



Improving the Heat Transfer Rate of Air Conditioning Condenser by Material Optimization

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JENRR/2021/v8i430219

Editor(s):

(1) Dr. Sreekanth. K. J., Kuwait Institute for Scientific Research, Kuwait.

Reviewers:

(1) Yogesh Agrawal, Rajiv Gandhi Proudhyogiki Vishwavidyalaya, India.

(2) T. V. Christy, PRIST University, India.

Complete Peer review History: <https://www.sdiarticle4.com/review-history/72830>

Original Research Article

Received 17 July 2021
Accepted 27 September 2021
Published 04 October 2021

ABSTRACT

Air conditioning systems have condensers that remove unwanted heat from the refrigerant and transfer the heat outdoors. The optimization of the global exploit of heat exchanging devices is still a burdensome task due to different design parameters involved. There is need for more and substantial research into bettering cooling channel materials so as to ensure elevated performance, better efficiency, greater accuracy, long lasting and low cost heat exchanging. The aim of this research work is to improve the heat transfer rate of air conditioning condenser by optimizing materials for different tube diameters. Simulations using thermal analysis and Computational Fluid Dynamic (CFD) analysis were carried out to determine the better material and fluid respectively. The analysis was done using Analysis System software. Different parameters were calculated from the results obtained and graphs are plotted between various parameters such as heat flux, static pressure, velocity, mass flow rate and total heat transfer. The materials used for CFD analysis are R12 and R22, and for thermal analysis are copper and aluminium. From the CFD analysis, the result shows that R22 has more static pressure, velocity, mass flow rate and total heat transfer than R12 at condenser tube diameter 6 mm. In thermal investigation, the heat flux is more for copper material at condenser tube diameter 6 mm. Copper offers maximum heat flux. Also, refrigerant R22 scores maximum for the heat transfer criteria, but cannot be recommended due to toxicity

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Keywords: Condenser; heat transfer; optimization; thermal analysis; computational fluid dynamics.

ABBREVIATIONS

ANSYS : Analysis System
 CFD : Computational Fluid Dynamics
 Nomenclatures
a : Contact surface area
A : Total surface area
m : Mass flow rate
h : Heat transfer coefficient
Q : Heat flux
U : Total heat transfer coefficient

1. INTRODUCTION

An air conditioner is a home appliance, system or mechanism devised to humidify and extract heat from a space. An air conditioning is an appliance, system or machine designed to stabilize the air temperature and humidity within an area typically using a refrigeration cycle but sometimes using evaporation, commonly for comfort cooling in buildings and motor vehicles.

It is also a system or machine that treats air in a defined, usually enclosed area via a refrigeration cycle. The air conditioning system transfers heat from a low energy reservoir to a warmer high energy reservoir [1]. The objective of air conditioner is to regulate the temperature, humidity, filtration and air movement of the indoor environment. In entity involving heat transfer, a condenser is a device used to condense a substance from its gaseous state to its liquid state, 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 several designs and come in various sizes ranging from rather small (hand-held) to very large industrial-scale units used in plant processes.

Heat transfer is a science that examines the energy transfer between two bodies due to temperature difference. In theory, thermal energy is linked to kinetic energy of molecules on minuscule scale. When material's temperature increases, the thermal unrest of its constituent molecules will increase. Then, the areas which contain greater molecular kinetic energy will pass this energy to areas with less kinetic energy. So, when an object or fluid is at different temperature from its surroundings, the heat transfer will take place in such a way that the body and the surroundings reach thermal equilibrium.

Wasi et al. [2] performed an experiment on window air conditioner with old condenser (made

up of magnesium) which was already installed. After accession of new condenser contrived of copper in the existed window air conditioner, they performed experiment by measuring the entire criterion with interruption of 15 minutes. From their result, they found out that AC with newly installed condenser cools the room in less time as compared to the previous one. i.e copper condenser transferred heat outdoors quickly than magnesium.

Babu and Srikanth [3] designed an ac condenser and optimized for outshine materials, refrigerants and thickness to enhance the heat transfer rate. Analysis was done using fin materials: Al1100, Al6065 and Mg. And also by changing the cooling fluid: HCFC and R404. In their thermal analysis result, they observed that thermal flux is more when using fin material Al1100 than using other two materials i.e. heat transfer increases when using Al₁₁₀₀. They also observed that refrigerant R404 has more heat transfer rate.

In the research work by Krishna and Kumar [4] the performance of a condenser was studied analytically by changing the fins materials when using R22 and R407C as refrigerants. Copper, aluminium and brass were used to analyse the performance of fin materials on condenser efficiency. ANSYS software was used to evaluate heat transfer rate and heat transfer coefficient for the fluid with different fin materials. By comparing results of aluminium and brass with copper fin of condenser, they observed that using copper as a fin material gives a better result. While considering fluent analysis for R22 and R407C, it was observed that R407C gives better result.

Chouhan et al. [5] analytically studied the effects of the relevant parameters and flow characteristics of R134a and R22 flowing through adiabatic condenser tube. The condenser tubes' diameter and parameter relating to inlet pressure and degree of sub cooling were the main parameters investigated. From their CFD result, they observe that pressure drop value is increased at tube diameter 25mm by the fluid R22. By observing the thermal analysis, they observe that heat is more for copper when compare with aluminium material. So, they concluded that copper material and fluid R22 are better.

