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Study on heat transfer analysis of AC condenser by varying materials and refrigerants

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ABSTRACT

An AC condenser is a vitally important part of an air conditioning system that performs much of the cooling function. The condenser causes the latent heat rejection by the refrigerant. The design of the condenser can vary from system to system. One of the most commonly used design is finned tube design. The material of the tubes and the fins, become the decisive factor in the rate of heat rejection and ultimately in the performance of the condenser. In this work, an air-cooled finned tube condenser is designed for vapour compression cycle-based air conditioning system. The modelling is done using Solidworks and the fluid flow and heat transfer analysis is done in Ansys. To evaluate the effects of different materials on the performance of the condenser, copper is used as the tube material while, Aluminium alloys, 1060, 6060 and 7050 are used for fins. Two different types of refrigerants, namely, R32 and R134a have been used for analysis. Thermal analysis is done to determine the temperature distribution and heat flux for different sets of materials and different refrigerants. By comparing the results obtained with different combinations, the optimal combination can be determined.

Keywords: *Condenser, Fins, Aluminium Alloys 1060, 6060, 7050, Refrigerants R32, R134a, Thermal Analysis and Heat Flux.*

1. INTRODUCTION

Most of the domestic air conditioning units run on the principle of vapour compression refrigeration (VCR) cycle. The VCR system functions on four major components, namely, compressor, condenser, expansion valve and evaporator. The condenser plays a key role in this refrigeration system or AC unit. The condenser converts the gaseous substance or vapour into liquid state by condensation.

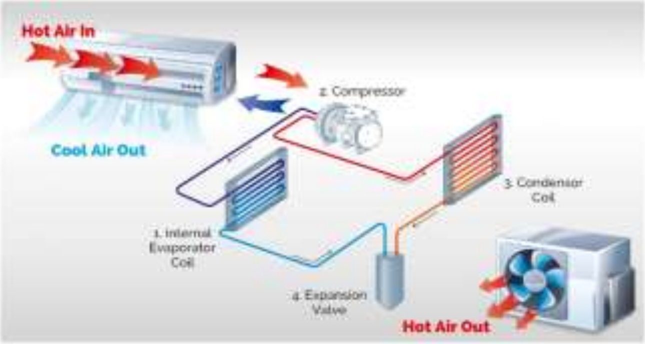

Figure-1: Home air conditioning unit

The above figure shows the process of refrigeration in a home air conditioning unit. The refrigeration impact is acquired in the cold region as heat is extracted by the vaporization of refrigerant in the evaporator. The refrigerant vapor from the evaporator is compressed in the compressor to a high pressure at which its saturation temperature is more than the ambient or some other heat sink. When the high pressure, high-temperature refrigerant passes through the condenser, condensation of the vapor into liquid takes place by heat dismissal to the heat sink. To finish the cycle, the high-pressure liquid refrigerant is made to flow through an expansion valve. In the expansion valve the pressure and temperature of the refrigerant reduces drastically. This low pressure and low-temperature liquid refrigerant then flow through the evaporator absorbing heat from the region to be cooled.

2. LITERATURE REVIEW

Air conditioning has proven great importance, not only for comfort, but also for maintaining appropriate temperature, humidity and oxygen conditions for purposes like medical needs, special industrial needs, high end and sophisticated computerized equipment, etc. Hence, many researchers have focused in different aspects of air conditioning in last few decades to make the system more appropriate, in general or for specific purposes.

Wang et al. (1999) directed a trial concentrate on the air-side execution for two explicit louver fin designs and their plain plate fin equivalent parts. This examination explored the impacts of fin pitch, longitudinal tube spacing and tube diameter on the air-side heat transfer execution and friction attributes. This examination found that for plain plate fin setups going from 8 to 14 fins for each inch, the impact of longitudinal tube pitch on the air-side was irrelevant for both the airside heat transfer and pressure drop. Notwithstanding, the heat transfer performance improved with diminished fin pitch [1].

Chi et al. (1998) directed a test examination of the heat transfer and friction attributes of plate fin and tube condensers having 7 mm diameter tubes. In this examination, 8 examples of industrially accessible plate fin and-tube condensers were tried. It was tracked down that the impact of differing fin pitch on the airside heat transfer execution and friction qualities was insignificant for 4-row coils. Anyway for 2-line loops, the heat transfer execution increased with a reduction in fin pitch. This investigation utilized a plate-fin and tube condenser setup with louver fin surfaces, which are generally utilized in both automotive and home AC systems. The transverse fin spacing went from 21 mm to 25.4 mm and longitudinal fin separating ranged from 12.7 mm to 19.05 mm [2].

One of the soonest and most complete examinations of condenser heat transfer and pressure drop attributes was performed by Kays and London (1984). A broad measure of test heat transfer and friction pressure drop information were accumulated for many various plate fin and-tube condenser arrangements as a feature of this examination. Be that as it may, no improvement of the heat transfer surfaces and geometry was performing [3].

In my paper, I have planned an air-cooled condenser for an air conditioner by changing the fin material and furthermore enhancement by varying the refrigerants.

3. CONDENSER COIL

Condenser coil is the major component of the air conditioning unit.

Here the material considered for the condenser coil is copper because of the following reasons. However, most of the companies use copper as material for condenser coil due to its properties towards heat transfer. When we differentiate between copper and aluminium, the durability and heat transfer rate is more when we use copper material. And also running cost is less is less when copper material is used.

Presently we have discovered that how much significant is a coil in an AC unit. In this way, in the event that we pick a superior coil metal sort, the cooling ability of our air conditioning system improves. The majority of the condenser coils are comprised of one or the other aluminium or copper as they are considered as outstanding amongst other directing material. The two metals have their own upsides and downsides.

