Performance Evaluation of Domestic Refrigerator's (VCRS) Condenser with Different Materials (Al, Al6061 and Cu) and Refrigerants (R022, R404, R154a and R134a)

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ABSTRACT

In present century vapor compression refrigeration systems has evolved as primary source of generating temperatures lower than the atmospheric, and therefore, are used universally. Present research is devoted to investigations regarding an important element of vapor compression refrigeration systems, condenser, which are used to eliminate latent heat from high temperature and high pressure refrigerant. The research paper portrays the evaluation of performance of the condenser of a domestic refrigerator with different condenser materials and refrigerants, and rankings of their combinations.

Keywords: *Vapor Compression Refrigeration System, Condenser, Latent Heat.*

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1. INTRODUCTION

The American Society of Refrigerating Engineers defines refrigeration as the science of providing and maintaining temperatures below that of surroundings atmosphere. This implies the development of temperature differentials rather than the establishment of a given temperature level. There are different types of refrigeration systems out of which vapor compression refrigeration system has acquired an important place. Its main parts are compressor evaporator condenser and expansion device. The working fluid is called refrigerant, which flows in the circuit connecting these components. Refrigerant absorbs heat energy from food items stored in evaporator, and then evaporates. It is then passes through a compressor due to which its temperature and pressure rises. After compressor it passes through the condenser where refrigerant rejects its latent heat and comes back to liquid state. After condenser refrigerant enters the expansion device where its pressure and temperature drops to the initial conditions from where it enters the evaporator again. Condensers are considered as the back bone of any refrigeration system, and help in heat rejection from refrigerant to the universal sink, i.e., atmosphere. At entry of condenser vapors coming out from compressor enters, during length of the condenser vapors get converted into liquid form, due to which at the exit of condenser, refrigerant is obtained in the form of saturated or even sub cooled liquid form. In present research work, performance evaluation of condenser of a domestic refrigerator is accomplished under different condenser materials and refrigerants.

1.1 Objectives of the Research Work

Following are the objectives of the research:

a) Modeling of a condenser;
b) Simulation of condenser for different materials, and
c) Simulation of condenser for different refrigerants.

2. Research Contributions of Different Researcher(s)

Table 2.1 shows the research outcomes and opinions of different researchers in the field of condensers and refrigerants.

Table 2.1: Research Contributions of Different Researchers

S.No	Researcher(s)	Contribution
1.	Rathore *et al.* (2018)	An Experimental Analysis is done of the refrigerator condenser by varying the fins spacing of the condenser. vapour compression refrigeration system is a cycle in which domestic refrigerator works. it consist of compressor, condenser expansion valve and evaporator . The performance of the system depends on the performance of all the components of the system. The main objective of the present work is to increase the performance of the condenser by increasing the heat transfer rate through the condenser. Heat transfer rate can be increased by the extended surfaces called fins. Heat transfer rate is also depends on the spacing between the fins of the condenser.
2.	Luo *et al.*(2017)	In this study, a new modeling, simulation and optimization methodology for LSC design is developed. A pass by-pass tube side modeling method is proposed. An equivalent heat transfer coefficient and total pressure drop are defined, modeled and validated.
3.	Saab and Ali (2017)	The COP of VRF system cycle was determined at various evaporator and condenser pressures as well as type of refrigerant in this study. Parametric studies were done after modeling the system on EES, where both the high and low pressures in the cycle were varied to obtain the corresponding COP range. It was noticed that COP increases non-linearly with an increase in evaporator pressure, and/or a decrease in condenser pressure. Finally, different types of refrigerants were modeled, and the commonly used one, R410a, was seen to be the second most efficient refrigerant after ammonia. As ammonia showed the most promising results, it would be debatable whether or not to introduce it to the market of VRF technology, since it has been used for other refrigeration purposes. However, being hazardous, the fear of facing pipe leakage incidents excludes ammonia from being a suitable candidate for replacing R410a in VRFs.
4.	Sheshardri *et al.* (2017)	This article addresses an opportunity to improve Low Exergy air-conditioning system efficiencies in the tropics by incorporating ’low-lift’ chillers.
5.	Ilie *et al.*(2017)	This paper reports experimental data obtained for ammonia condensation heat transfer in an evaporative condenser. Experiments were carried out on a specially designed set-up equipped with both measuring and control devices, and a data acquisition system.
6.	Bakhshipour *et al.* (2017)	In the present study, numerical simulation of refrigeration cycle incorporated with a PCM heat exchanger is carried out. To this end, the refrigeration cycle without PCM has been simulated and then, the performance coefficients of the refrigerator in either with and without PCM are evaluated.
7.	Diwan and Sahu (2016)	In the research work, design of shell and tube type heat exchanger with helical baffle is accomplished with the help of modeling software CATIA, and analysis software ANSYS. With the help of ANSYS, study of flow and temperature fields is conducted inside the shell.
8.	Bheemesh and Venkateswarlu (2015)	The objective of this research work is to develop a system for utilizing the highly-efficient heat transfer of an air conditioning system. The researchers stress on the fact that in such systems, a condenser acts the principal device or unit for condensing a substance from its liquid or gaseous state, typically by cooling process. During this process, the substance releases latent heat which gets transferred to the coolant of the condenser. The researchers also add that for such cases optimization techniques play dominant roles in assessing the best configuration of the systems. The research focuses on finding the

		optimum configuration of a finned-tube condenser. The research work is conducted for a air-cooled finned tube condenser used in an common air conditioning system. In the research work, heat transfer analysis is conducted on the condenser for the purpose of evaluating the suitable material as well as refrigerant. The material alternatives for tubes were copper, and aluminum alloy 1100, and for fins the options were aluminum 1050, and aluminum 110. The targeted refrigerants were R22, R12, and R134. For the research work a *three* dimensional model of the condenser was made on Pro/E, and analysis was conducted on ANSYS.
9.	Yadav *et al.* (2015)	Present research work is devoted to modeling and simulation of a house hold refrigerator. In the research work, the vapor compression refrigeration system consisting of evaporator, compressor, condenser, and expansion device is modeled using 3D modeling software Pro-E wild fire 5, and thermal analysis is performed on different parts of the modeled system with the help of ANSYS 14. In the research work, refrigerants used are HCFC, HFC-152A, and 404R, also, the commonly used tube material copper is replaced with A, and, Al6061.

