



# Material and Parametric Design Optimization of Improved Heat Transfer Rate of AC Condenser

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## Authors' contributions

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

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## ABSTRACT

Air conditioner system is made up of a condenser that removes unwanted heat in an enclosure through the refrigerant and transfers the heat outside. Improving the heat transfer of air conditioning condenser is still a difficult task because of the broader set of materials and various parametric designs involved. Due to this high cost, the experimental set-up cost cannot be modified, instead, simulation analysis was introduced in the optimization process in order to achieve a near-optimal solution. The aim of this research is to improve the heat transfer rate for air conditioning condenser by material and parametric design optimization. The system was designed based on one basic parameter optimization: varying the condenser tube diameter. This variable was changed in order to improve the heat transfer of the condenser. Simulations using Computational Fluid Dynamic (CFD)

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analysis and thermal analysis were carried out to have a better understanding and distinct visualization of the fluid flow and materials used, and to compare the results. The materials that were used for CFD analysis are R32 and R290, and for thermal analysis are copper (C12200) and aluminum. The analysis was done using Analysis System (ANSYS) software. Different parameters were calculated from the results that were obtained and graphs were plotted between various parameters such as heat flux, static pressure, velocity, mass flow rate and total heat transfer. From the CFD analysis, the result shows that R32 has more static pressure, velocity, mass flow rate and total heat transfer than R290 at a condenser tube diameter of 7mm. In thermal analysis, the heat flux is more for copper (C12200) material at a condenser tube diameter of 7mm than aluminum.

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

## 1. INTRODUCTION

Air conditioner is an appliance, system, or mechanism designed to dehumidified and extract heat from an area. It provide comfort during either hot or cold weather [1,2]. And in systems involving heat transfer, a condenser condense a substance from its gaseous state to its liquid state, by cooling [3] because heat generation can cause overheating problems and thermal stresses that may lead to system failure. The removal of heat from these devices has been a critical challenge to thermal design engineers and researchers. Heat transfer in heat generating devices occurs by conjugate heat conduction and forced convection. Heat conduction is the transfer of thermal energy from more energetic particles to less energetic counterparts. This is largely influenced by the thermal conductivity of the material. Working towards the goal of saving energies and making a compact design for mechanical devices, chemical devices, and plants. The enhancement of heat transfer is one of the key factors in the design of condenser. And due to less time consumption, dependable output, and accurate results, simulation analysis was introduced in the optimization process in order to achieve near optimal solution. The advance in technology improvement and the introduction of simulation has brought about great improvement. Therefore, the solution is to ensure that there must be optimal design variables at which the system will have maximum performance.

Thermal flux is more in aluminum1100 fin material with refrigerant R404 than other aluminum alloys materials [4,2,5]. Heat transfer coefficient is higher with refrigerant R134 and heat transfer rate is more with refrigerant R22 than other fluids, and in thermal analysis, heat flux is higher with R22 refrigerant and copper material [6-10]. Sriram and Sekhar [11] modelled and performed a thermal analysis on the

condenser by taking tube material as copper and varying the plate material with refrigerants HC and HFC. They analyzed thermal properties such as nodal temperature, thermal gradient and thermal flux and discovered that plate material Al204 has higher thermal conductivities and also observed that HFC refrigerant has higher thermal conductivity.

Srividhya and Venkateswara [12] designed an air cooled condensers on COSMOS works usi ng copper material for the tube and copper Al99 and Magnesium for the fins with refrigerants HC and HCFC. The material used for tube is copper and the materials used for fins are copper Al99 and Magnesium. They optimized the fin thickness and observed that heat transfer rate is more in A199.

Goswama and Babu [13] carried out a thermal and CFD analysis on an AC condenser by varying the refrigerant and observed that heat flux is more in copper material with R134a refrigerant. Ramesh [14] worked on the heat transfer analysis of a condenser using copper material for the coil and aluminum for fins. He optimized the design parameters of the condenser by changing the thickness of the fin for the same length without failing the load condition using refrigerants HC and HCFC. The thermal analysis result showed that thermal flux is more when using aluminum for fin and observed that the optimum thickness value for decreased value is 1mm. He concluded that using condenser with fin thickness of 1mm and aluminum gives better result.

Improving the heat transfer of air conditioning condenser is still a difficult task because of broader set of materials and various parametric designs involved. Also, most of the currently applied methods especially the experimental/practical methods consume time and the experiment entail set up cost is

expensive. And due to this high cost of the experimental set up, simulation analysis was introduced in the optimization process in order to achieve near optimal solution. The advance in technology improvement and the introduction of simulation has brought about great improvement. Therefore, the solution is to ensure that there must be optimal design variables at which the system will have a maximum performance. The materials mostly used for the AC condenser coil, condenser tube and condenser fin are aluminum or copper. The aluminum have low thermal conductivity compared to copper. Therefore, to increase the heat transfer rate, an alloy of copper material C12200 (Phosphorus Deoxidized Copper) which has higher thermal conductivity compared to aluminum was majorly considered. The aim of this research is to improve the heat transfer rate for AC condenser by material and parametric design optimization.