Thinking about all the above realities, the decision of best coil is extremely clear. For each situation, copper is overwhelming aluminium. In this way, our decision will be copper coils that is most appropriate for a more extended existence of AC systems and it let individuals appreciate the solace for a more drawn out span.

4. FINS FOR AC CONDENSER

Fins are the extended surfaces that increase the rate of heat transfer. Condenser fins are situated on the outdoor portion of an air conditioner near the compressor is something that looks like a grill with metal fins all along it. These air conditioner fins are a part of the condenser that helps heat in passing away from the air conditioner so that the heat scatters very rapidly. Each performs a comparative job of permitting air to stream smoothly through and out of an air conditioner, while each does this in a one of a kind way. Here the materials considered for fins are

1. Aluminium alloy 1060
2. Aluminium alloy 6060
3. Aluminium alloy 7050

4.1 Material Properties

Table 1: Properties of Copper and aluminium alloy 1060, 6060 and 7050

Property	**Values**			
	Copper	**Al alloy 1060**	**Al alloy 6060**	**Al alloy 7050**
Density (Kg/m^3)	8950	2705	2710	2700

Thermal conductivity (W/m-K)	401	231	200-220	180
Specific heat capacity (J/kg-K)	385	900	898	860
Tensile strength (Mpa)	210	69	140-230	515

5. REFRIGERANTS

Refrigerant is a fluid or substance which flows through the condenser coil.

5.1 Types of Refrigerants

The most common refrigerants used for air conditioning systems for many years incorporate:

- **Chlorofluorocarbons (CFC):** It includes R12. This is known to add to the ozone harming substance impact. Creation of new stocks stopped in 1994.
- **Hydrochlorofluorocarbons (HCFC):** It includes R22. Somewhat less harming to the ozone than R12, however the EPA has still ordered an eliminate because of the Clean Air Act of 2010. R22 will get eliminated totally by 2020.
- **Hydrofluorocarbons (HFC):**It includes R410A and R134. With no chlorine in the blend, this is more secure for the climate and is currently being utilized instead of R22.Air conditioning systems that run on R410A are high efficient, provide good air quality, enhance both comfort and dependability. Here, the refrigerants used for the given condenser are:

1. Refrigerant R32
2. Refrigerant R134a

5.2 Refrigerant R32

R32 refrigerant is otherwise called difluoromethane and has a place within the HFC group of refrigerant. This gas is ready to replace the other gases, for example, R-410A and R-407C as the R32 gas because of its low global warming potential. The chemical formula of R32 is **CH_2F_2**.

5.3 Refrigerant R134a

Tetrafluoroethane (CF_3CH_2F) is the other name for R134a which is also a HFC group of refrigerants. The HFC group of refrigerant has been broadly utilized as the substitution for CFCs and HCFCs refrigerants due to their revelation of the disadvantage impact to the ozone layer.

Currently R-12 CFC refrigerant is being replaced with R134a in the area of centrifugal, rotary screw, scroll and reciprocating compressors. This gas is non-poisonous, non-combustible and anti-corrosive. So, this gas is secure for gentle handling.

Table-2: Refrigerants R32 and R134a properties

Property	**Values**	
	R32 refrigerant	**R134a refrigerant**
Boiling point	-51.65°C	-26.1°C
Critical temperature	78.1°C	122°C
Critical pressure	5.78 Mpa	4060 KPa
Critical density	424 kg/m^3	515.3 kg/m^3
Freezing point	-136°C	-103.3°C
Latent heat of vaporization	382 kj/kg	217.2 kj/kg
Density saturated liquid	961 kg/m^3	1.206 kg/m^3
Density saturated vapor	47.34 kg/m^3	5.25 kg/m^3
Isobaric specific heat saturated liquid	1.937 kj/kg-k	1.44 kj/kg-k
Isobaric specific heat normal pressure vapor	0.848 kj/kg-k	0.852 kj/kg-k
Thermal conductivity saturated liquid	125 mW/m*k	0.0824 W/m*k
Thermal conductivity normal pressure vapor	13 mW/m*k	0.0145 W/m*k
Viscosity saturated liquid	0.116 MPa-s	0.202 MPa-s
Viscosity normal pressure vapor	0.0126 MPa-s	0.012 MPa-s
Ozone depletion potential	0	0
Global warming potential	675	1200

The values in the above tabular column are at 25°C.

6. MODELLING AND DESIGN OF THE CONDENSER

The 3D model of the condenser is designed in the SOLIDWORKS software.

6.1 The SOLIDWORKS software

The SOLIDWORKS software is a mechanical design automation application which allows engineers immediately draw out concepts, experiment with features and dimensions, and generate models and definite sketches.

6.2 Modelling Procedure

The modelling procedure normally includes the accompanying points:

- Point out the model necessities.
- Based on the identified needs conceptualize the model.
- Develop the model dependent on the ideas.
- Analyze the model.

- Prototype the model.
- Construct the model.
- Edit the model, if necessary.

6.3 Modelling methodology

Before we really sketch the model, it is useful to prepare a strategy for how to make the model. After we recognize necessities and separate the suitable ideas, we can build up the model.

6.4 Sketches

Draw the sketches and conclude how to give measurements and where to apply correlations.

6.5 Features

Choose the suitable features, for example extrudes and fillets, decide the finest features to apply, and choose in which order to apply these features.