Reddy et al. [6] studied the heat transfer of a condenser in a refrigeration system by varying the condenser length which was determined by CFD and thermal analysis. The work was carried

out on an air cooled tube condenser of a vapour compression cycle. The materials considered for tubes are copper and aluminium, and the refrigerant varied was R12. In the CFD analysis result, they found that heat transfer rate is more at condenser length 505mm and heat flux is more for copper material and condenser length 405mm. For the thermal analysis, they concluded that the better material is copper.

Nirmal et al. [7] optimized ac condenser using R404 to enhance the heat transfer rate. In the research work, ac condenser was outlined and upgraded for superior material and refrigerant to enhance the heat transfer rate. To enhance the condenser for superior material, thermal analysis was done on the condenser. Examination was done utilizing blade materials (Al 1100 and Al6063), also by changing the cooling fluid HCFC to R404. From the result, they observe that utilizing fin material Al1100, heat flux is more. They concluded that by utilizing Al1100, heat transfer rate increases with refrigerant R404.

When designing and optimizing the condenser to improve heat transfer rate, there are large numbers of condenser tube geometric design parameters that can be varied in order to optimize the performance of an air conditioning system. These parameters are the tube diameter, tube spacing, number of refrigerant parallel flow circuits and fin spacing per pitch.

Shafiudeen et al. [8] designed and studied the flow analysis of condensed fins by using CFD. The material use for tube was copper and fin was made with different materials (aluminium 1100 and aluminium 1050). The refrigerants used are R12, R22 and R134a which are used for analysis on condenser using ANSYS. From their analysis result, the heat transfer rate is more when R22 was used. When the results for fin material between aluminium 1100 and aluminium 1050 were compared, the observed that aluminium 1050 is better.

Some of the researchers not only worked on material but also varied the refrigerants in the system. For example, in the research work by Mallikarjun and Malipatil [9] heat transfer by convection in condensers was evaluated and attempts are made to enhance it. For this purpose, an air-cooled condenser of finned type used in vapour compression air conditioning system was utilized, and computational fluid dynamics (CFD) approach was being applied to it with the objective of determining the better design and material. The materials used for

tubes are copper, for fins are Aluminum 1100, Aluminum 6063, and Magnesium alloy. The refrigerants used for this purpose are HCFC, and 404R. They concluded that thermal flux is more when Aluminium alloy 1100 is used for fin and refrigerant used is R404 than other combinations.

The comparison of R12, R22 and R134a has also been done by Bhimesh and Vankateshwarlu [10]. In the study, heat transfer was investigated for finding the optimum material and refrigerant in vapor compression refrigeration system. The materials used for tubing were Copper and Aluminum alloy 1100 and for fins are Al 1050, and Al1100. The refrigerants options considered by the researchers are R-12, R-22, and R-134A. In their analysis, it was discovered that R 22 gives maximum heat flux and hence has better heat transfer. Although R 22 because of its toxic properties may get phased out by 2020 as it was banned in many countries in 2015 and we must rely on some of the new blends of refrigerant. R 404A is a blend of HFC refrigerants mostly used for medium and low temperature refrigeration applications. Its composition constitute: HFC-125 (44%), HFC-143a (52%), HFC134a (4%). It is nontoxic and non-flammable and gives better heat transfer at condenser side.

Raghu and Srikanth [11] carry out design optimization technique that can be useful in assessing the best configuration of a finned tube condenser. Heat transfer by convection in air cooled condensers was investigated and improved in this work. The assessment has been done on an air-cooled finned-tube condenser of a vapour compression cycle for air conditioning system. Heat transfer analysis and CFD analysis is carried out on the condenser to evaluate the better design and material. The materials considered for tube is copper and for fins are Aluminium alloys 1100, 6063 and Magnesium alloy for different refrigerants HCFC and 404R. 3D modelling is done in Pro/Engineer and analysis is done in Ansys. CFD analysis is performed at different velocities. Theoretical calculations are performed to determine heat transfer rate.

The optimisation of the global performance of heat-exchanging devices is still a tedious task due different design parameters involved. There is a need for more and comprehensive research into enhancing cooling channel materials so as to ensure high performance, more efficient, more accurate, long lasting and low cost heat exchanging.

Bejan et al. [12] argue that “when a system consists of several components, the overall system should be optimised, since optimisation of components individually does not guarantee an optimum overall system”. This view is supported by Ordonez and Bejan [13] who recommended that an entire system can be conceived from the beginning as a system designed to perform certain global objectives optimally, rather than as an assembly of already existing parts. Therefore, we believe that there is a need to introduce a Computer Fluid Dynamics analysis in the optimisation process in order to accomplish a near-optimal solution of the global performance. Most of the currently applied methods are time-consuming, expensive and do not achieve a near-optimal solution. The advance in technology improvement and especially the advent of Computer Fluid Dynamics has brought about significant improvement, which has made it possible to analyse difficult design variables with a satisfactory design. However, the approach is to assume that there must be optimal design variables at which the system will perform best.

The aim of this research is to improve the heat transfer rate of air conditioning condenser by optimizing different materials and refrigerants.

The objectives of this research work are the following;

- i To model air conditioner condenser using ANSYS software.
- ii To execute thermal analysis on the air conditioner condenser for thermal loads to evaluate better material.
- iii To execute CFD analysis in order to determine the heat transfer coefficient, heat transfer rate, mass flow rate and pressure drop for the model with different fluids.

The result obtained for different materials and refrigerants will be compared.

