study physical responses, such as stress levels, temperature distributions, or the impact of electromagnetic fields.
4. Optimize a design early in development process to reduce production costs.
5. Do prototypes testing in environment where it otherwise would be objectionable or impracticable.
6. The main purpose of finite element analysis is to inspect how a structure or component take actions to certain loading conditions.

VI. PROCEDURE FOR ANSYS ANALYSIS

Static analysis is used to determine the displacements, stresses, strains and forces in structures or components due to loads that do not induce significant inertia and damping effects. Steady loading in response conditions are imagined. The kinds of loading that can be functional in a static analysis contain externally applied pressures and forces, steady state inertial forces such as gravity or rotational velocity imposed (non zero) displacements, temperature (for thermal strain). This analysis can be either linear or non linear. In our present work we are going to regard as linear statistic analysis.

The method for static analysis consists of these main steps:

- Building the model
- Obtaining the solution.
- Reviewing the results.

Building the Model

In this method, we spell out the job name and analysis title use PREP7 to define the element real constraints. element types, material properties and the model geometry element types both non linear and linear structural elements are permissible The ANSYS elements library have in excess of 80 different element types. A exclusive number and prefix identify each element type. Example; BEAM94, PLANE71, SOLID96 and PIPE16.

Material properties

Young's modules (Ex), Must be distinct for a static analysis. If we plan to apply inertia loads (such as gravity) we define mass properties such as density (DENS). In the same way if we plan to concern thermal loads (temperatures); we define coefficient of thermal expansion.

Obtaining the Solution

In this method we classify the analysis type and options, apply loads and initial conditions the finite element solution. This has three phases:

- Pre processor phase.
- Solution phase.
- Post processor phase.

Pre-Processor

Pre processor has been improved so that the similar program is obtainable on micro, mini, super mini and main frame computer system to other. Pre processor is an interactive model builder to prepare FE (finite element) model and input data. The solution phase uses the input data developed by the pre processor, and dies the solution according to the problem definition. It creates input files to the temperature, etc., on the screen in the type of contours. The following section describes various capabilities and features of the pre-processor.

Mesh Generation

In finite element analysis the fundamental concept is to evaluate the structure, which is an assemblage of separate pieces called elements, which are joined together at a finite number of points called nodes. Loading boundary conditions are applied to these elements and nodes. A arrangement of these elements is known as mesh.

Finite Element Generation

The most amount of time in finite element is spent on generating elements and nodal data. Pre processor allows the user to create node elements automatically simultaneously allowing control over size and number of elements. These are a variety of types of elements that can be marked or generated on a range of geometric entities. The elements created by a range of automatic element generation capabilities of pre processor can be inspected by element characteristic that may require to be established before the finite element analysis for connectivity, distortion index etc.,

Normally, regular mesh generating capabilities of pre processor are used, rather than essential the nodes independently. If required nodes can be defined easily by defining the allocations or by translating the existing nodes. Also, one can plot, delete or search nodes. Some features for node are given below:

Material Definitions

All elements are distinct by nodes, which have only their position defined. In the case of plate and shell elements, there is no sign of thickness. The thickness can be given as element property. Property tables for a particular property set 1-D have to be input. Various types of elements have different properties for e.g.

Beams: cross-sectional area, moment of inertia etc.

Shells: thickness;

Springs: stiffness;

Solids: none

The user also desires to define material properties of the elements. For linear static analysis, modulus of elasticity and Poisson ratio require to be provided. For heat transfer coefficient of thermal expansion, densities etc. are necessary.

They can be specified elements by the material property set 1D.

Solution

The solution phase interacts with the solution of the problem regarding to the problem definitions. All the dull work of formulating and assembling of matrices are finished by the computer, and finally displacements and stress values are given as output. Some of the capabilities ANSYS are linear static analysis, transient dynamic analysis etc.

Post Processor

It is a powerful user-friendly post processing program. Using interactive color graphics; it has wide-ranging scheming features for displaying consequences obtained from the finite element analysis. One image of analysis results (i.e., results in a visual form) can frequently expose in seconds what would obtain an engineer hour to asses from a numerical output, saying a tabular form. The engineer may also see significant aspects of the results that could be simply missed in a stack of numerical data.