6.6 Cooling plate (Fin)

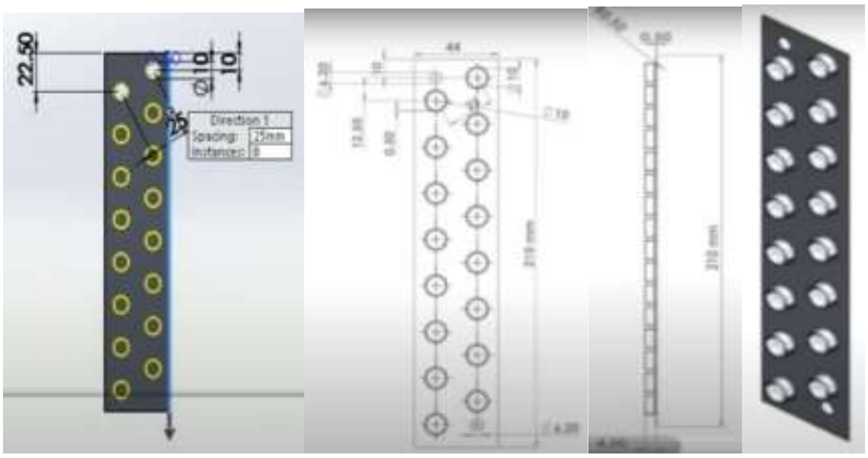

Figure-2: Images of fin plate

The dimensions of the cooling plate are:
Length of plate = 210 mm
Breadth of plate = 44 mm
Diameter of holes = 10 mm
Length from centre of first circle to the top end = 22.50 mm
Length from centre of first circle from right to the top = 10 mm
Spacing between the circles = 25 mm
No. of circles from both sides = 8
Total no. of circles = 16
Diameter of strainer (small circle) on both sides = 6.2 mm
Total no. of strainers = 2
Length from centre of strainer to the centre of first circle on the top left = 12.50 mm
Thickness of cooling plate = 0.5 mm
Length of extrusions on back side of the cooling plate = 4.5 mm
Thickness of holes on back side of cooling plate = 0.5 mm
Outer diameter of extrusions on backside of cooling plate = 10.5 mm
Inner diameter of extrusion holes on backside of cooling plate = 10 mm
The dimensions of the end plate are:
Breadth of end plate = 20.50 mm
Diameter of circles on the extrusion in end plate = 7 mm
Total no. of circles on the extrusion in end plate= 2

6.7 Condenser assembly:

Figure-3: Image of condenser model

No. of fins on the condenser = 55
Length of connecting rod between end plates= 282.50 mm
Diameter of connecting rod = 6 mm
Outer diameter of the pipe or coil = 10 mm
Inner diameter of the pipe = 9.5 mm
Thickness of pipe = 0.5 mm
Length of pipe between end plates = 291 mm

6.8 Assembly

Choose the components to mate and the kinds of mates to apply.

We can consolidate different parts that fix jointly to make assembly.

We incorporate the parts in a get together utilizing Mates, for example, Concentric and Coincident. Mates characterize the passable bearing of development of the segments. In the spigot get together, the fixture base and handles have concentric and correspondent mates.

With tools, for example, Move Component or Rotate Component, we can perceive how the parts in a gathering capacity in a 3D setting.

6.9 Mates

Mates situate the segments in a gathering decisively regarding one another.

Situating the segments characterizes how they move and turn concerning one another. Mates make mathematical relations, for example, incidental, opposite, and tangent. Each mate is legitimate for explicit blends of geometry, for example, cones, chambers, planes, and extrusions.

7. THERMAL ANALYSIS

The steady state thermal analysis is done in ANSYS software.

7.1 ANSYS software

ANSYS develops, markets and supports engineering simulation software used to foresee how product designs will behave in real-world environment. Steady state thermal analysis is done in ANSYS software. First of all, we have to give the material properties in engineering data and we have to do meshing for the given geometry or model by selecting the mesh. We should apply convective type heat transfer and heat flux in steady state thermal analysis. In solution, we can find the temperature distribution, total heat flux and directional heat flux results for the given boundary conditions.

Here, the temperature applied is 40^0C and the ambient temperature is 22^0C for the given model. The convection coefficient is temperature dependent and average film coefficient for the given temperature 22^0C is 5.e-006 W/mm^2-^{0}C.

7.2 Thermal analysis of condenser with copper tube, fins aluminium alloy 1060 and refrigerant R32

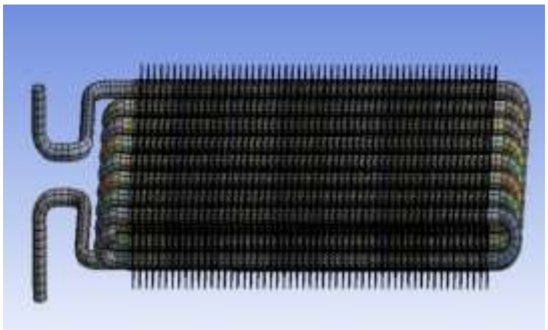

Figure-4(a) : Meshing for tube copper fins Al alloy 1060 and R32,

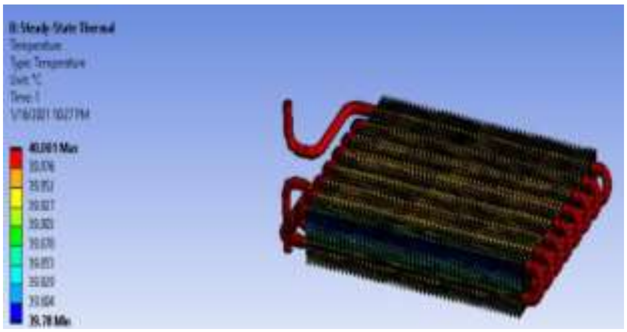

Figure 4(b): Temperature variation for tube copper, fins Al alloy 1060 and R32

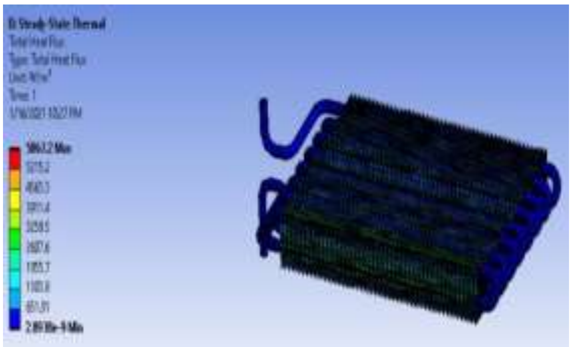

Figure-4(c) : Total heat flux variation for tube copper, fins Al alloy 1060 and R32