2. METHODOLOGY

In the present research work, ANSYS 2020 R1 simulation software was used with the aim of simulation, and obtainment of results. ANSYS is general-purpose Finite Element Analysis (FEA) software package. Finite Element Analysis is a numerical method of deconstructing a complex system into very small pieces called elements. The software executes equations that govern the behaviour of these elements and solves them all;

creating a comprehensive explanation of how the system acts as a whole. These results then can be presented in tabulated or graphical forms. This type of analysis is typically used for the design and optimization of a system far too complex to analyze by hand. Systems that may fit into this category are too complex due to their geometry, scale, or governing equations. ANSYS provides a cost-effective way to explore the performance of products or processes in a virtual environment. This type of product development is termed virtual prototyping.

2.1 Heat Flux Calculation

Energy balance of heat transfer system can be expressed as given by following equations;

- (i) Area of condenser

$$a = \frac{\pi}{4} x d^2 \quad (1)$$

- (ii) Inner surface area of the condenser

$$A = \pi dL \quad (2)$$

- (iii) Mass flow rate

$$m = a \times V \times \rho \quad (3)$$

- (iv) Heat transfer rate

$$Q = m \times C_p \times \Delta T \quad (4)$$

- (v) Heat transfer coefficient

$$h = \frac{Q}{A(T_{in}-T_{out})} \quad (5)$$

- (vi) Overall heat transfer coefficient

$$U = \frac{1}{\frac{1}{ha} + \frac{r}{k} + \frac{1}{hb}} \quad (6)$$

2.2 CFD Analysis Procedure

Computational fluid dynamics (CFD) study of the system begins with the construction of desired geometry and mesh for modeling the dominion. Generally, geometry is simplified for the CFD studies. Meshing is the discretization of the domain into small volumes where the equations are solved by the help of iterative methods. Modeling begins with the describing of the boundary and initial conditions for the dominion and leads to modeling of the entire system. Finally, it is followed by the analysis of the results, discussions and conclusions.

2.3 Solid Modeling and Formulation of Parameter of a Condenser

The typical modeling process was performed by the ANSYS workbench. The design modeler workbench was used for modeling the geometry in ANSYS. The only geometric parameter that was varied in the condenser is the tube diameter. The number of rows, tube spacing and number of tubes were maintained at the values utilized for the configuration. The formulation parameter used in designing the model can be found in Table 1

2.4 Meshing of the Condenser

At the beginning a relatively coarser mesh was generated. This mesh consist of mixed cells (Tetra and Hexahedral cells) having both triangular and quadrilateral faces at the boundaries. At the time of the meshing process of whole body, the name selection parameter was also defined to easily identify the different region of inlet and outlet.

2.5 Problem Setup and Boundary Condition of the Condenser

The mesh was automatically checked and the quality was obtained to know if it is compatible. The type analysis was replaced with pressure based type. The velocity was replaced with absolute and the time was set to steady state. Then next comes the turbulence model section. As we have gone through different papers which suggested the k-epsilon model to be the most effective method for a heat exchanger evaluation. This model was selected base on its greater accuracy in heat exchanger cases from model settings, turn on the energy equation. It also enable the viscous settings to k-epsilon realizable settings and enhance wall functions. In cell zone, fluid selected will be R-12 and R22; aluminum was selected as material for

simulation. The properties of fluid flowing in the condenser are given below Table (2). Boundary condition was chosen for inlet and outlet. Boundary conditions are used according to the need of the model. The inlet temperatures and velocities are selected to the setup.

2.6 Solution of the Problem

The CFD provides the solution of different fluid flow and heat flow problems based on the given boundary condition and some assumption. Second order upwind scheme was selected in spatial discretization section for momentum, pressure, turbulent kinetic energy, energy and turbulent dissipation rate. In Solution control initialization, pressure, density, body force ,momentum, turbulent kinetic and turbulent dissipation rate were set to 0.7, 1,1,0.2,1, 1 and 1 respectively. Solution initialization was hybrid method and solution was initialized from inlet with 300k temperature.

2.7 Thermal Analysis Procedure

Thermal analyses are used to determine the temperature distribution, thermal gradient, heat flow and other thermal quantities in a structure. The procedure for thermal analysis is divided into three distinctive steps;

- Build the model.
- Applying boundary condition and obtain the solution.
- Review the results.

2.8 Building the Model

The title of the analysis was first specified. Then, the ANSYS pre-processor was used to define the materials and model of the geometry. The materials to be selected here are copper and aluminum. Table 1 was used as reference for modeling the geometry.

Table 1. Parameter Formulation

| S/N | Condenser configuration | Value |
|-----|-------------------------|-------|
| 1 | Condenser length | 100mm |
| 2 | Number of turns | 4 |
| 3 | Tube thickness | 1mm |

Table 2. Properties of Refrigerants

| | R12 | R22 |
|--------------------------------|--------|-------|
| Thermal conductivity (W/mk) | 0.072 | 0.071 |
| Specific heat capacity (J/kgK) | 978.1 | 984 |
| Density (kg/m ³) | 1305.8 | 1295 |