## 2. METHODOLOGY

In the research work, ANSYS 2019 R2 simulation software was used for the simulation of CFD and thermal analysis. It was also used for obtaining the results generated. 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 is embedded with equations that govern the behaviour of these elements and solves them all.

### 2.1 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.

### 2.2 Solid Modeling and Formulation of Parameter of a Condenser

The solid modelling of the condenser was designed on SOLIDWORKS. 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.

### 2.3 Meshing of the Condenser

From the start, a relatively coarser mesh was generated. This mesh consists 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.

### 2.4 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 based on its greater accuracy in heat exchanger cases from model settings, turn on the energy equation. It also enables the viscous settings to k-epsilon realizable settings and enhance wall functions. In cell zone, fluids selected were R-32 and R290; copper (C12200) was selected as material for simulation. The properties of fluid flowing in the condenser are given below Tables (2 and 3). 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.

### 2.5 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.

## 2.6 Thermal Analysis Procedure

Thermal analyses are used to determine the temperature distribution, thermal gradient, heat flow and other thermal quantities in a structure (Fig. 1). The procedure for thermal analysis is divided into three distinctive steps;

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

## 2.7 Meshing

From the start, 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.

## 2.8 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 then calculated the appropriate heat transfer across the condenser surface. The heat transfer and flow characteristics of a condenser can be observed from the contour diagrams of temperature, heat flux, pressure, velocity, mass flow rate, and their iteration residues (Figs. 2, 3, 4). The applying loads used can be found in the Table 4.

**Table 1. Parameter formulation**

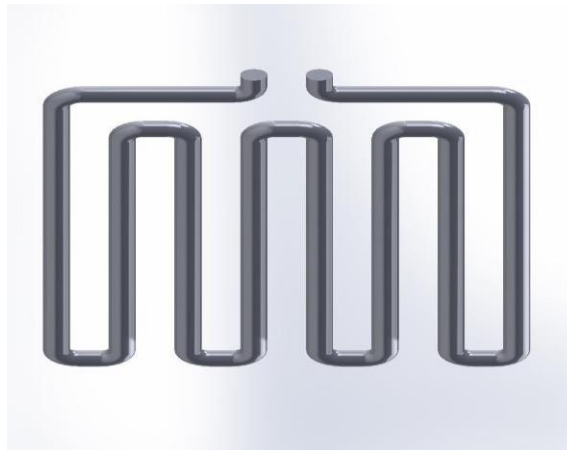
S/N	Condenser configuration	Value
1	Condenser length	100 mm
2	Number of turns	4 mm
3	Tube thickness	1 mm

**Table 2. Properties of material**

Aluminium		Copper(C12200)
Thermal conductivity (W/mk)	235	385
Specific heat capacity (J/kgK)	896	385
Density (kg/m <sup>3</sup> )	2700	8940

**Table 3. Properties of refrigerant**

R32		R290
Thermal conductivity (W/mk)	0.076	0.074
Specific heat capacity (J/kgK)	988.1	960
Density (kg/m <sup>3</sup> )	1305.8	1295