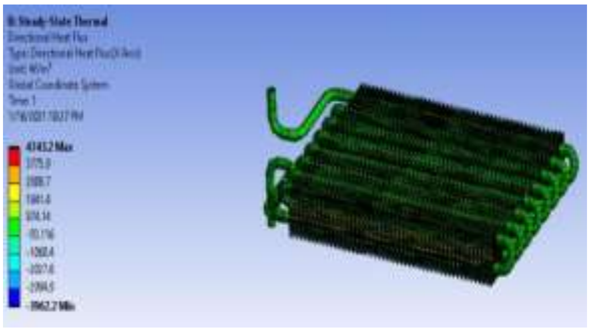

Figure-4(d): Directional heat flux variation for tube copper, fins Al alloy 1060 and R32

As we can see in the above images with respect to copper tube, fins Al alloy 1060 and refrigerant R32, the minimum temperature distribution is 39.78^0C and the maximum temperature distribution in the condenser is 40.001^0C. The minimum total heat flux in the condenser is 2.8938e-009 w/m^2 and the maximum total heat flux is 5867.2 w/m^2. And also the minimum directional heat flux is -3962.2 w/m^2 and the maximum directional heat flux is 4743.2 w/m^2.

7.3 Thermal analysis of condenser with copper tube, fins aluminium alloy 6060 and refrigerant R32

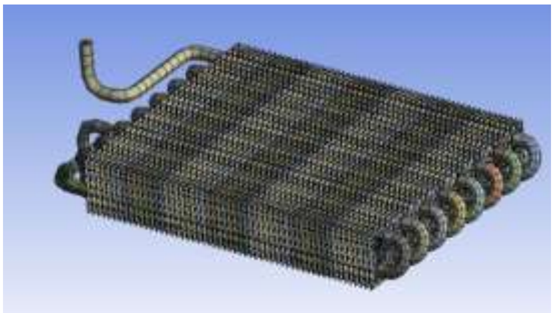

Figure-4(e): Meshing for tube copper fins Al alloy 6060 and R32

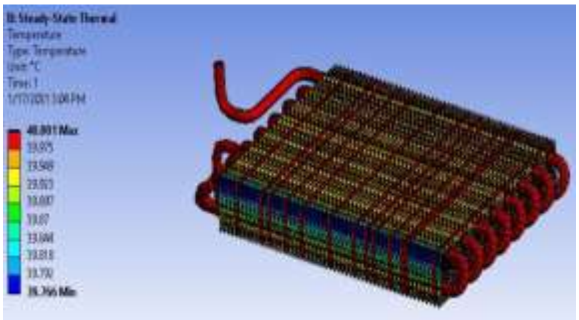

Figure-4(f): Temperature variation for tube copper, fins Al alloy 6060 and R32

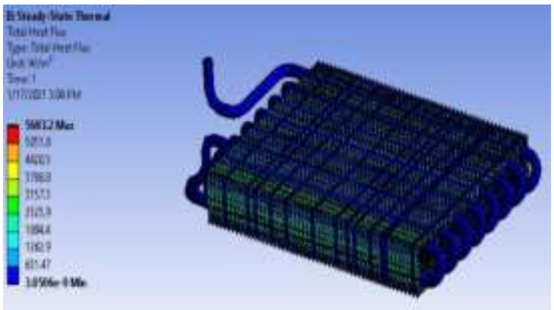

Figure-4(g): Total heat flux variation for tube copper, fins Al alloy 6060 and R32

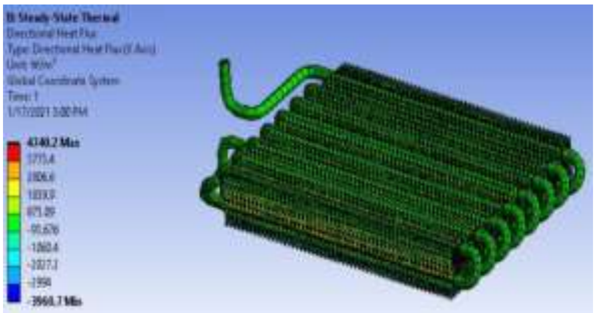

Figure-4(h): Directional heat flux variation for tube copper, fins Al alloy 6060 and R32

In the above figures with regards to copper tube, fins Al Alloy 6060 and refrigerant R32 shows that the minimum temperature distribution in the condenser is 39.766^0C and the maximum temperature distribution is 40.001^0C. As well as the minimum total heat flux is 3.0506e-009 w/m^2 and the maximum total heat flux is 5683.2 w/m^2. The minimum directional heat flux is -3960.7 w/m^2 and the maximum directional heat flux is 4740.2 w/m^2.