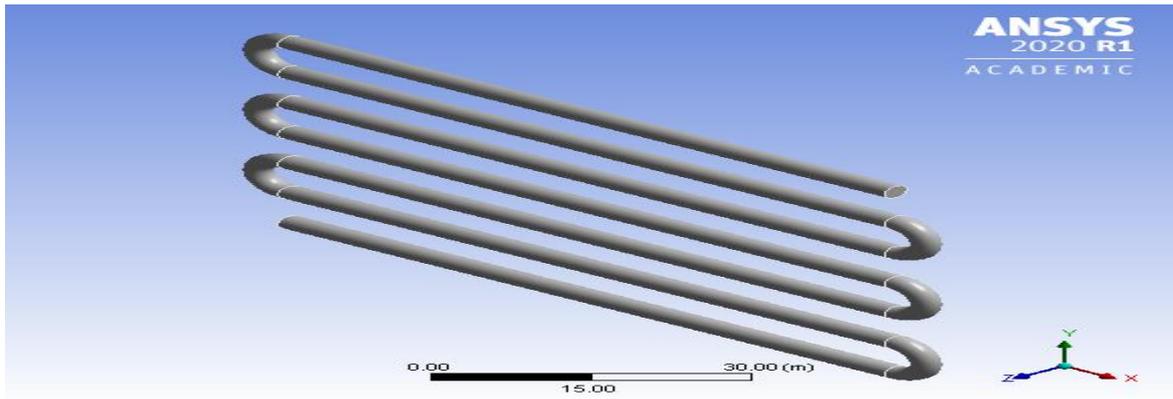


Fig. 1. Model of the Condenser



Fig. 2. Meshing of the Condenser

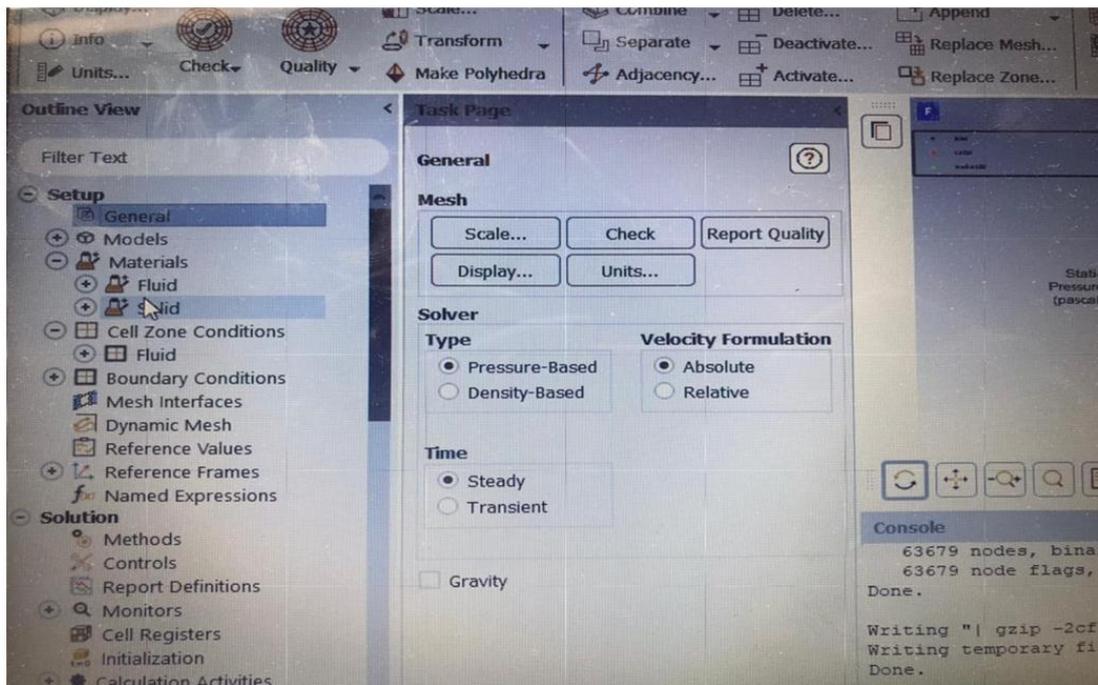


Fig. 3. Fluent setup (General)