Employing state of the art picture improvement techniques, services viewing of:

- Contours of stresses, displacements, temperatures etc.,
- Deform geometric plots
  - Animated deformed shapes
  - Time history plots
  - Hidden line plot
  - Solid sectioning
  - Light source shaded plot
  - Boundary line plot etc.,

The entire ranges of post processing option are various types of analysis can be accessed through the command / menu mode there by giving the user added flexibility and convenience.

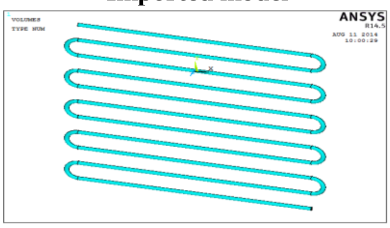
Vonmisses Stresses

Before discussing the theory of von misses stresses, it is necessary to know about the maximum distortion energy theory. According to this theory, yielding will occur whenever the distortion energy in the similar volume when uni-axially stressed to the yield strength.

The stress is known by a special name, because it represents the whole stress developed in the body. The ideal names are the effective stress and the Von misses stress, after DR. R. Von Misses, who contributed to the theory. The von misses' stress can be used to signify the whole stress developed in the body. The superior way of testing the strength of a member is to analyze Von Misses stresses and evaluate with the stress of the material.

After modeling the same is imported to ANSYS.

Imported model



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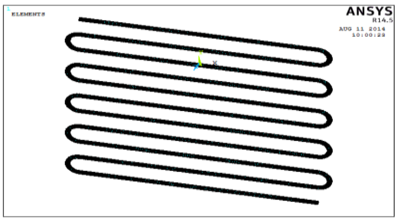
Meshed model



THERMAL ANALYSIS OF CONDENSER

R404 REFRIGERANT & ALUMINUM

Thermal conductivity=210w/mk

Specific heat=900J/Kg.k

Density=269Kg/m^3

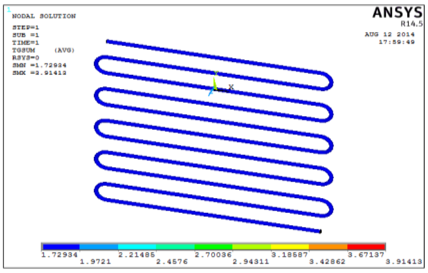
Loads>define loads>apply>thermal>temperature>select temperature area>ok>enter temperature value>313k>ok

Convection>on areas>select convection area>enter film coeffieicent value=0.09w/m^2

Bulk temperature value=303k

Solution>solve>current Ls>ok

Thermal gradient>vector sum thermal gradient>ok



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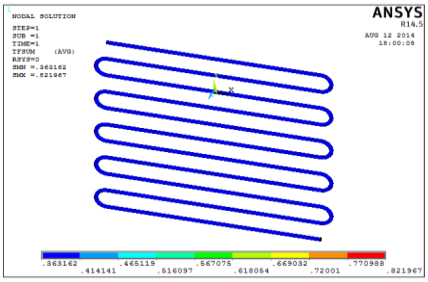


R404 REFRIGERANT & AL ALLOY 6061

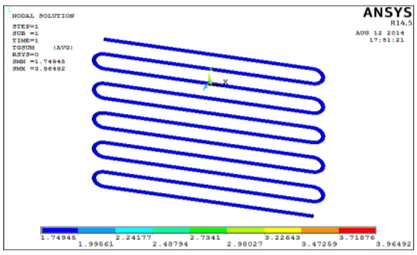
Thermal conductivity=151w/mk

Specific heat=873J/Kg.k

Density=28100Kg/m^3

Solution>solve>current Ls>ok

Thermal gradient>vector sum thermal gradient>ok



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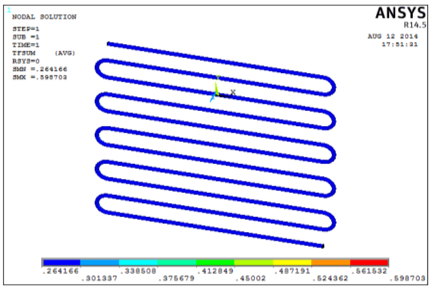