7.4 Thermal analysis of condenser with copper tube , fins aluminium alloy 7050 and Refrigerant R32

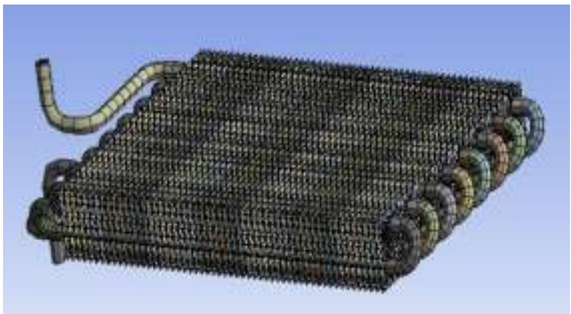

Figure-4(i): Meshing for tube copper, fins Al alloy 7050 and R32

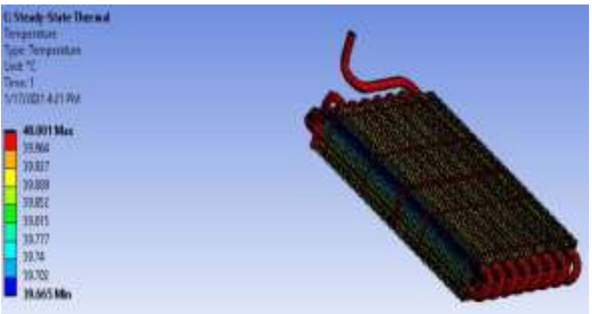

Figure-4(j): Temperature variation for tube copper, fins Al alloy 7050 and R32

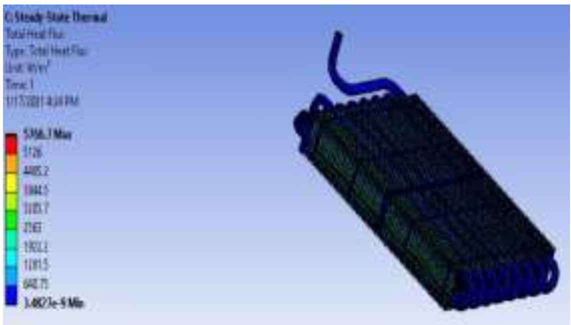

Figure-4(k): Total heat flux variation for tube copper, fins Al alloy 7050 and R32

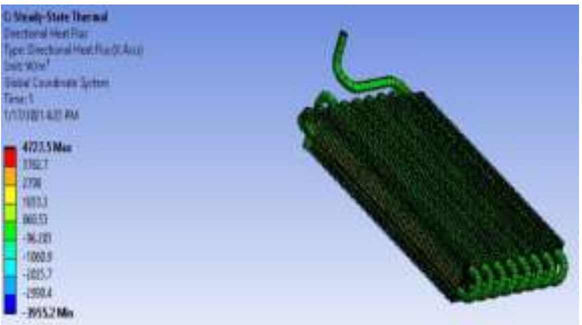

Figure-4(l): Directional heat flux variation for tube copper, fins Al alloy 7050 and R32

The above images of thermal analysis of condenser with respect to copper tube, fins Al Alloy 7050 and refrigerant R32 represents that the minimum temperature distribution is 39.665^0C and the maximum temperature distribution is 40.001^0C. The minimum total heat flux is 3.4827e-009 w/m^2 and the maximum total heat flux is 5766.7 w/m^2. And the minimum directional heat flux is -3955.2 w/m^2 and the maximum directional heat flux is 4727.5 w/m^2.

7.5 Thermal analysis of condenser with copper tube, fins aluminium alloy 1060 and refrigerant R134a

Figure-5(a): Meshing for tube copper, fins Al alloy 1060 and R134a

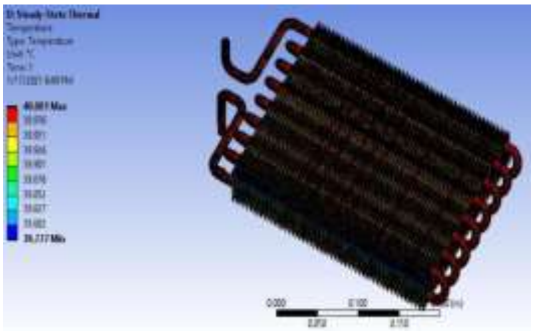

Figure-5(b): Temperature variation for tube copper, fins Al alloy 1060 and R134a

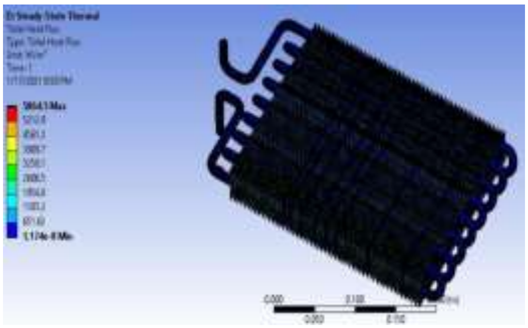

Figure-5(c): Total heat flux variation for tube copper, fins Al alloy 1060 and R134a

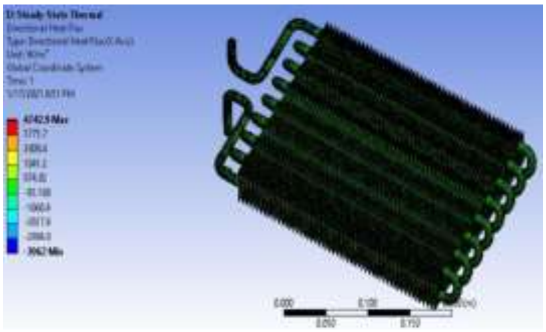

Figure-5(d): Directional heat flux variation for tube copper, fins Al alloy 1060 and R134a

The thermal analysis of condenser with respect to copper tube, fins Al Alloy 1060 and Refrigerant R134a shows that the minimum temperature distribution is 39.777^0C and the maximum temperature distribution is 40.001^0C. The minimum total heat flux is 1.174e-008 w/m^2 and the maximum total heat flux is 5864.5 w/m^2. And also the minimum directional heat flux is -3962 w/m^2 and the maximum directional heat flux is 4742.9 w/m^2.