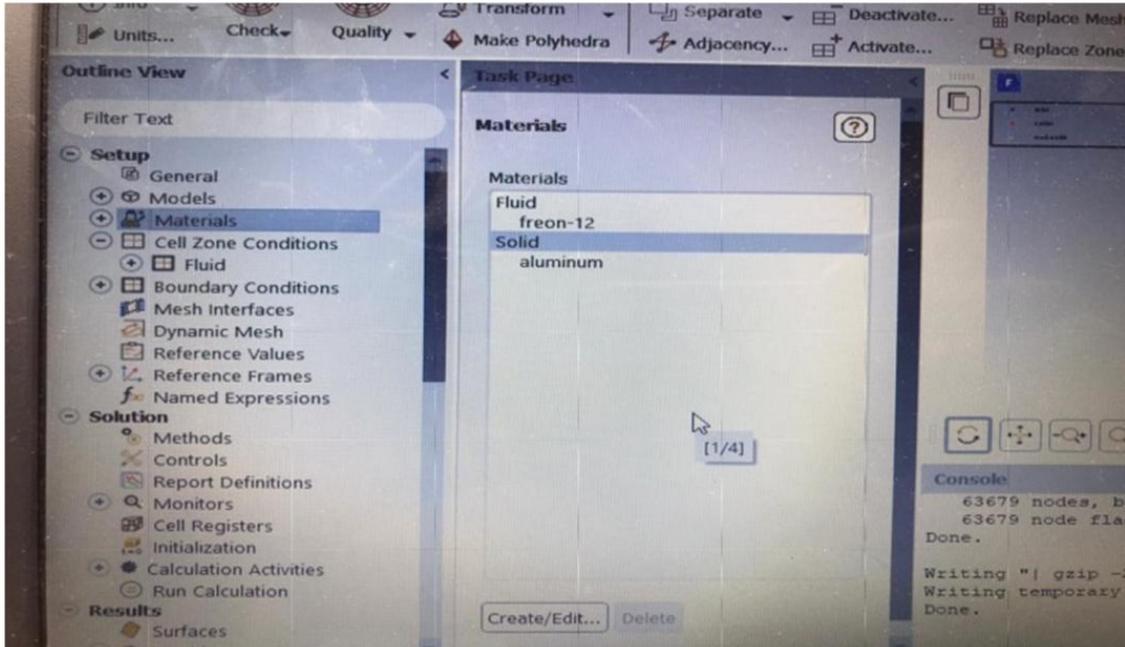


Fig. 4. Material Selection

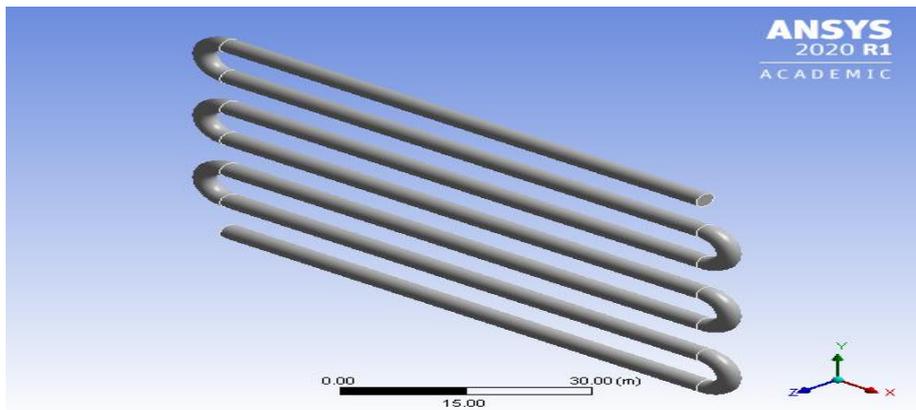


Fig. 5. Condenser Model

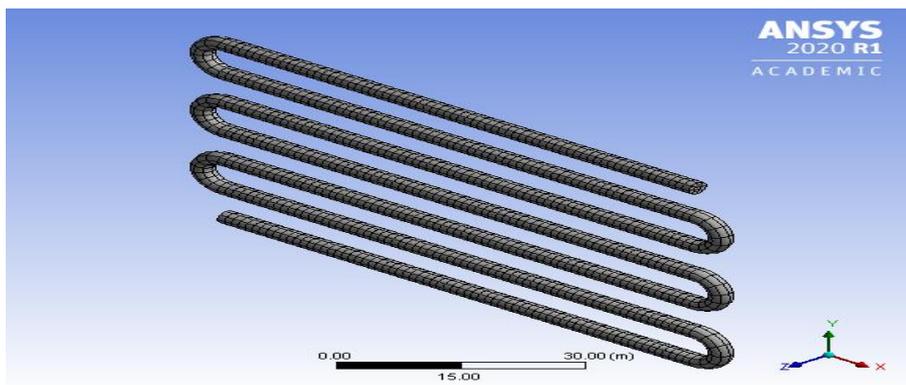


Fig. 6. Mesh model

2.9 Meshing

At the beginning, a relatively coarser mesh was generated. This mesh consist of mixed cells (Tetra and Hexahedral cells) having both triangular and quadrilateral faces at the boundaries.

2.10 Applying Loads

The convection film coefficient and bulk temperature was specified at the surface of the condenser. Since the coefficient depends upon temperature, then a table of temperatures along with the corresponding values at each temperature was also specified. ANSYS will then

calculate the appropriate heat transfer across the condenser surface. The applying loads used can be found in the Table 3.

3. RESULT AND DISCUSSION

The results from calculations for CFD analysis and Thermal analysis through using software ANSYS to show the performance of the air conditioner by comparing the refrigerant and the condenser material at various tube diameter are shown in Table 5 and 6. The heat transfer and flow characteristics of a condenser can be observed from the contour diagrams of temperature, heat flux, pressure, velocity, and mass flow rate.