**Fig. 1. Model of the condenser**

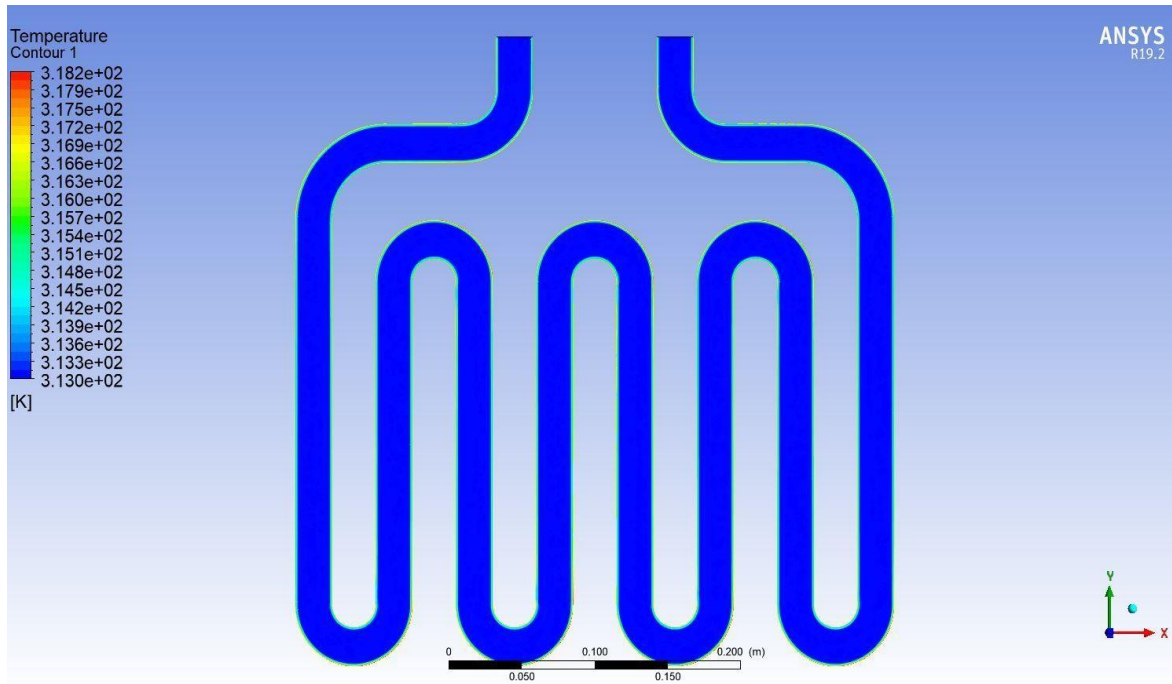


Fig. 2. Temperature contour

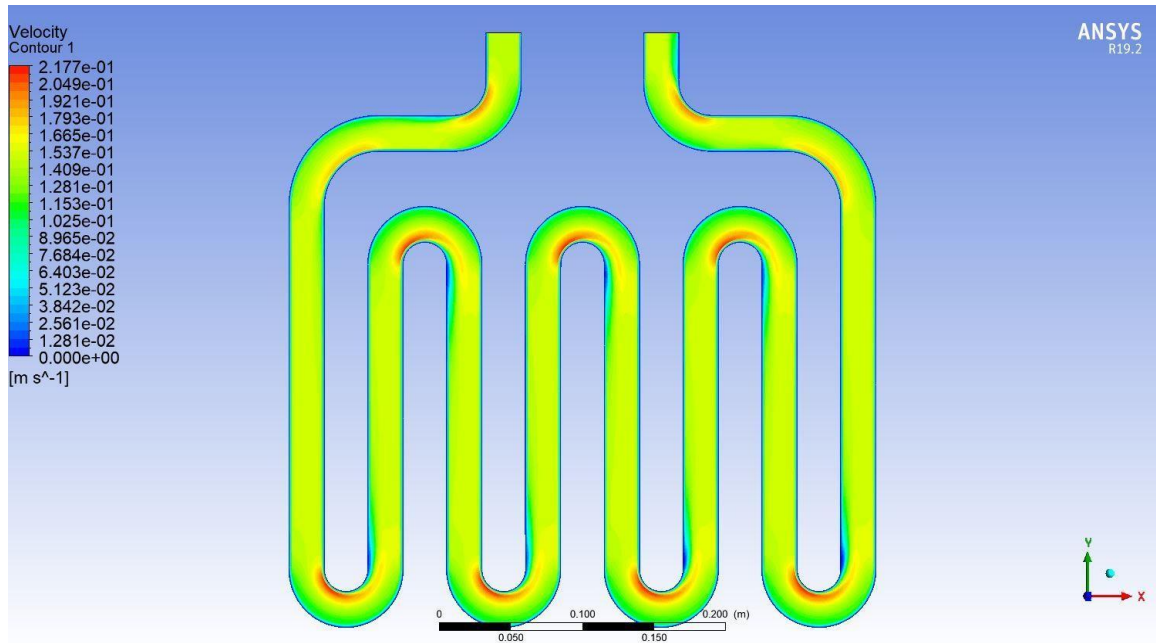


Fig. 3. Velocity contour

Table 4. 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 <sup>2</sup>

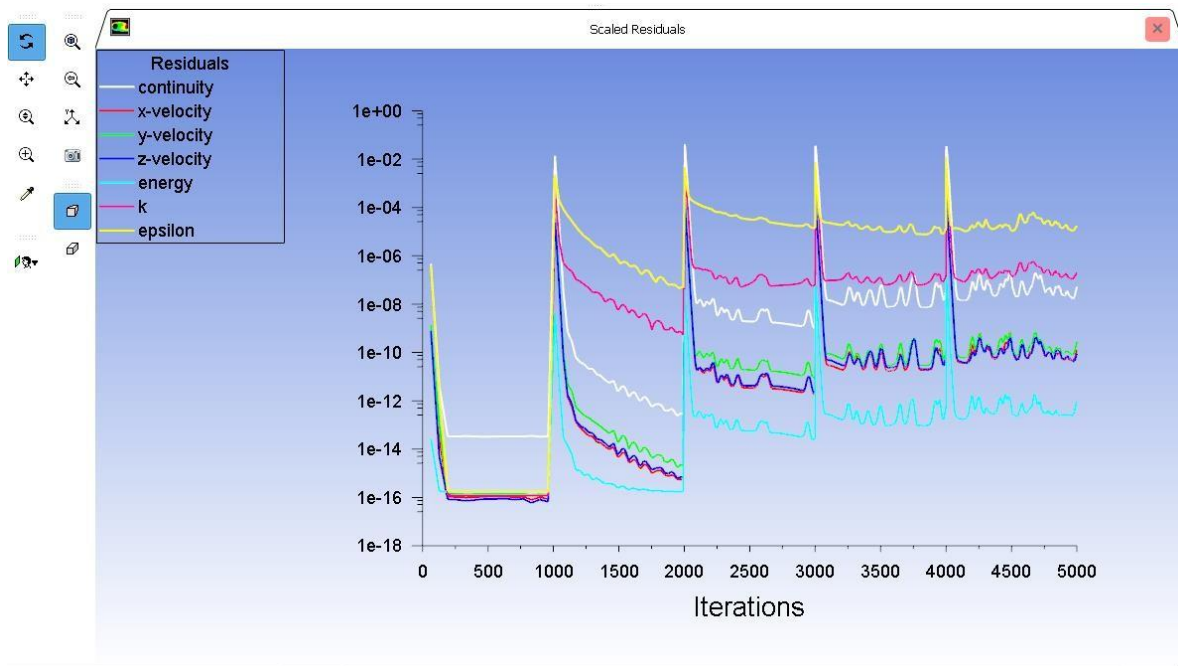


Fig. 4. Iteration residue

### 3. RESULT AND DISCUSSION

The results obtained from calculations for CFD analysis and Thermal analysis 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 Tables 5 and 6.

The comparison of heat flux for the two materials at different tube diameters (Fig. 5) shows that

copper with 7mm tube diameter has more heat flux value than aluminium. This is gratified with the statement of Fourier's Law of Conduction "The rate of heat transfer in conduction is proportional to the thermal conductivity of the material (K.W/m<sup>2</sup>)" given by Joseph Fourier in 1822. And comparison between refrigerant and tube diameter for R32 and R290 refrigerant (Figs. 6, 7, 8, and 9) shows that the R32 has more static pressure, velocity, mass flow rate and total heat transfer than R290.

Table 5. Thermal analysis result table

Material (mm)	Tube diameter	Temperature (°C)	Heat Flux (w/mm <sup>2</sup> )
Aluminium	5	40	7.9856
	6	40	8.8642
	7	40	9.6697
Copper (C12200)	5	40	11.579
	6	40	12.562
	7	40	13.613

Table 6. CFD result table

Fluid	Tube Diameter (m)	Pressure(kPa)	Velocity (m/s)	Mass FlowRate (kg/sec)	Total Heat Transfer (w)
R290	5	1.94e+04	3.86e+00	18.8792	42362.154
	6	2.45e+04	4.14e+00	65.6848	118046.09
	7	2.95e+04	4.80e+00	63.969	1133941.76
R32	5	5.43e+04	4.83e+00	59.5463	111853.87
	6	2.98e+04	4.04e+00	56.7434	106566.06
	7	1.80e+05	2.55e+00	62.9146	86446.46