7.6 Thermal analysis of condenser with copper tube, fins aluminium alloy 6060 and refrigerant R134a

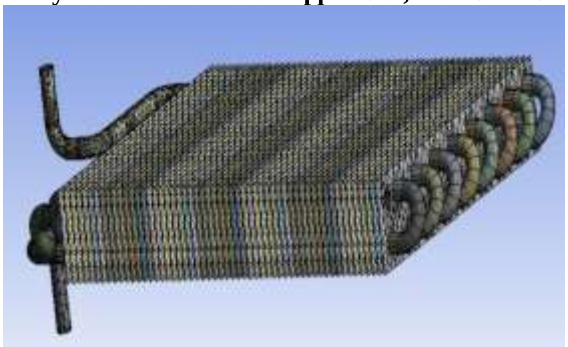

Figure-5(e): Meshing for tube copper, fins Al alloy 6060 and R134a

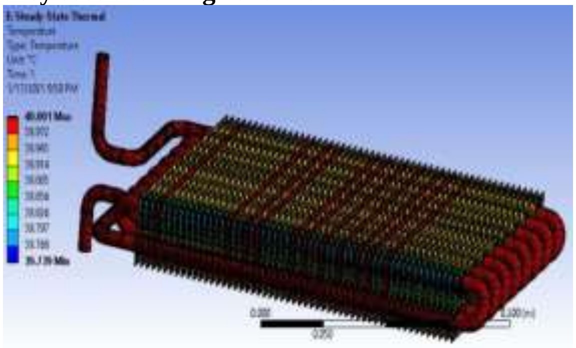

Figure-5(f): Temperature variation for tube copper, fins Al alloy 6060 and R134a

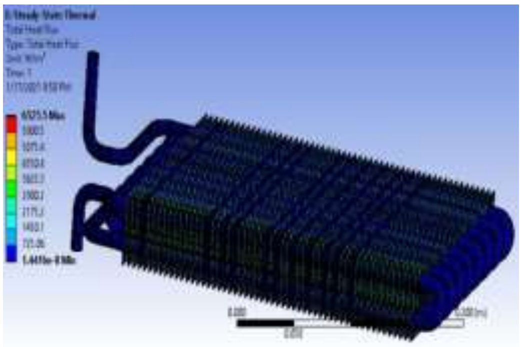

Figure-5(g): Total heat flux variation for tube copper, fins Al alloy 6060 and R134a

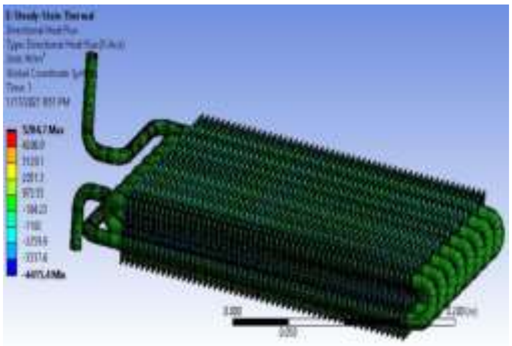

Figure-5(h): Directional heat flux variation for tube copper, fins Al alloy 6060 and R134a

The above figure of thermal analysis with respect to copper tube, fins Al Alloy 6060 and refrigerant R134a shows that the minimum temperature distribution is 39.739^{0}C and the maximum temperature distribution is 40.001^{0}C. The minimum total heat flux is 1.4416e-008 w/m^2 and the maximum total heat flux is 6525.5 w/m^2. The minimum directional heat flux is -4415.4 w/m^2 and the maximum directional heat flux is 5284.7 w/m^2.

7.7 Thermal analysis of condenser with copper tube, fins aluminium alloy 7050 and refrigerant R134a

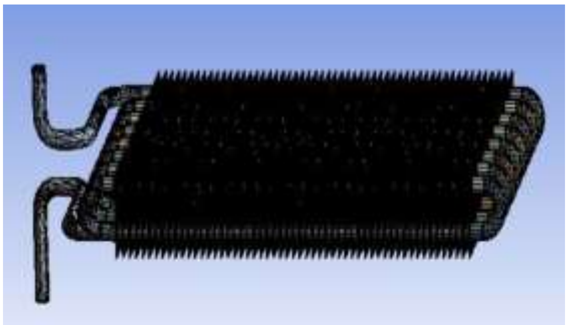

Figure-5(i): Meshing for tube copper, fins Al alloy 7050 and R134a

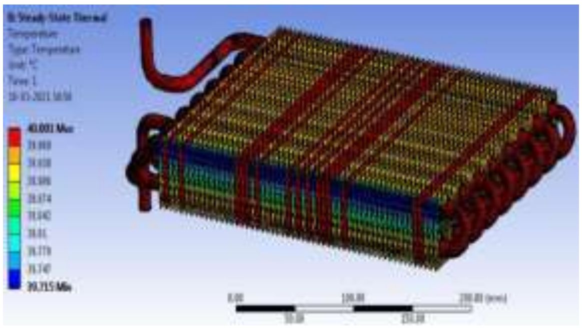

Figure-5(j): Temperature variation for tube copper, fins Al alloy 7050 and R134a

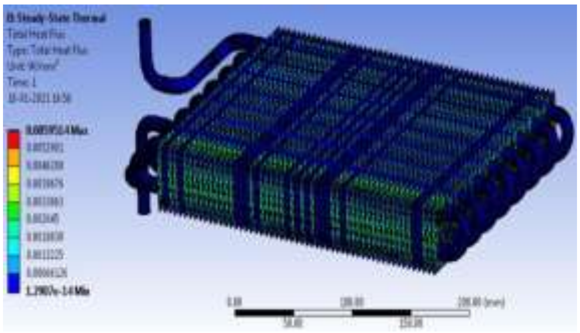

Figure-5(k): Total heat flux variation for tube copper, fins Al alloy 7050 and R134a