2.1 Gaps in the Contributions

On the basis of analysis of theoretical considerations, and research contributions made by different researchers, following gaps in the research are being identified.

a) There is almost nil research available which compares different materials for condensers; and

b) There is almost nil research available which compares different refrigerants.

On the basis of above mentioned gaps objectives of the research work are formulated.

3. Solution Methodology

Present section tells about the details of software used in the research work. In Figure 3.1 shows the flowchart of solution methodology adopted for solving the research problem.

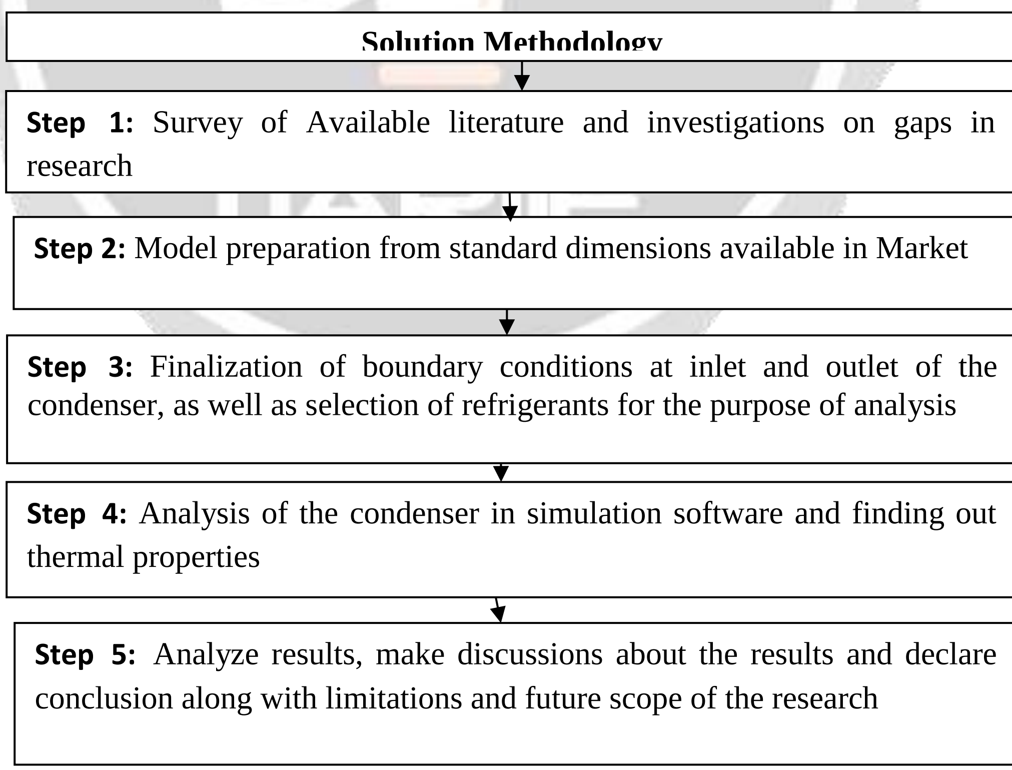


Figure 3.1: Flow chart for Solution Methodology

Details of software are presented in succeeding section.

3.1 ANSYS

ANSYS is considered as one of the renounced tools in the field of simulation, developed by ANSYS Inc., USA. It can be used successfully for the purpose of simulating problems of thermal analysis, structural analysis, computational fluid dynamics, harmonic analysis, modal analysis, transient dynamics, buckling, and other categories. In addition to this, software also offers the facility to develop simple models. With the help of inbuilt library, one can find out the properties of materials, and even add the desired properties or new materials with the known values of properties. ANSYS also include a set of models to solve complex problems of engineering, architecture, physical sciences, mathematical models and other applications. Following are the salient features of the software:

- Offers excellent simulation facility;
- Easy modules for different types of complex analysis like modal, transient, etc;
- Offers different theoretical perspective to solve a problem with different inbuilt models;
- Simple parts can be easily created;
- Inbuilt library to offer material properties; and
- Better graphics facilities.

4. Case Study

Present section is devoted to the details of solution methodology adapted to for solving the research problem, and explains in details about problem formulation, development of condenser model, and application of simulation technique used for solving the model with the applications of different materials and refrigerants.

4.1 Model Formulation

First step in the research work was the formulation of model of condenser for a refrigeration system. For this purpose dimensions of a standard coil condenser are used. Following are the details of dimensions.

Table 4.1: Dimensions of Condenser (Gupta *et al.*, 2013)

S. No	Dimension	Value
1.	Length	9.14 m
2.	Outer diameter	9.52 mm
3.	Inner diameter	8.91 mm
4.	Number of turns	06

With the help of dimensions shown in Table 4.1, first of all, a model of condenser was prepared using ANSYS R 15.0, as shown in Figure 4.1.

Figure 4.1: Model of Condenser

4.2 Solution of the Model

After formulation of model, its solution was derived. For this purpose, first of all meshing of the model was carried out. With the help of meshing, a body can be made deformable due to which, it can show changes in its properties, dimensions, stress levels, etc. Figure 4.2 shows the mesh diagram for the condenser.

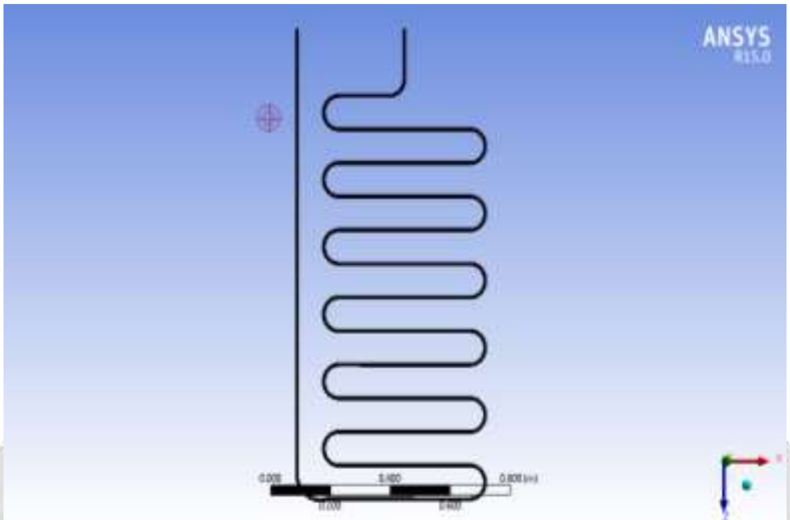


Figure 4.2: Mesh structure of Condenser Coil

In next step values of heat flux and thermal gradient for different combinations of materials and refrigerants were calculated. For this purpose, based on literature survey, following parameters were used.