HFC-134A & ALUMINUM

Thermal conductivity=210w/mk

Specific heat=900J/Kg.k

Density=269Kg/m^3

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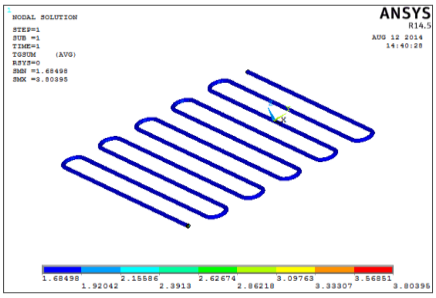
Convection>on areas>select convection area>enter film coeffieicent value=0.055w/m^2

Bulk temperature value=303k

Solution>solve>current Ls>ok

Thermal gradient>vector sum thermal gradient>ok



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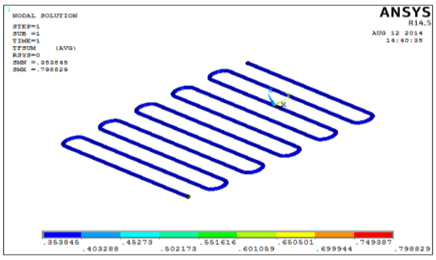


HFC-134A & ALUMINUM ALLOY 6061

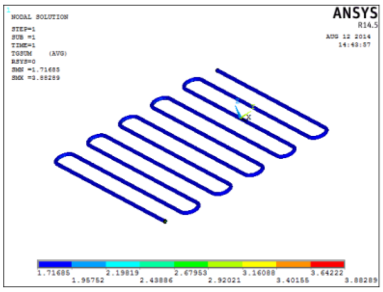
Thermal conductivity=151w/mk

Specific heat=873J/Kg.k

Density=28100Kg/m^3

Solution>solve>current Ls>ok

Thermal gradient>vector sum thermal gradient>ok



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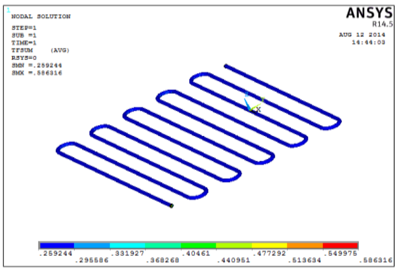

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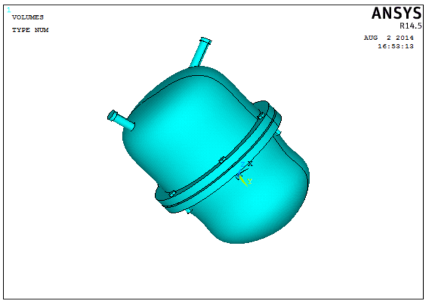

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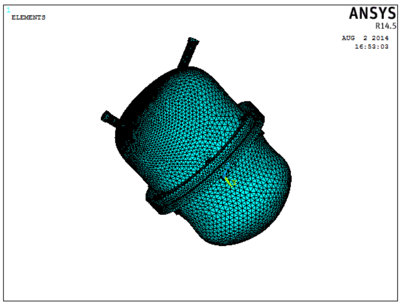
Meshed model



THERMAL ANALYSIS OF COMPRESSOR

R404 REFRIGERANT & ALUMINUM

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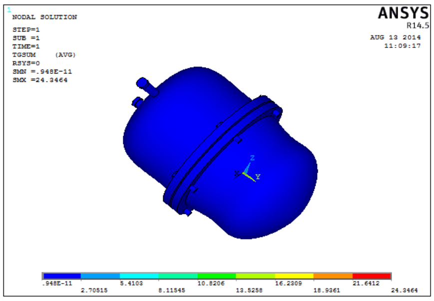