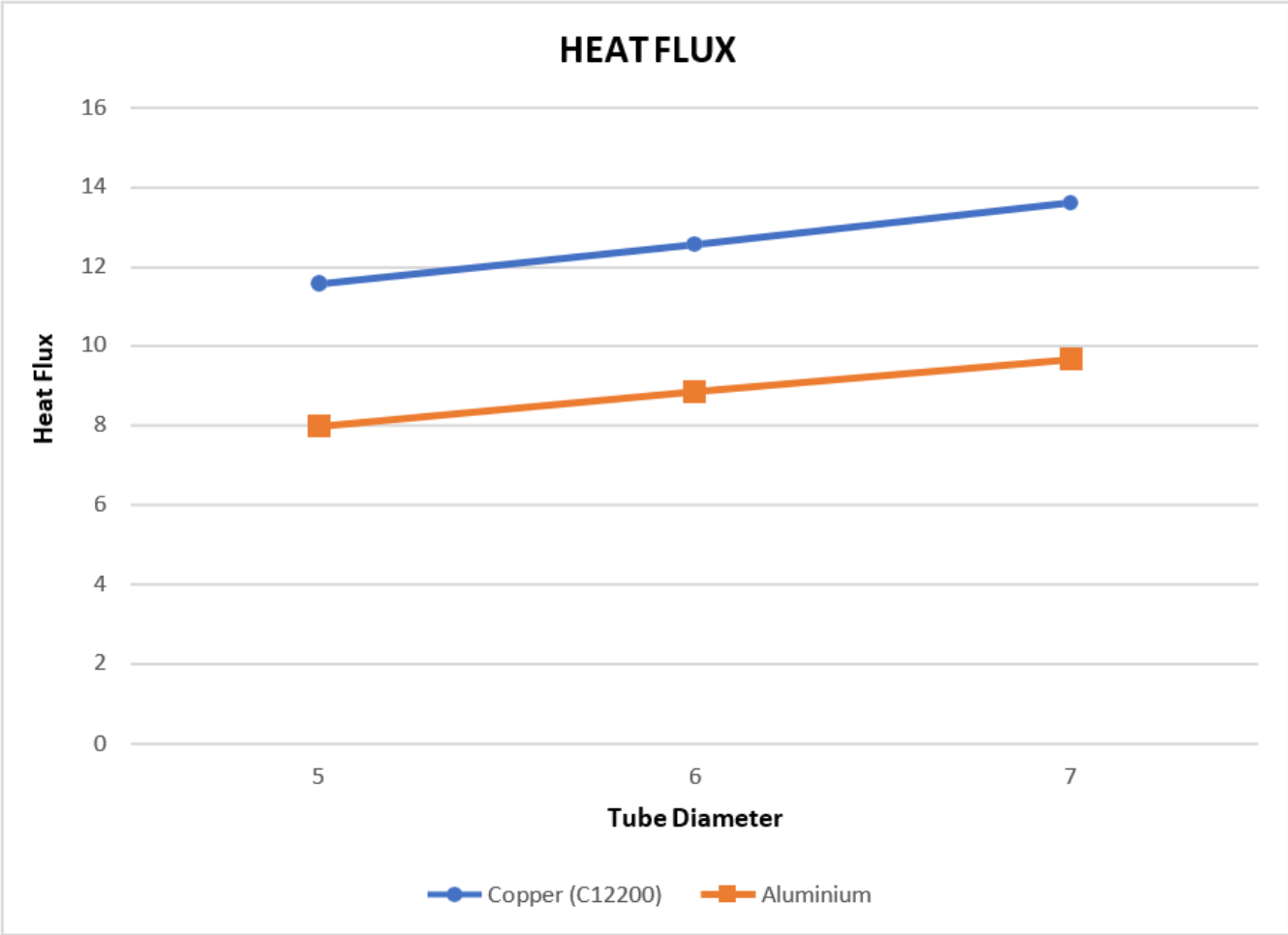


Fig. 5. Heat flux

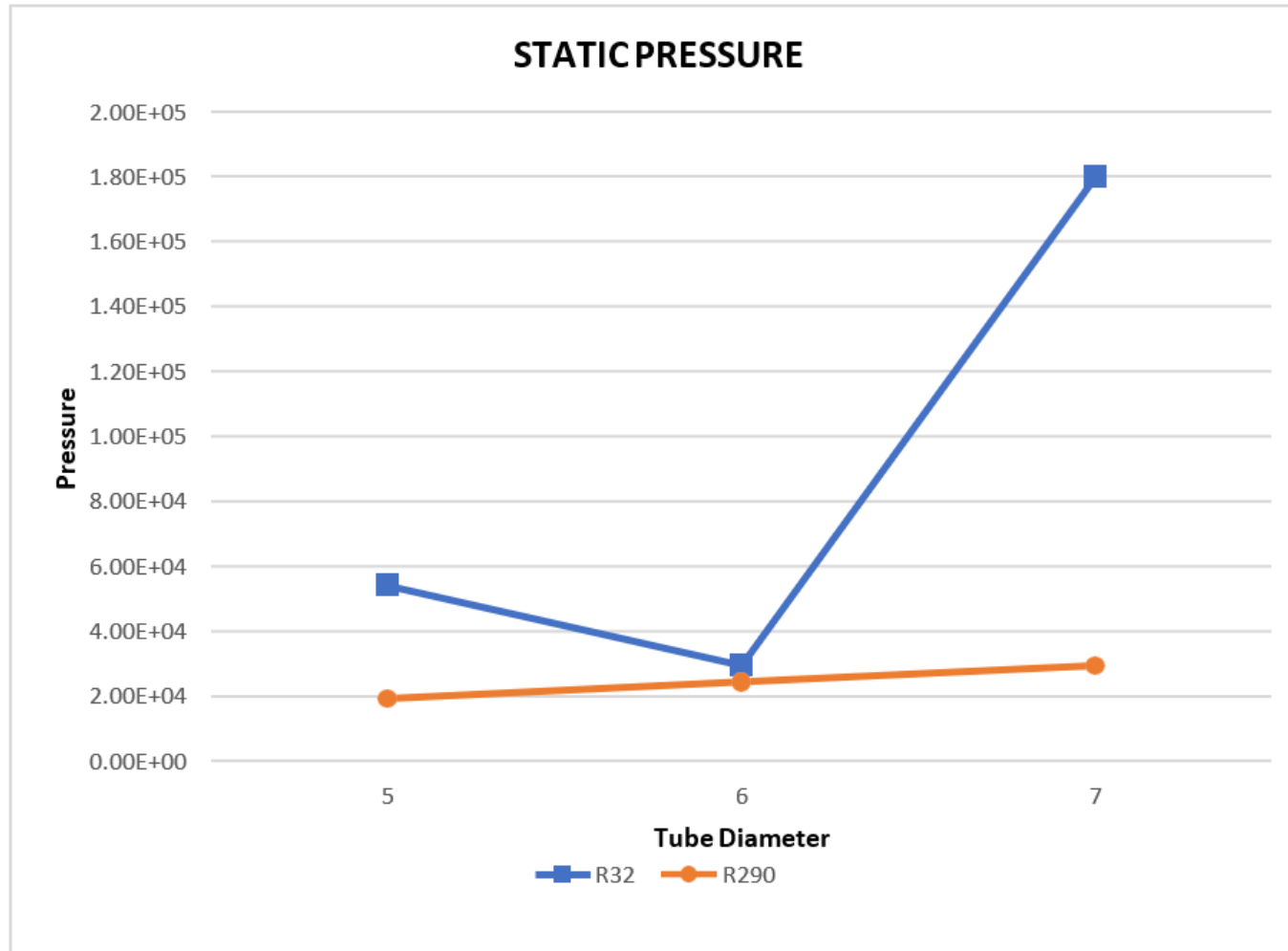


Fig. 6. Static pressure comparison graph



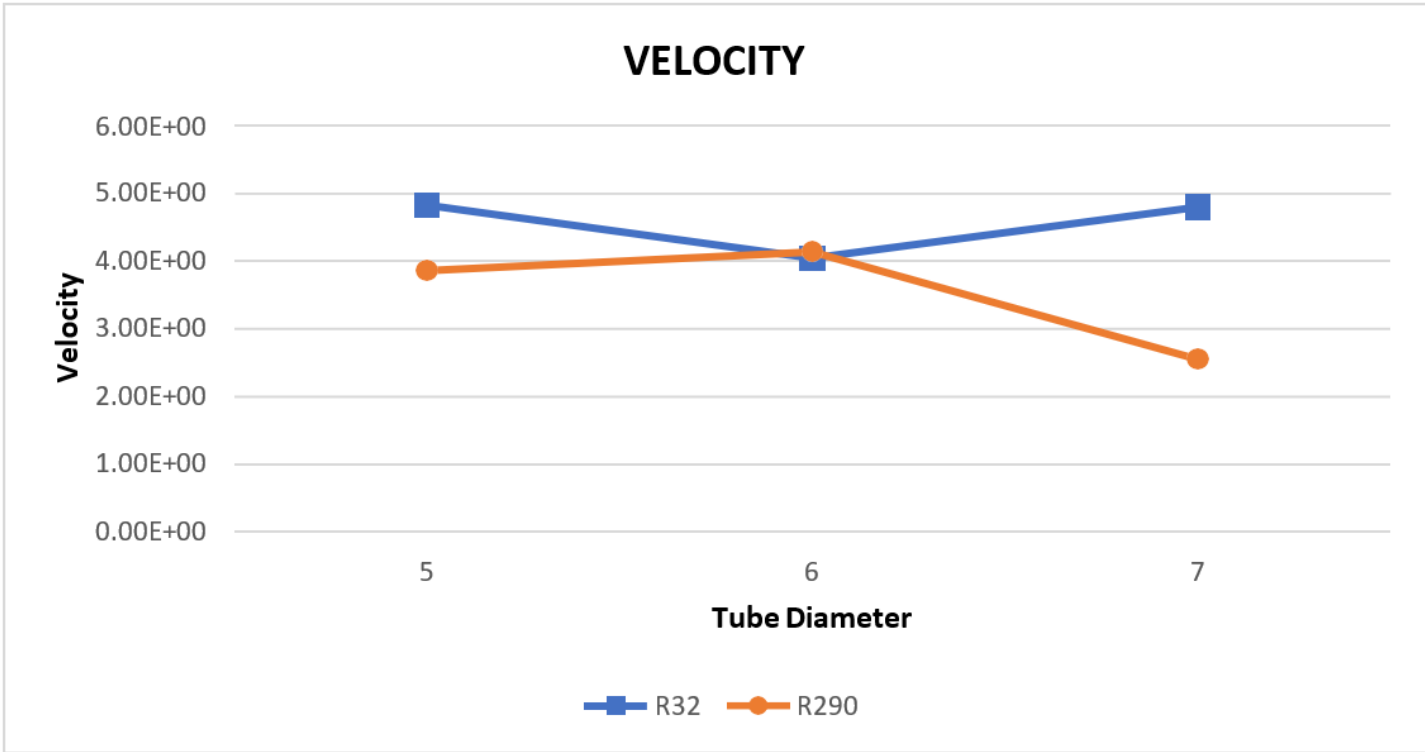


Fig. 7. Velocity comparison graph

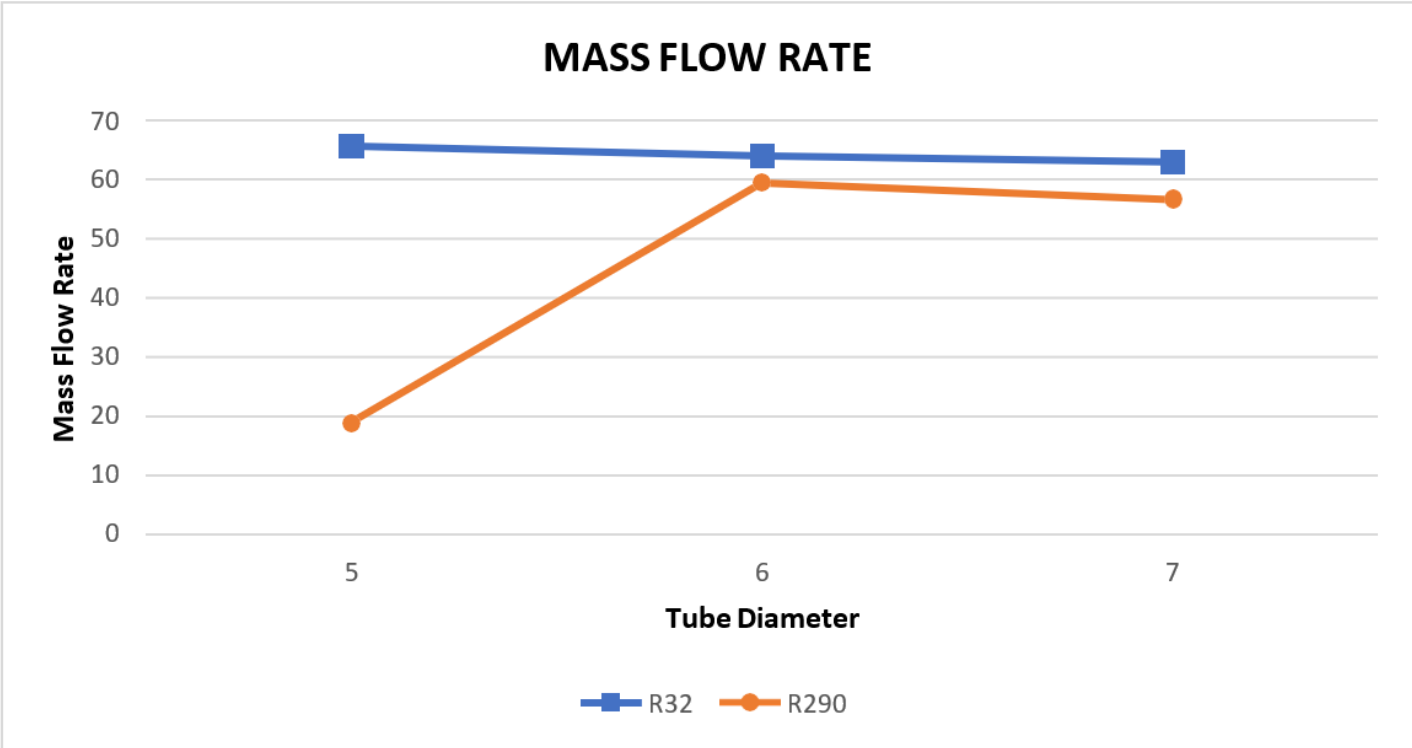


Fig. 8. Mass flow rate comparison graph

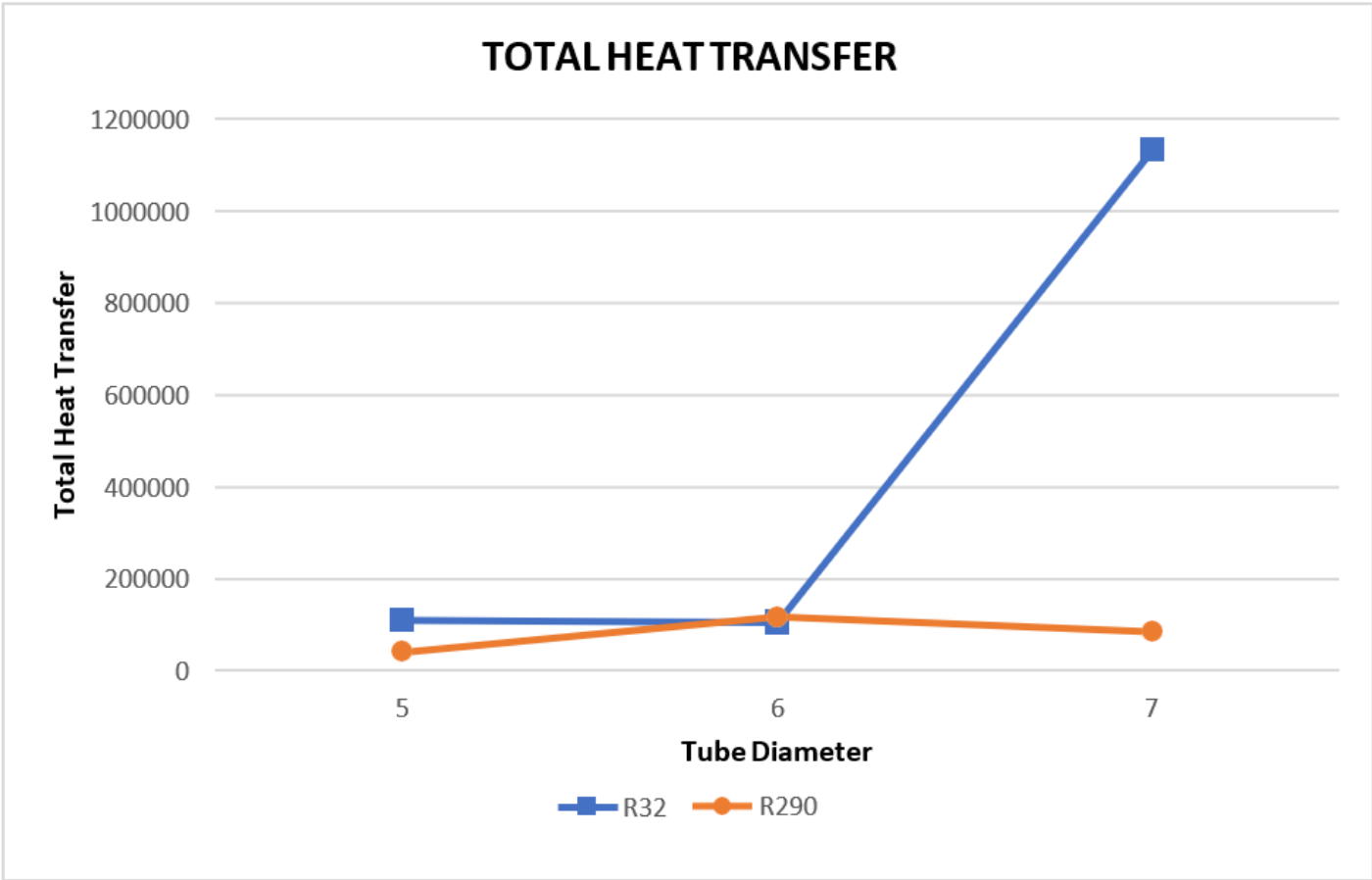


Fig. 9. Heat transfer comparison graph

## 4. CONCLUSION

In this research, an air conditioning condenser was designed and optimized for better material and refrigerant and to improve the heat transfer rate by carrying out simulation analysis. The condenser was modelled using Solid Works software and simulation analysis was performed on the condenser using Analysis System Software in order to optimize the condenser for accurate results. Thermal analysis was carried out on copper (C12200) and aluminum in order to establish better material and CFD analysis was also performed on the tube for two refrigerants R32 and R290 at different tube diameters 5mm, 6mm and 7mm to determine the heat transfer rate.

- (i) From the CFD analysis results, it was observed that the static pressure, velocity magnitude, mass flow rate and heat transfer rate are more when R32 was used.
- (ii) From the thermal analysis results, using copper (C12200) material, thermal flux is more than aluminum
- (iii) By observing the trends of the results obtained, it was concluded that using copper (C12200) and R32 at 7mm tube diameter improves the heat transfer. This is inductive because an increase in diameter significantly expands the heat transfer area.

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Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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