Table 4.2: Parameters used in finding values of Heat Flux and Thermal Gradient

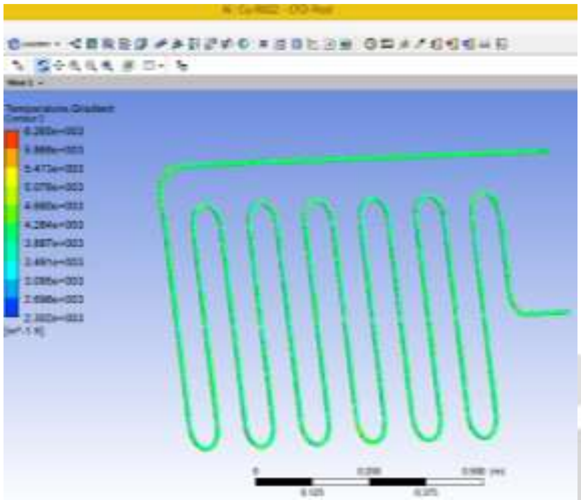
S. No	Parameter	Value
1.	Type of load	Thermal
2.	Area temperature	313k
3.	Bulk temperature	303k
4.	Temperature gradient type	Vector sum

Table 4.3 shows different properties of refrigerants used for obtainment of results.

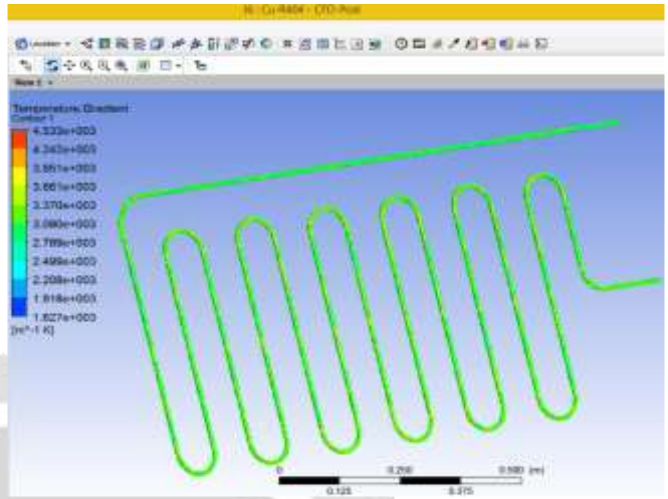
Table 4.3: Properties of Refrigerants

S. No	Temp.	Property	Refrigerant			
			R22	R404	R152A	R134
1.	303K	**Density**	7.06 kg/m³	8 kg/m³	2.739 kg/m³	8.42 kg/m³
		Viscosity	12.8 microPa-s	13.5 microPa-s	15.10.84 microPa-s	12 microPa-s
		Sp. Heat	0.6496 kJ/kg·K	0.88 kJ/kg.K	0.0706kJ/kg.K	0.833kJ/kg·K
		Thermal Conductivity	0.0109 W/m-K	0.0172 W/m-K	0.129 W/m-K	0.0138 W/m-K
2.	313K	**Density**	6.81 kg/m³	7.71 kg/m³	3.174 kg/m³	8.12 kg/m³
		Viscosity	13.3 microPa-s	14 microPa-s	10.64 microPa-s	12.4 microPa-s
		Sp. Heat	0.853 kJ/kg·K	0.95 kJ/kg.K	0.0895 kJ/kg.K	0.7334 kJ/kg·K
		Thermal Conductivity	0.0115 W/m-K	0.0181 W/m-K	0.143 W/m-K	0.0146 W/m-K

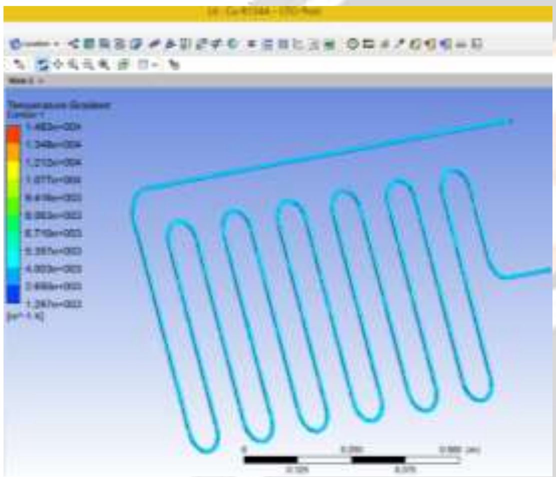
Following are the results obtained from calculations for thermal gradient.