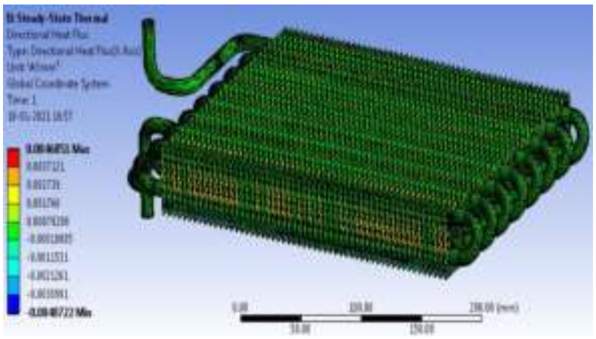

Figure-5(l): Directional heat flux variation for tube copper, fins Al alloy 7050 and R134a

The thermal analysis of condenser with respect to copper tube, fins Al Alloy 7050 and refrigerant R134a shows that the minimum temperature distribution is 39.715^{0}C and the maximum temperature distribution is 40.001^{0}C. The minimum total heat flux is 1.2907e-014 w/mm^2 and the maximum total heat flux is 5.9514e-003 w/mm^2. And the minimum directional heat flux is -4.0722e-003 w/mm^2 and the maximum directional heat flux is 4.6851e-003 w/mm^2.

8. RESULTS

8.1 Graphical representations

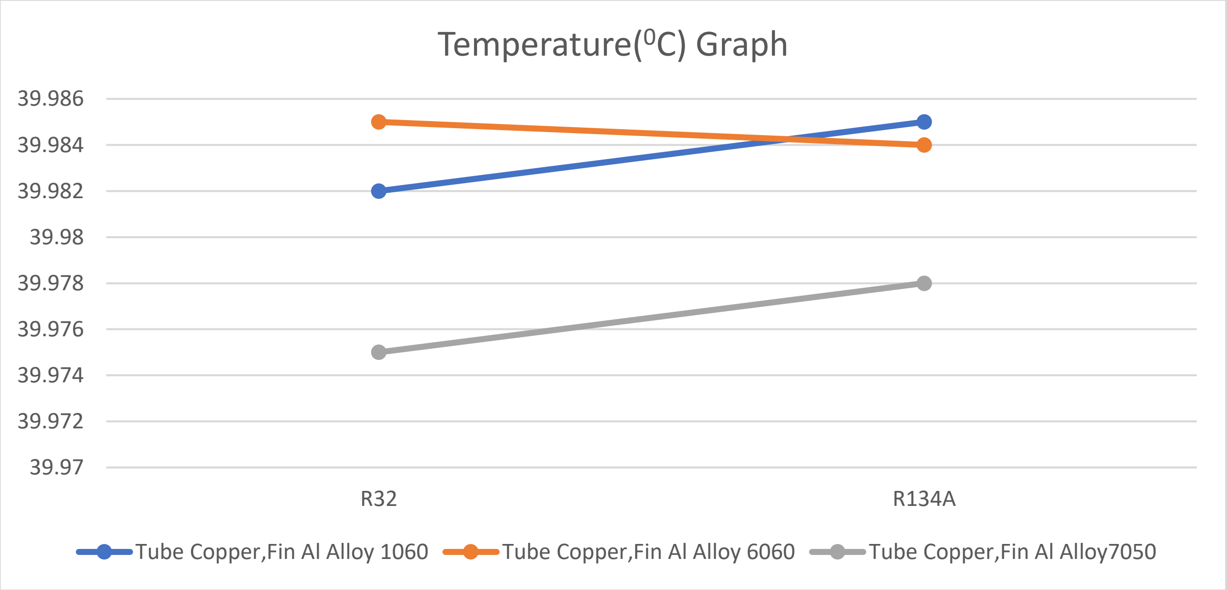

Figure-6(a):Graphical representation of temperature variation for tube copper and fins aluminium alloys

The above graphical representation shows the temperature variation in the condenser for copper tube , fins Al Alloys 1060,6060 and 7050 and refrigerants R32 and R134a. Here, the combination with copper tube, fin Al Alloy 1060 and refrigerant R134a as well as the combination with copper tube, fins Al Alloy 6060 and refrigerant R32 shows equal results compared to others and remain top in the order than the remaining materials considered for the condenser equipment.