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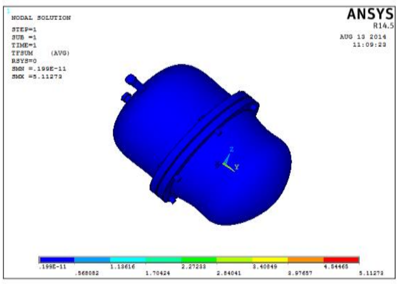
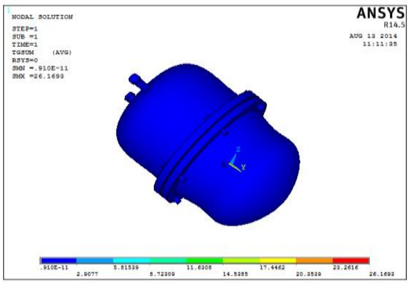


R404 & ALUMINUM ALLOY 6061

Thermal gradient



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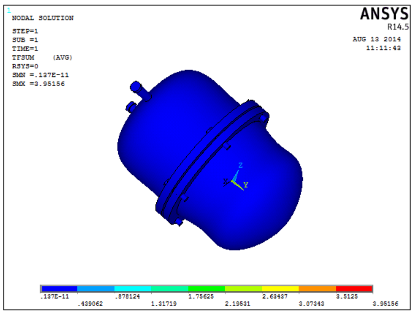
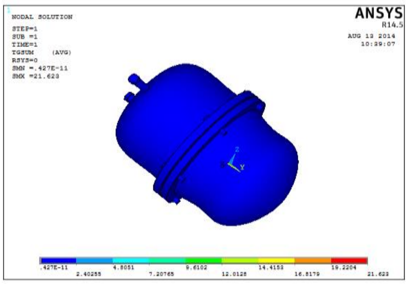
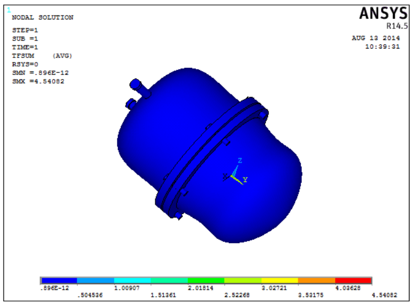


REFRIGERANT HFC-134A & Al

Thermal gradient



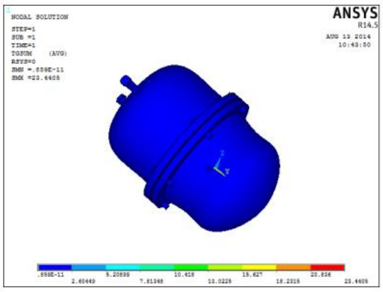
Heat flux



REFRIGERANT - HFC-134A

ALUMINUM ALLOY 6061

Thermal gradient



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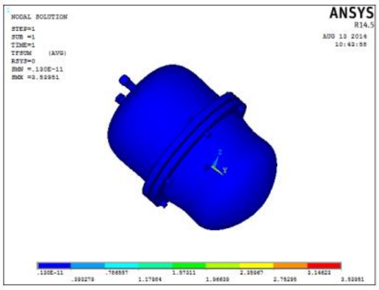

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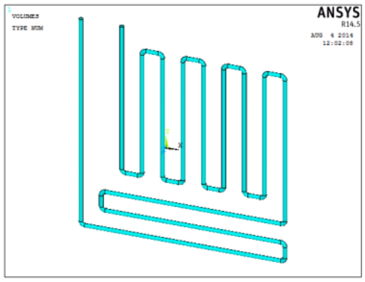

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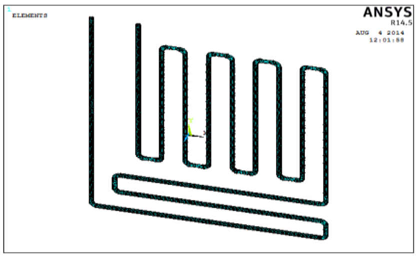
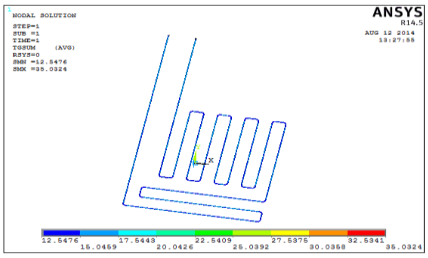