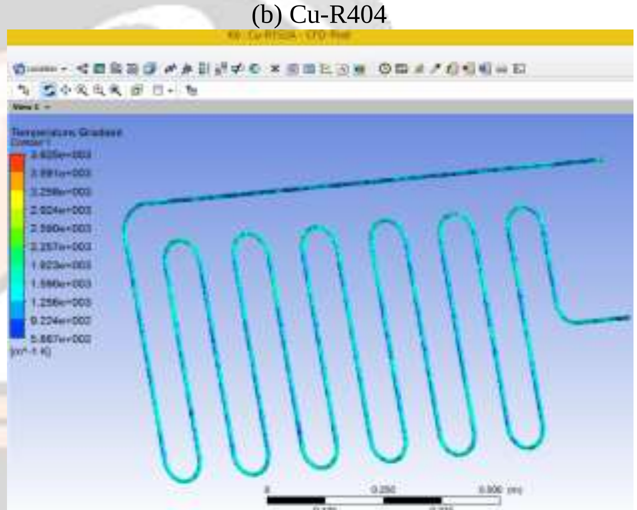
(a) Cu- R22



(b) Cu-R404

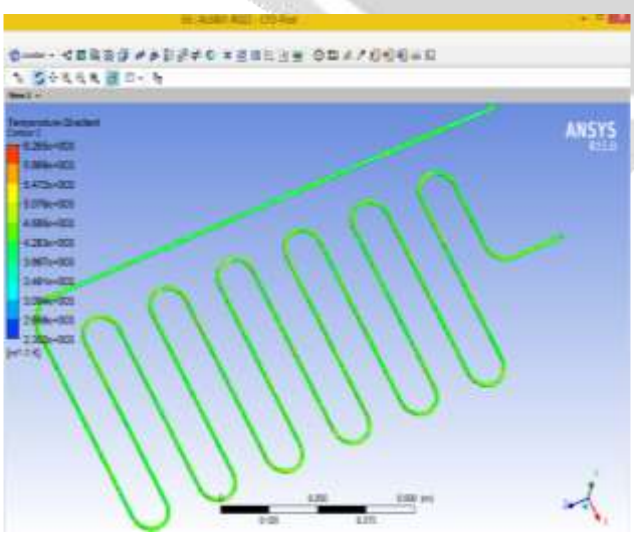


(c) Cu-134a

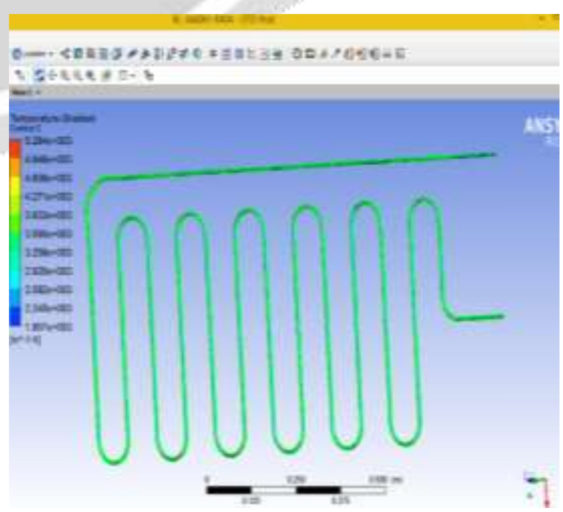


(d) Cu-152a

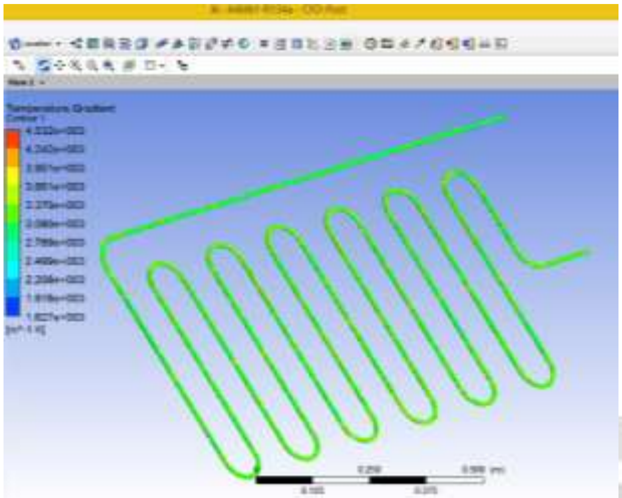
Figure 4.3: Thermal Gradients for Cu



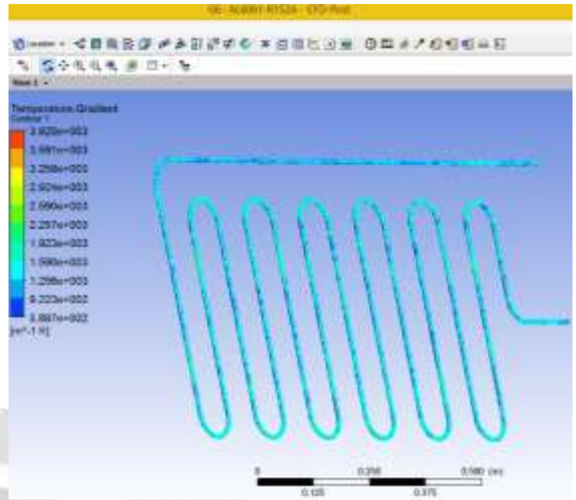
(a) Al6061-R22



(b) Al6061-R404

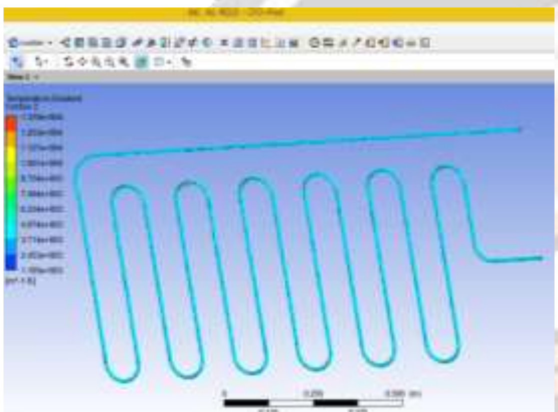


(c) Al6061-134a

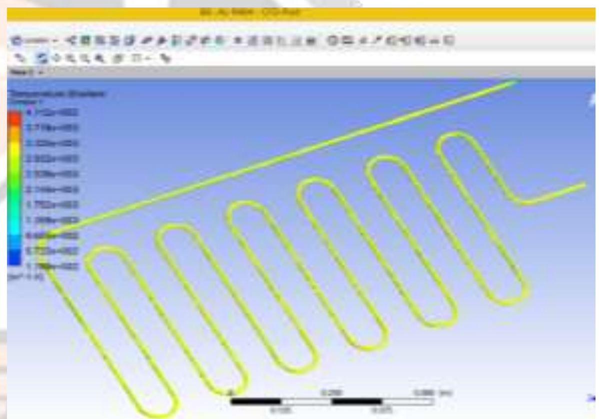


(d) Al6061-152a

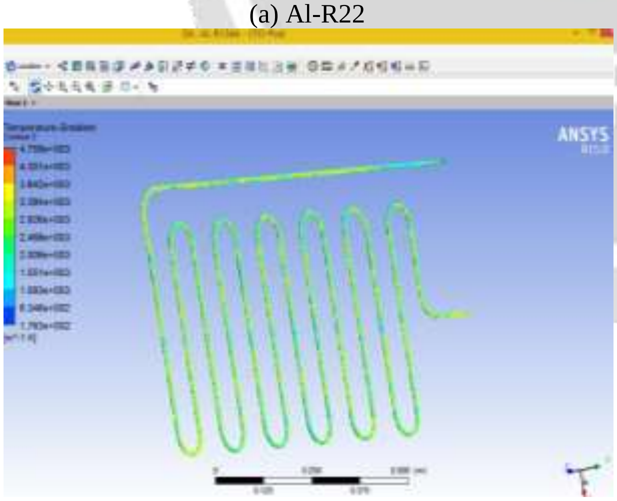
Figure 4.4: Thermal Gradients for Al6061