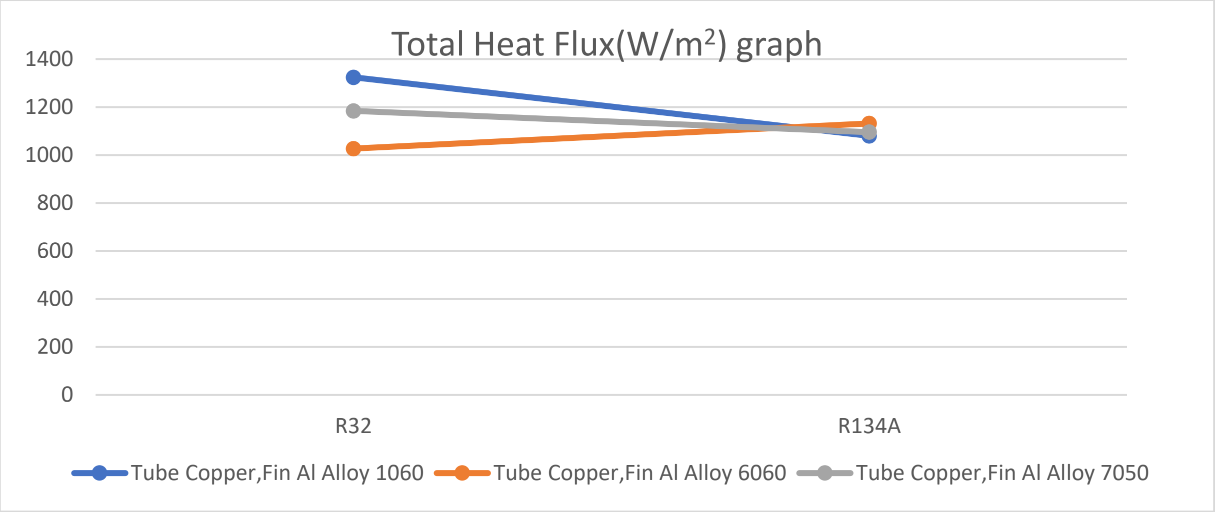

Figure-6(b): Graphical representation of total heat flux variation for tube copper and fins aluminium alloys

The above graph represents the variation of total heat flux in the condenser with copper tube, fins Al Alloys 1060,6060 and 7050 and refrigerants R32 and R134a. In this graph the combination with copper tube, fins Al Alloy 1060 and refrigerant R32 gives best results compared to other combination of materials. Whereas all the other combinations of materials in the condenser provides low performance. So, here the condenser with copper tube, Al alloy 1060 and refrigerant R32 works better compared to others.

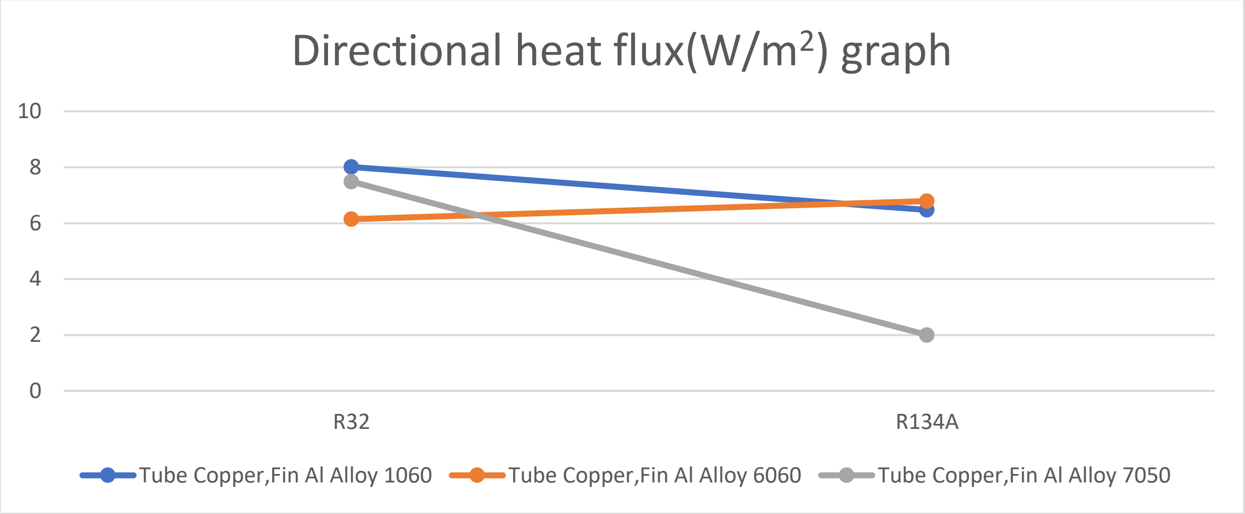

Figure-6(c): Graphical representation of directional heat flux for tube copper and fins aluminium alloys

The above graphical representation shows the variation of directional heat flux in the condenser with copper tube, fins Al Alloys 1060, 6060 and 7050 and refrigerants R32 and R134a. Here also the condenser equipment with copper tube, fins Al Alloy 1060 and the refrigerant R32 has given good results compared to other combination of materials. And remaining combinations for the given equipment has got low heat transfer rate. So, even in this criteria the condenser with copper tube, fins Al Alloy 1060 and refrigerant R32 has given good performance compared to other materials.

Table-3: Results for tube copper and fins aluminium alloys 1060, 6060 and 7050

Tube	Refrigerant	Fins	Temperature (°C)	Total heat flux(W/m²)	Directional heat flux(W/m²)
Copper	R32	Al alloy 1060	39.982	1324.1	8.0092
		Al alloy 6060	39.985	1027	6.1419
		Al alloy 7050	39.975	1184.2	7.4873
	R134a	Al alloy 1060	39.985	1080.1	6.4738
		Al alloy 6060	39.984	1131.6	6.7893
		Al alloy 7050	39.978	1095.2	5.0810

9. CONCLUSION

From the above analysis results, it is observed that heat transfer rate is more when the refrigerant R32 is used. Whereas Refrigerant R134a has low heat transfer rate when compared to the refrigerant R32 for the given equipment. So, here the best suitable refrigerant for the condenser is R32.

Here the materials used for tube is copper and for fins are aluminium alloy 1060, aluminium alloy 6060, aluminium alloy 7050. By comparing the analysis results from the above table, it is observed that heat flux is more when the material aluminium alloy 1060 is used for fins and the material used for tube is copper. Whereas when other fin materials aluminium alloy 6060 and aluminium alloy 7050 are used, the heat flux is less compared to the fin material aluminium alloy 1060 for the given condenser equipment. So, here the best suitable material for the fins is aluminium alloy 1060. Moreover, the thermal conductivity and specific heat capacity of Al Alloy1060 is more compared to other materials. Hence, the heat transfer rate and heat flux is more when copper tube, fin material aluminium alloy 1060 and refrigerant R32 are used.

10. REFERENCES

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