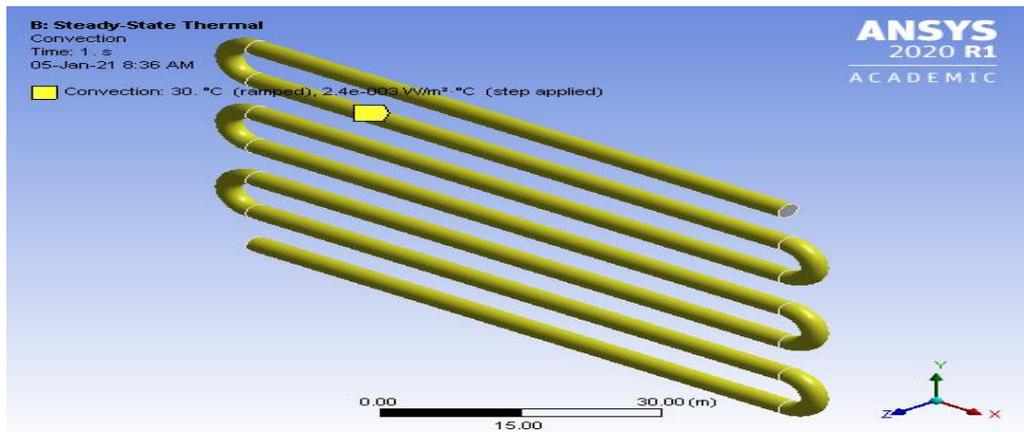


Fig. 7. Convection

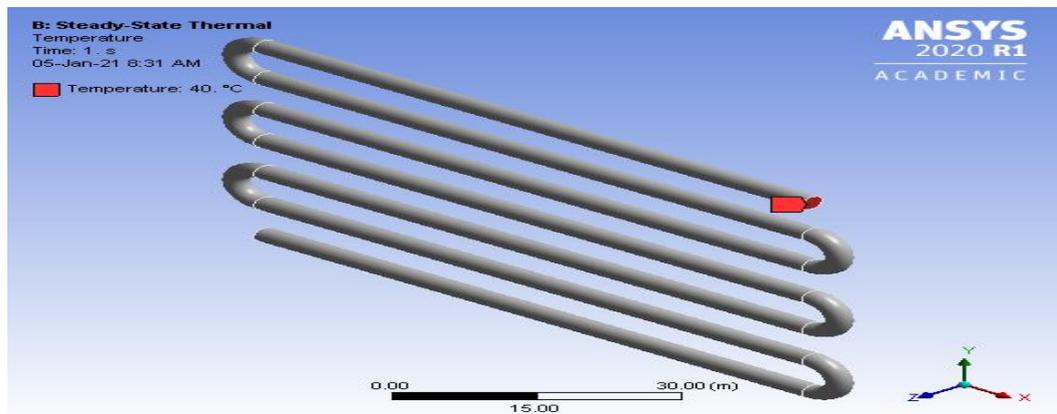


Fig. 8. Temperature

Table 3. Applying loads

| S/N | Parameter | Value |
|-----|------------------------|------------------------|
| 1 | Type of load | Thermal |
| 2 | Area temperature | 313K |
| 3 | Bulk temperature | 303K |
| 4 | Film coefficient value | 0.0024w/m ² |

Table 4. Properties of Material

| Aluminium | Copper | |
|--------------------------------|--------|------|
| Thermal conductivity (W/mk) | 235 | 385 |
| Specific heat capacity (J/kgK) | 896 | 385 |
| Density (kg/m ³) | 2700 | 8940 |

Table 5. CFD Analysis Result Table

| Fluid | Tube Diameter (m) | Pressure (kPa) | Velocity (m/s) | Mass Flow Rate (kg/s) | Total Heat Transfer (w) |
|-------|-------------------|----------------|----------------|-----------------------|-------------------------|
| R12 | 4 | 1.92e+04 | 3.67e+00 | 17.8792 | 32352.154 |
| | 5 | 2.35e+04 | 4.12e+00 | 64.6848 | 117046.09 |
| | 6 | 2.95e+04 | 4.60e+00 | 62.969 | 1133941.76 |
| R22 | 4 | 5.23e+04 | 4.63e+00 | 58.5463 | 110853.87 |
| | 5 | 2.96e+04 | 4.02e+00 | 55.7434 | 106546.04 |
| | 6 | 1.70e+05 | 2.53e+00 | 63.9146 | 84346.45 |

Table 6. Thermal Analysis Result Table

| Material | Tube Diameter (mm) | Temperature (°C) | Heat Flux |
|-----------|--------------------|------------------|-----------|
| Aluminium | 4 | 40 | 8.2958 |
| | 5 | 40 | 8.8943 |
| | 6 | 40 | 9.9766 |
| Copper | 4 | 40 | 10.957 |
| | 5 | 40 | 11.452 |
| | 6 | 40 | 12.361 |

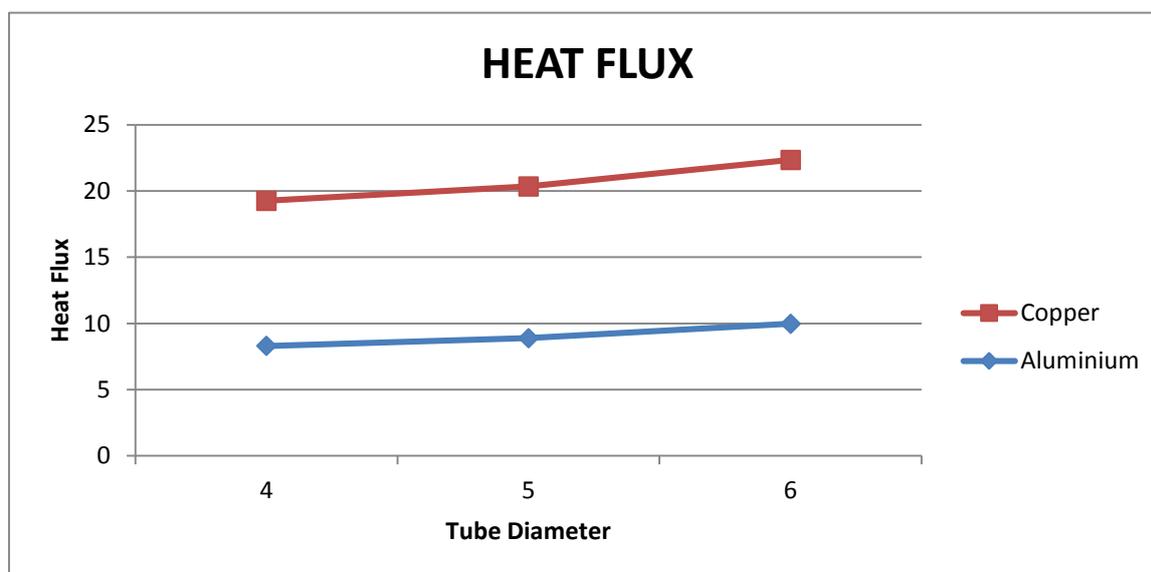


Fig. 9. Heat flux

The above graph represents the comparison of heat flux for the two materials at different tube diameter. It shows that copper with 6mm tube diameter has more heat flux value than

aluminium due to more heat transfer rate base on increase in total surface area of the condenser or evaporator. The thicker the tube, the lower the heat transfer effectiveness.