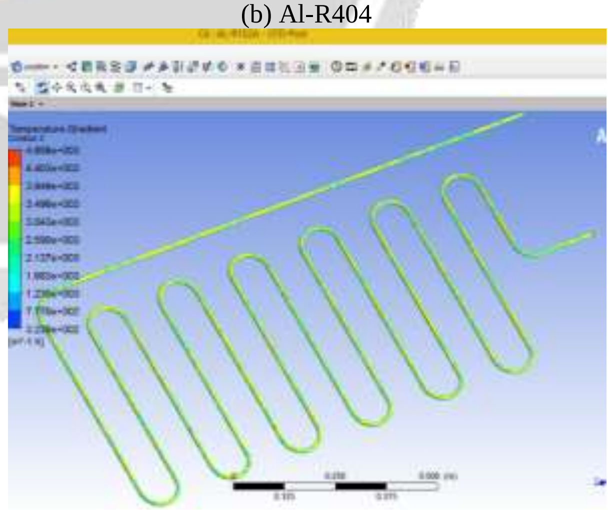
(a) Al-R22



(b) Al-R404



(c) Al-134a



(d) Al-152a

Figure 4.5: Thermal Gradients for Al

Table 4.4 shows the summary of results obtained for thermal gradients.

Table 4.4: Thermal Gradient Values (in e+0.003)

S.No	Material	Refrigerant			
		R022	R404	R134a	R152A
1.	Al	4.000	3.325	2.926	3.043
2.	Al6061	4.283	3.933	3.661	1.256
3.	Cu	4.284	3.370	4.003	1.256

Graphical representations of above results are as follows.

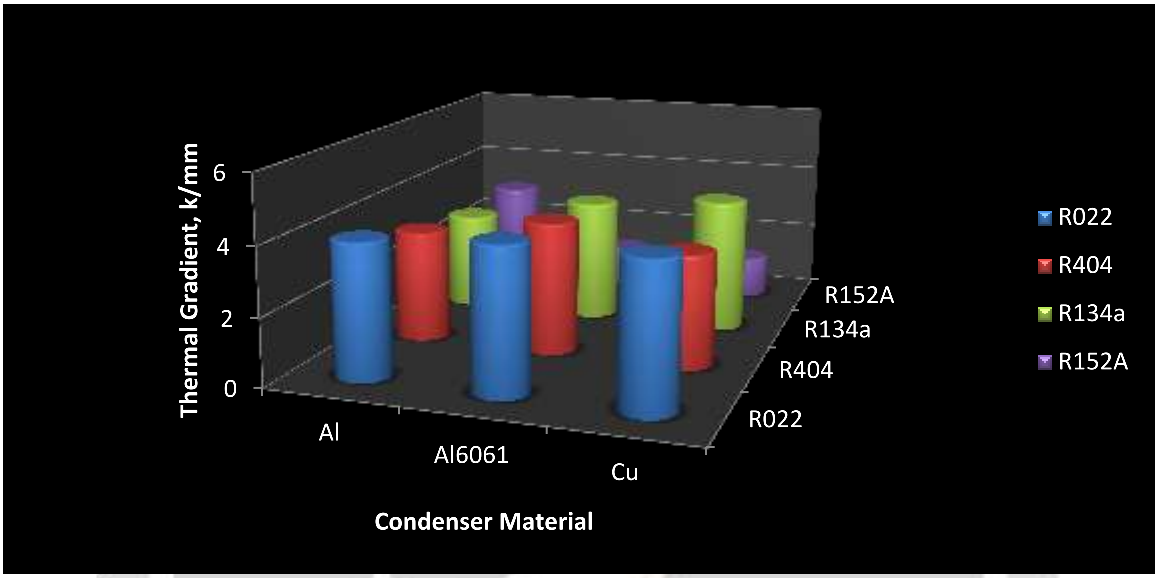
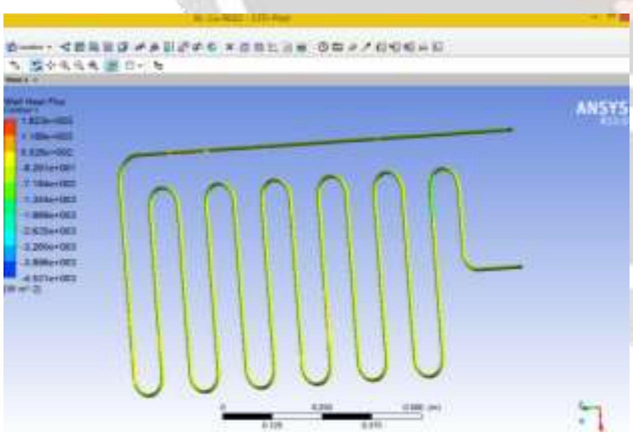
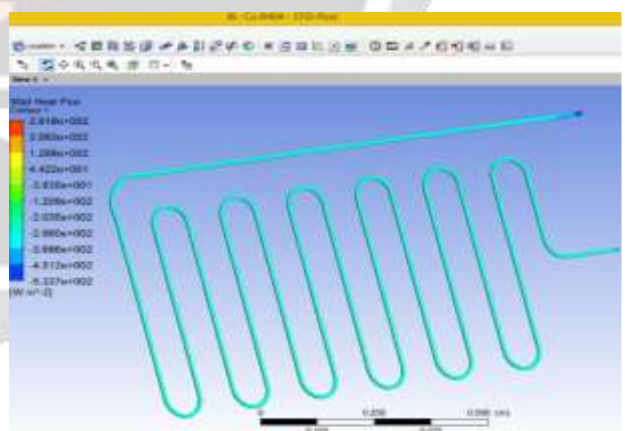