THERMAL ANALYSIS OF EVAPORATOR

404R REFRIGERANT & ALUMINUM

Thermal gradient



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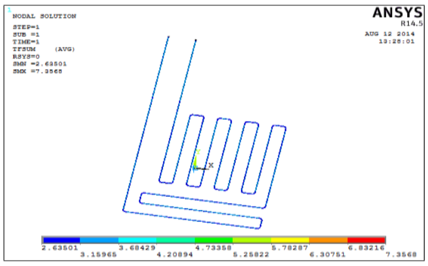
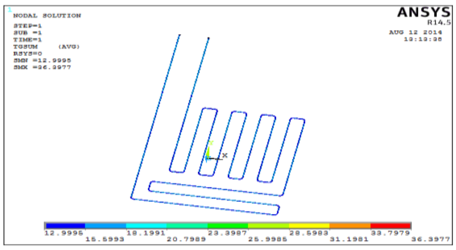
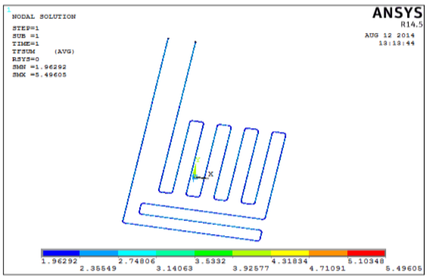


R404 & ALUMINUM ALLOY 6061

Thermal gradient

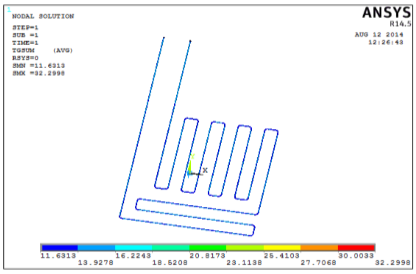


Heat flux

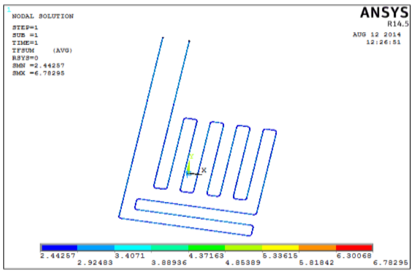


HFC-134A &ALUMINUM

Thermal gradient

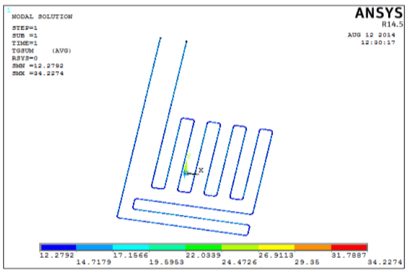


Heat flux

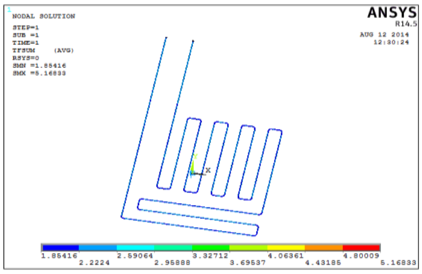


R134A &ALUMINUM ALLOY

Thermal gradient



Heat flux



VII. RESULTS

CONDENSER

MTRL	Perfromance parameter	HCFC	R404	HFC-134A	HFC-152A
AL	Thermal gradient (K/mm)	7.384	3.914	3.803	3.878
	Heat flux (W/mm²)	1.115	0.821	0.798	0.814
AL Alloy 6061	Thermal gradient (K/mm)	7.09	3.964	3.882	3.938
	Heat flux (W/mm²)	1.488	0.598	0.586	0.594
COPPER	Thermal gradient (K/mm)	6.344	3.771	3.587	3.711
	Heat flux (W/mm²)	2.442	1.451	1.381	1.428