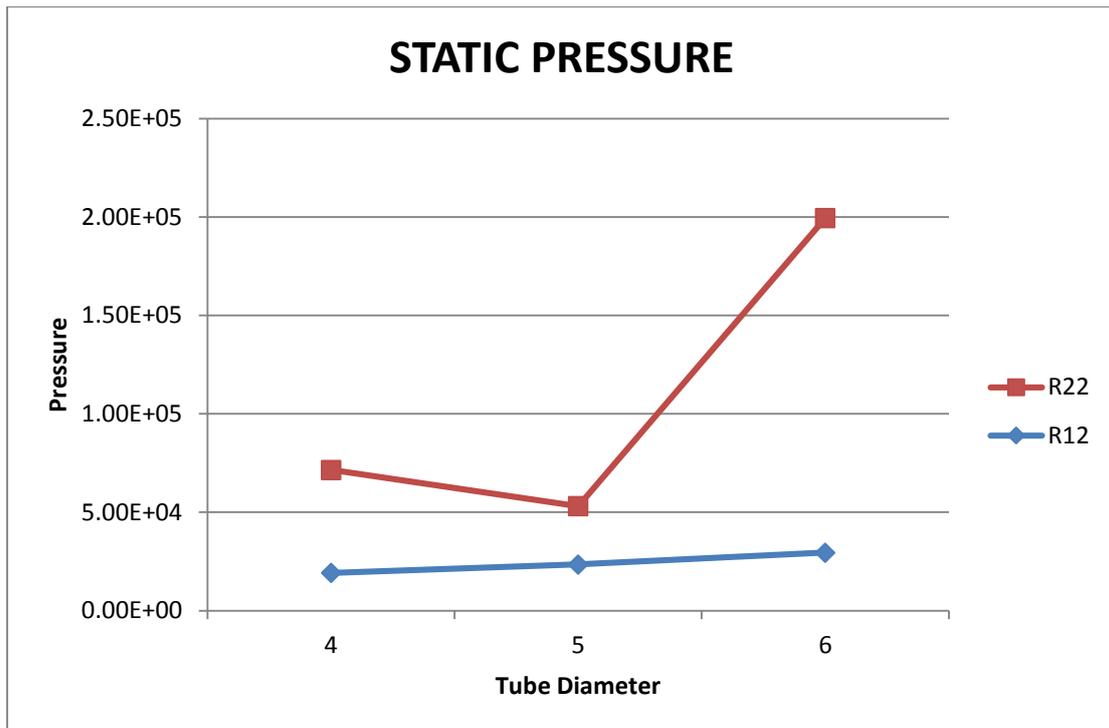


Fig. 10. Static pressure comparison graph

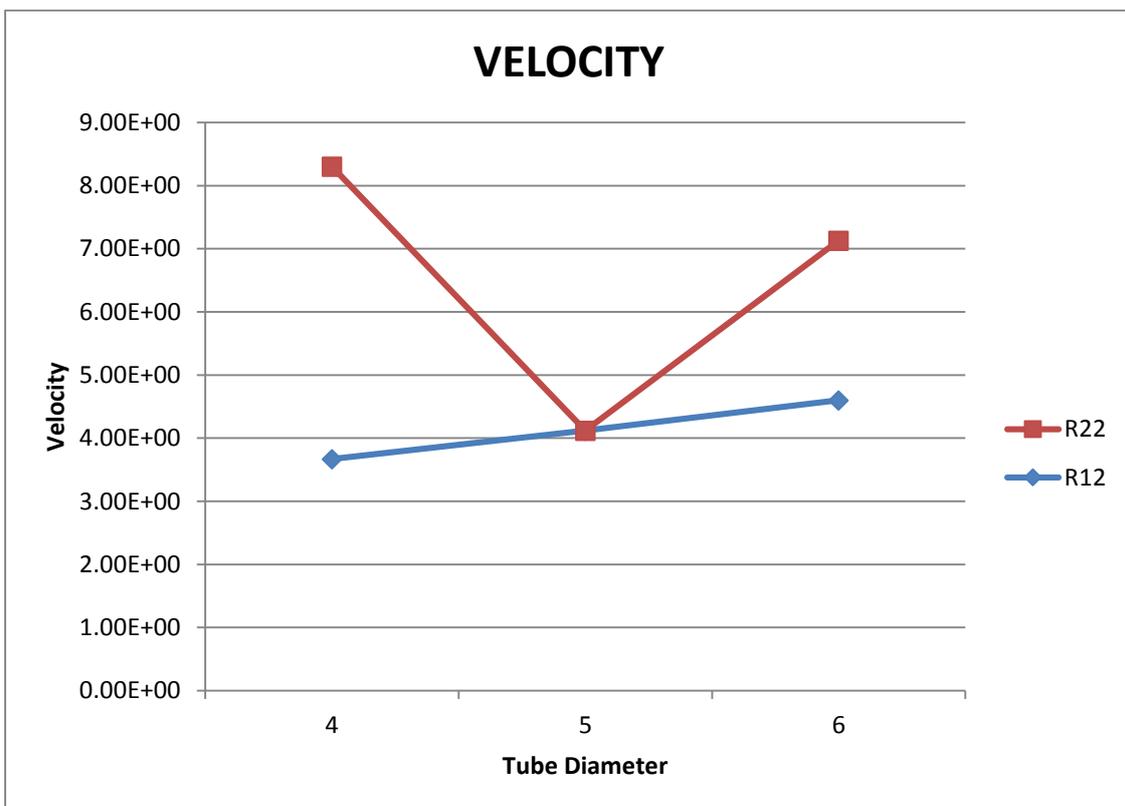


Fig. 11. Velocity comparison graph

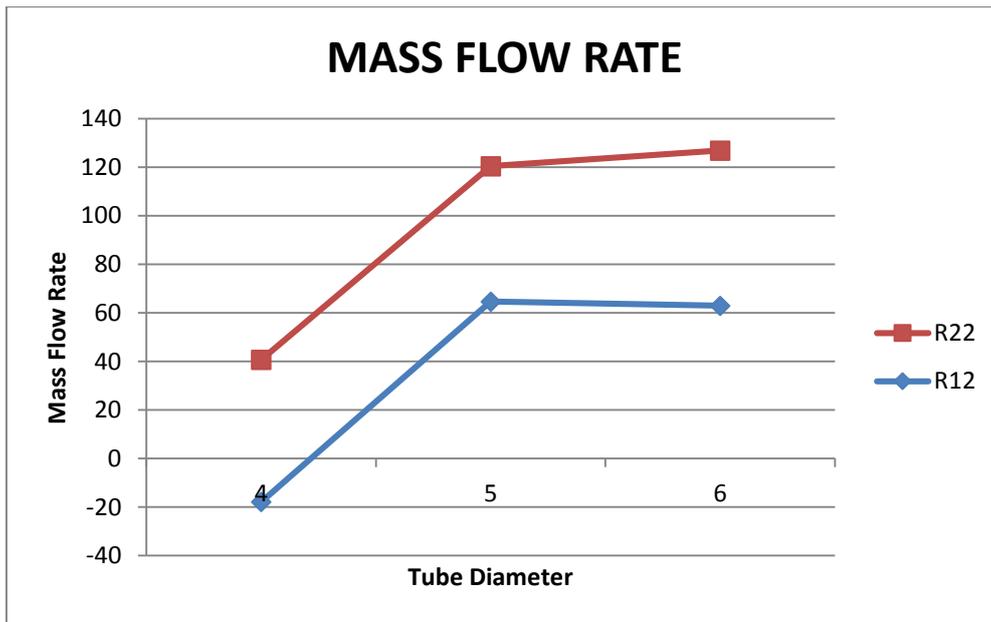


Fig. 12. Mass flow rate comparison graph

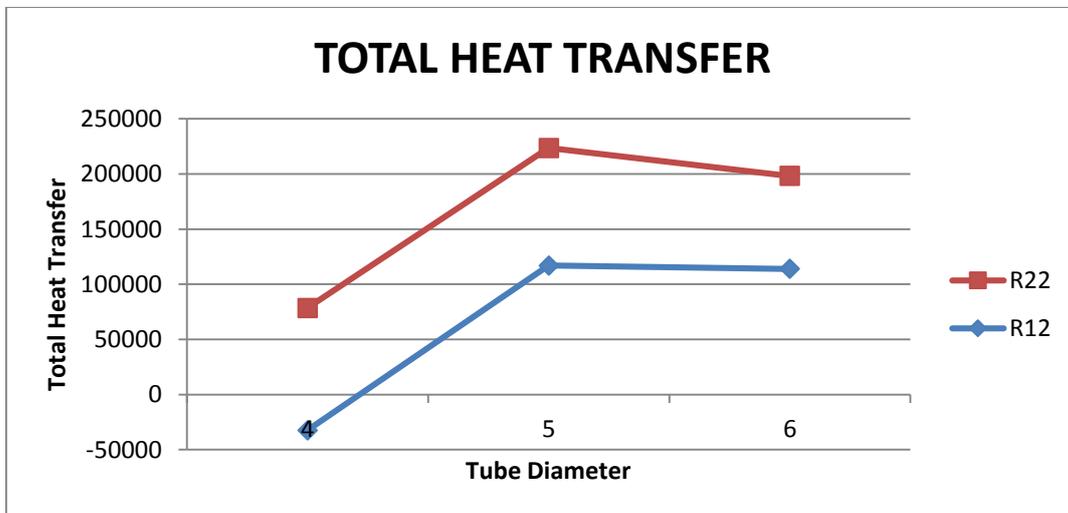


Fig. 13. Heat transfer comparison graph

The above graphs represent the correlation various refrigerant and tube diameter for the two materials of R12 and R22 refrigerant. It shows that the R22 has more static pressure, velocity, mass flow rate and total heat transfer than R12.

4. CONCLUSION

In this paper, an air conditioner condenser was designed and optimized for the purpose of better material and refrigerant. The condenser was modeled using Analysis System software. To optimize the condenser for best result, simulation analysis was done on the condenser using Analysis System software. Thermal analysis was

perform on the condenser to evaluate the better material and CFD analysis was carried out to determine the heat transfer rate by varying the refrigerants. In the research work, two different materials for condensers, namely, aluminum and copper were considered. At the same time, two different types of refrigerants namely, R12 and R22 were tested for investigation.

By observing the thermal analysis results, thermal flux for copper material is more than aluminium.

By observing the CFD analysis result, the static pressure, velocity magnitude, mass flow rate and heat transfer rate for R22 is more than R12.

The following are the conclusions drawn out of the research:

- (i) Copper offers maximum heat flux.
- (ii) Refrigerant R22 scores maximum for the heat transfer criteria, but cannot be recommended due to toxicity

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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