Figure 4.6: Graphical Representation of Thermal Gradient Values

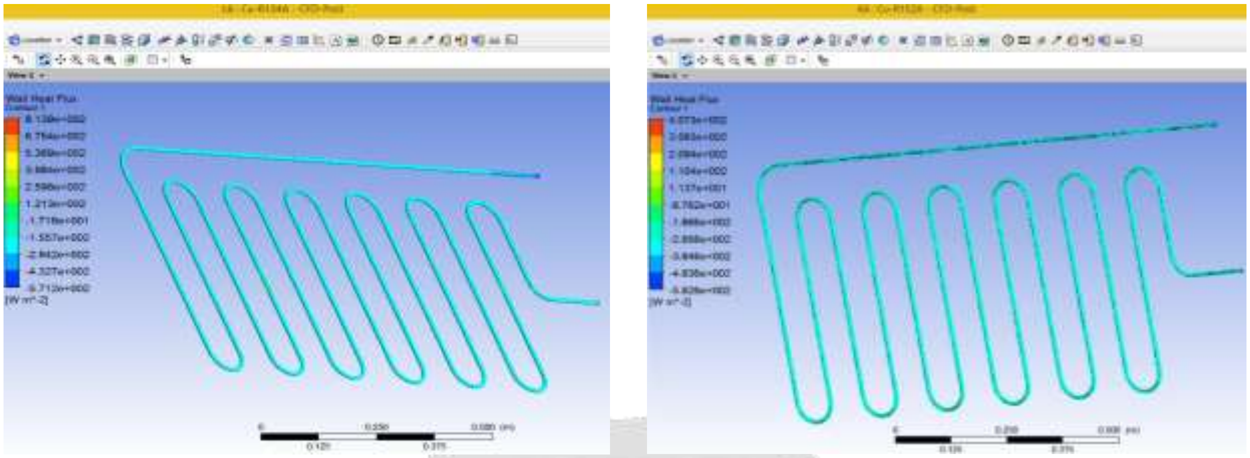
Following are the results obtained from calculations for heat fluxes.