COMPRESSOR

MTRL	Performance parameter	HCFC	R-404	HFC-134A	HFC-152A
AL	Thermal gradient (K/mm)	18.63	24.35	21.62	23.33
	Heat flux (W/mm²)	3.913	5.112	4.54	4.899
AL ALLOY 6061	Thermal gradient (K/mm)	20.48	26.17	23.44	25.17
	Heat flux (W/mm²)	3.092	3.951	3.539	3.8
COPPER	Thermal gradient (K/mm)	15.62	21.01	18.47	20.04
	Heat flux (W/mm²)	6.014	8.088	7.109	7.716

EVAPORATOR

MTRL	Perfromance parameter	HCFC	404R	HFC-134A	HFC-152A
AL	Thermal gradient (K/mm)	25.676	35.032	32.299	34.123
	Heat flux (W/mm²)	5.392	7.356	6.782	7.165
Al Alloy 6061	Thermal gradient (K/mm)	28.596	36.397	34.227	35.685
	Heat flux (W/mm²)	4.318	5.496	5.168	5.388
Copper	Thermal gradient (K/mm)	19.712	31.54	27.689	30.218
	Heat flux (W/mm²)	7.5891	12.143	10.66	11.634

CONCLUSIONS

From the modeling of household vapor compression refrigerated system by using 3D software Pro/Engineer and thermal analysis by ansys, the following conclusions were made.

In the present work a compact model of household refrigerator is modeled using 3D Pro/Engineer. The refrigerated system consists of condenser, evaporator, compressor and expansion value. The refrigerant used mostly now a days is HFC-134a.

. The present existing refrigerant is HFC-134a and the material used in making of compressor, condenser and evaporator is copper. In the present work the existing refrigerant is replaced with HCFC, HFC-152a, R-404.Where as material is replaced with aluminum alloy 6061 and aluminum.

In this project the modeling is done for compressor, condenser, evaporator using various materials and various refrigerants conducted thermal analysis on compressor, condenser and evaporator using the materials of copper, aluminum, aluminum alloy 6061 using refrigerants HCFC,404R,HFC-134a,HFC-152a.

In this project work Pro/Engineer is used for the modeling of components and Ansys is used for the thermal analysis .In this thesis a compact model of house hold refrigerator, refrigeration system is designed and modeled in 3D modeling software Pro/Engineer. The refrigeration system consists of condenser, evaporator, compressor and expansion valve. The refrigerant used most nowadays is HFC-134a.

From the results it is observed that the thermal gradient and Heat flux are higher for the refrigerant HCFC compared to 404R, HFC 134a and HFC-152a. But HCFC leads to high pollution compared to remaining three refrigerants. So in connection to the eco friendly refrigerant HCFC is not preferable and only best is selected among remaining refrigerants.

The thermal gradient is higher for 404R refrigerant than HFC-134a and HFC-152a for all the components i. e condenser, compressor and evaporator.

Heat flux is more for copper than other materials. The density of copper is 0.00000794.Hence the more density causes the components weights increases.

- The thermal gradient of condenser for R-404 using aluminum -6061 is 1.298% more than aluminum.
- The thermal gradient of compressor for R-404 using aluminum-6061 is 6.966% more than aluminum.
- The thermal gradient of evaporator for R-404 using aluminum -6061 is 3.751% more than aluminum.
- The average thermal gradient of condenser, compressor, and evaporator for R-404 using aluminum-6061 is 4.005% more than aluminum.
- The heat flux of condenser for R-404 using aluminum is 27.162% more than aluminum-6061.
- The heat flux of compressor for R-404 using aluminum is 22.711% more than aluminum-6061.
- The heat flux of evaporator for R-404 using aluminum is 25.293% more than aluminum-6061.
- The average heat flux of condenser, compressor, evaporator for R-404 using aluminum is 25.05533% more than aluminum-6061.
- When comparing both aluminum and aluminum alloy-6061 it is observed that thermal flux is 84.015% more for aluminum than aluminum-6061.
- By observing analysis results the refrigerant using 404R and the material aluminum is better.

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