(a) Cu-R22

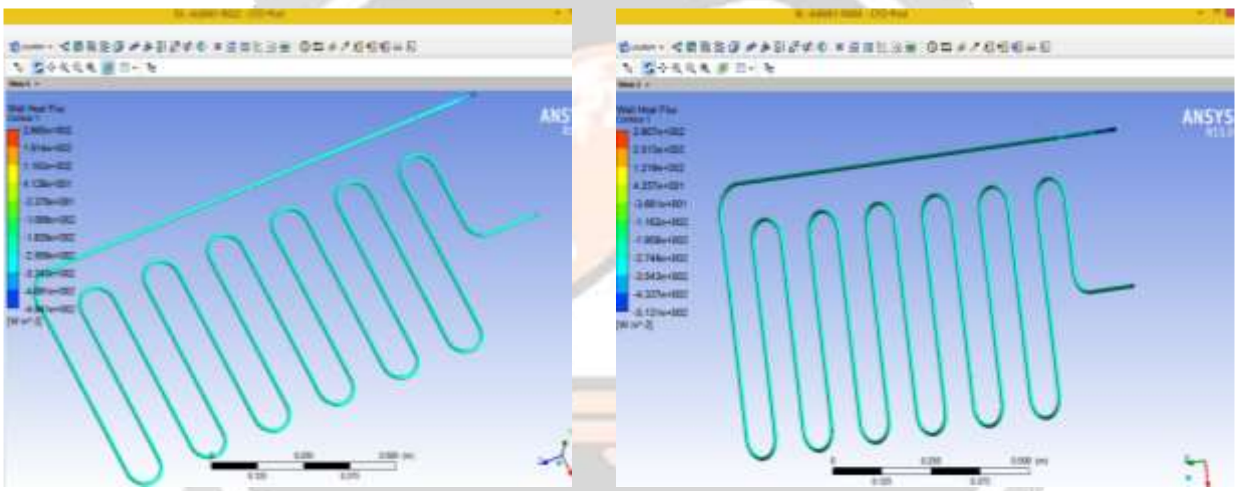


(b) Cu-R404

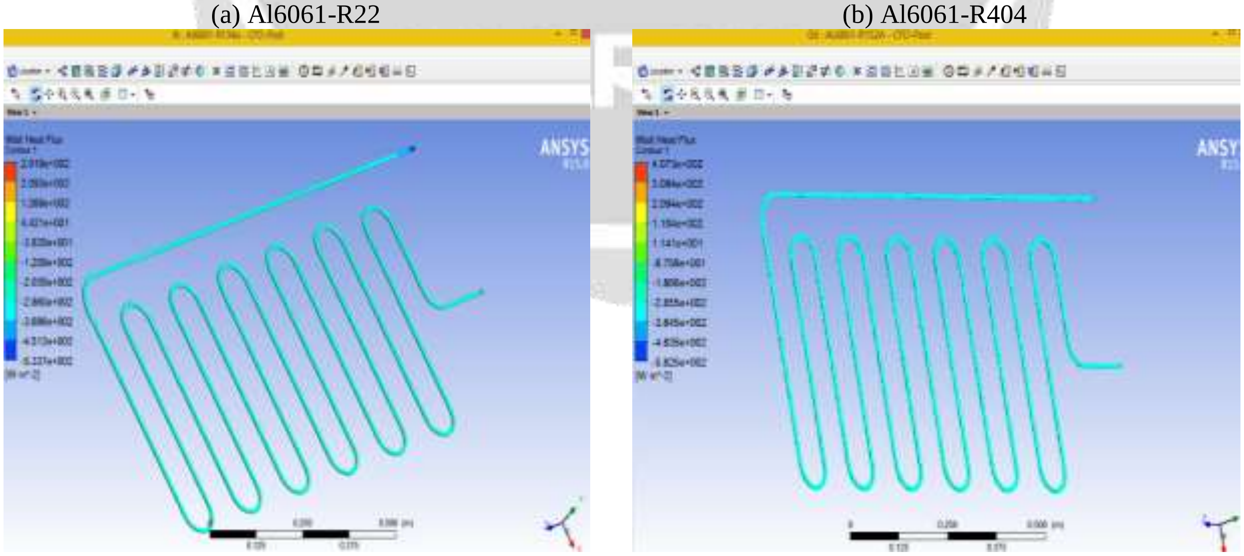


(c) Cu-134a (d) Cu-152a

Figure 4.7: Heat Fluxes for Cu

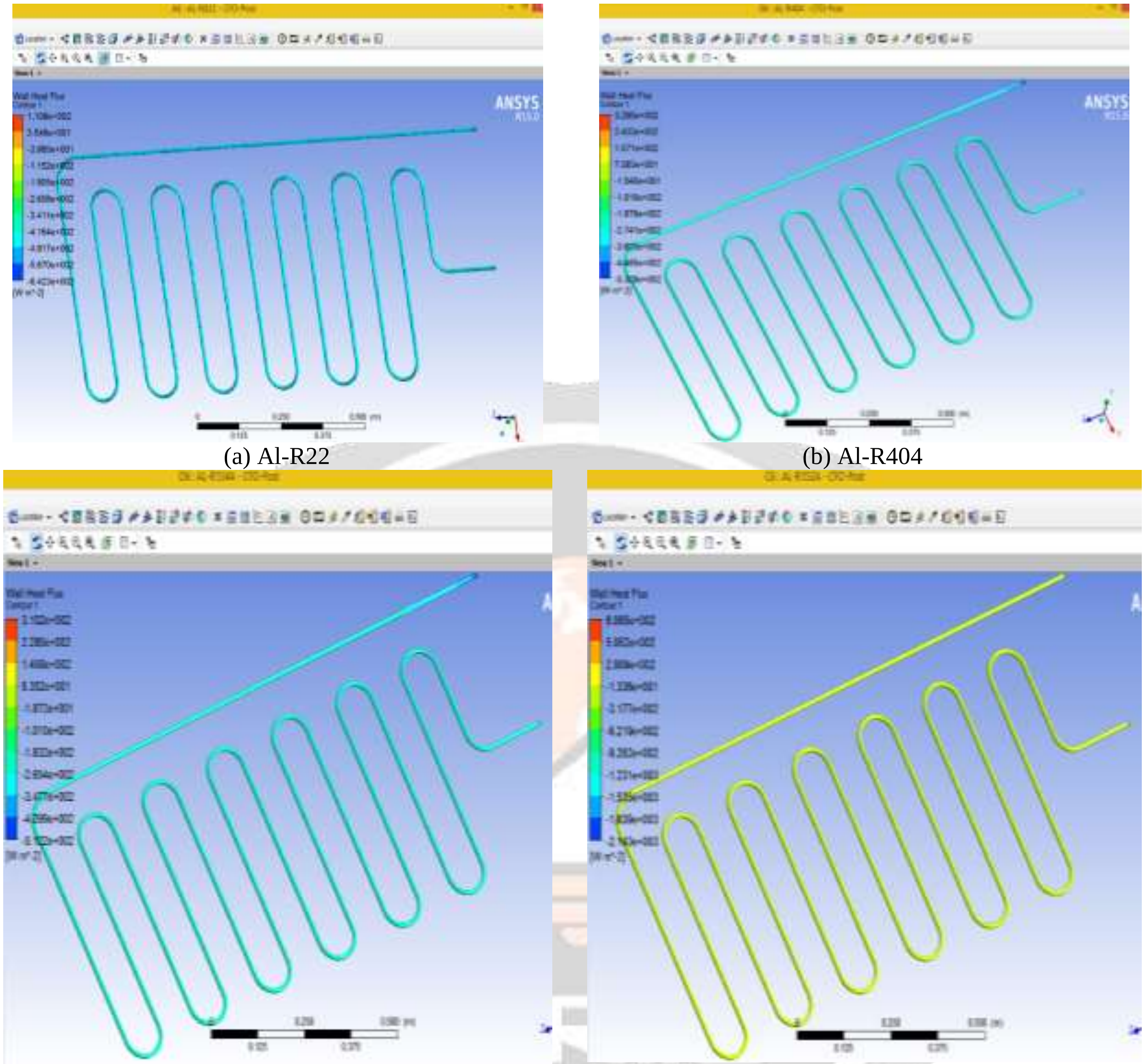


(a) Al6061-R22 (b) Al6061-R404



(c) Al6061-134a (d) Al6061-152a

Figure 4.8: Heat Fluxes for Al6061



(a) Al-R22 (b) Al-R404

(c) Al-134a (d) Al-152a

Figure 4.9: Heat Fluxes for Al

Table 4.5 shows the summary of results obtained for heat fluxed.

Table 4.5: Heat flux Values (in e+0.002)

S. No	Material	Refrigerant			
		HCFC	**R404**	**R134a**	**R152A**
1.	Al	4.164	1.88	1.832	2.909
2.	Al6061	2.589	2.322	2.035	1.866
3.	Cu	8.219	2.035	1.557	3.846

Graphical representations of above results are as follows.

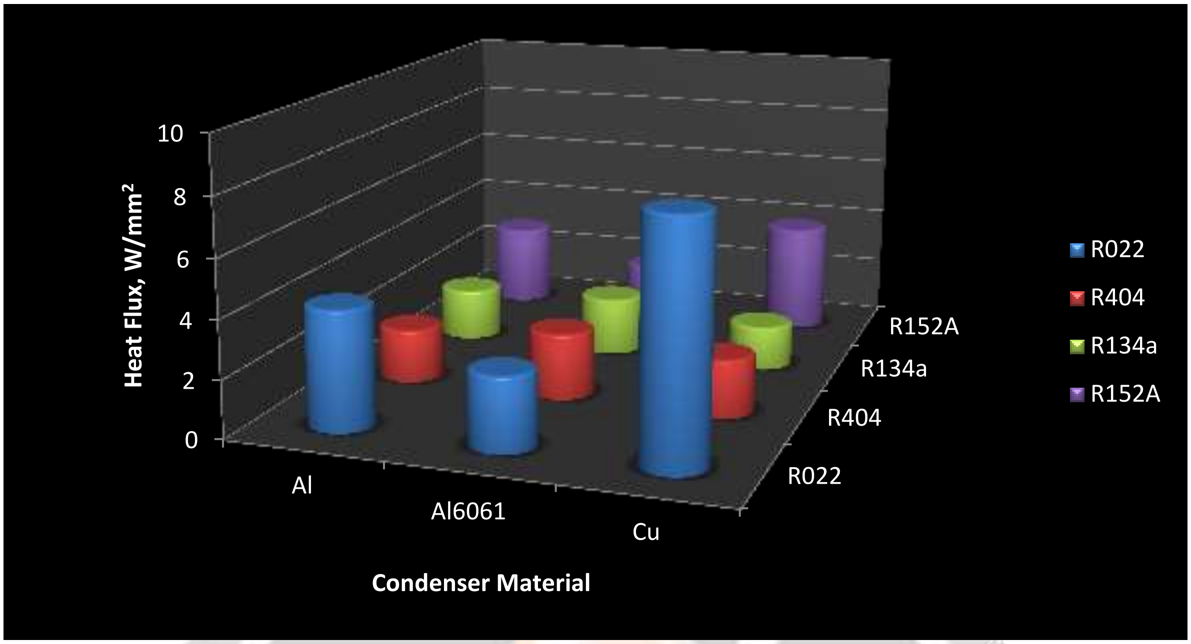


Figure 4.10: Graphical Representation of Heat Flux Values

5. Results and Discussion

Present section is devoted to results and discussions about the research work. The details of the results obtained, and discussion made on the basis of yielded results are presented in succeeding chapters.

5.1 Results

Tables 5.1 and 5.2 show the rankings of various combinations of materials and refrigerants on thermal gradients and heat fluxes.

Table 5.1: Rankings based on Thermal Gradients

S. No	Material	R022	Rank	R404	Rank	R134a	Rank	R152A	Rank
1.	Al	4.000	1	3.325	2	2.926	4	3.043	3
2.	Al6061	4.283	1	3.933	2	3.661	3	1.256	4
3.	Cu	4.284	1	3.370	3	4.003	2	1.256	4

Table 5.2: Rankings based on Heat Fluxes

S. No	Material	R022	Rank	R404	Rank	R134a	Rank	R152A	Rank
1.	Al	4.164	1	1.88	3	1.832	4	2.909	2
2.	Al6061	2.589	1	2.322	2	2.035	3	1.866	4
3.	Cu	8.219	1	2.035	3	1.557	4	3.846	2

Following are the results of thermal gradient and heat flux calculations, along with the type of refrigerants.

a) Thermal Gradient Results (considering all refrigerants): Al6061 > Cu> Al;
b) Heat Flux Results (considering all refrigerants): Cu > Al >Al6061;
c) Thermal Gradient Results with Refrigerants: R022 > R404 >R134a > R152a; and
d) Heat Flux Results with Refrigerants: R022 > R152a > R404>R134a.

5.2 Discussion

Results show variations in results obtained for thermal gradient, and heat flux values. According to results, copper should be preferred from heat flux point of view, while aluminum 6061 should be preferred when thermal gradient criteria is followed. The reasons behind such results are the material properties of both the alternatives. Due to greater thermal conductivity of copper than aluminum 6061, greater heat can be carried by copper, and due to this fact, value of heat flux for copper is greatest.

On the other hand, aluminum 6061 shows the greatest thermal gradient in two the available options. The reason behind this behavior is the fact that heat dissipation of rate of aluminum 6061 is greater, due to which it can dissipate maximum amount of heat due to its light weight. So therefore, considering both the requirements, Al6061 should be considered as the replacement of copper.

Table 5.3 and Table 5.4 show the ranking earned by different refrigerants on different criteria.

Table 5.3: Ranking of refrigerants for Thermal Gradient Criteria

S. No	Material	Refrigerant	Rank	Frequency
1.	Al, Cu and Al6061	R022	1	3
2.	Al and Al6061	R404	2	2
3.	Al6061	R134a	3	1
4.	Al6061 and Cu	R152a	4	2

Table 5.4: Ranking of refrigerants for Heat Flux Criteria

S. No	Material	Refrigerant	Rank	Frequency
1.	Al, Al6061 and Cu	R022	1	3
2.	Al and Cu	R404	3	2
3.	Al, Cu	R134a	4	2
4.	Al, Cu	R152a	2	2

Above tables show that in case of refrigerants, score of R022 is maximum for both heat flux, and temperature gradient. But R22s help in depleting the ozone layer. So therefore, while considering the criteria of thermal gradient refrigerant R404 may be suggested. R404 is a blend of HFC refrigerants commonly used for medium and low temperature refrigeration applications. Its composition comprises: HFC-125 (44%), HFC-143a (52%), and HFC-134a (4%). It is non-toxic and non-flammable. In this case Al6061 is suggested.

Considering heat flux criteria, Cu may be used. With copper, in order to enhance heat dissipation rate, if a fan is used along the Cu, its heat dissipation rate may be enhanced, in order to take advantage of high thermal conductivity, R152a is suggested as refrigerant.

6. Conclusion, Limitations, and Future Scope of the Research

Present section tells about conclusion, limitations and future scope of the research work, details of which are presented in succeeding portions.

6.1 Conclusion

Present research work is devoted to selection of improved condenser material and refrigerant for a vapor compression refrigeration system. In the research work, *three* different materials for condensers, namely, aluminum, aluminum 6061 alloy, and copper were considered. At the same time, *four* different types of refrigerants namely, R022, R404, R152a, and R134a were tested for investigative *two* parameters namely, thermal gradient, and heat flux. As a results obtained, copper scored maximum for heat flux, and aluminum 6061 for thermal gradient. In case of refrigerants, refrigerant R22 scored maximum values in both the criteria. Following are the conclusions drawn out of the research:

a) Aluminum 6061offers maximum thermal gradient;
b) Copper offers maximum heat flux; and
c) Refrigerant R022 scores maximum for both, heat flux, and thermal gradient criteria, but cannot be recommended due to toxicity.

6.2 Limitations and Future Scope of the Research

Following are the limitations of the present research work:

a) The research work is limited to a particular set of materials;

b) The research work is limited to a particular set of refrigerants; and

c) The work is also made limited to the investigations on heat flux, and thermal gradients.

Following points represent the future scope of the research work;

a) An extensive research consisting of broader set of materials is still pending;

b) A broader research, considering different classes of refrigerants can be initiated;

c) A detailed research focusing on a broader set of thermal properties is still awaited.

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