Material andParametricDesign Optimization of Improved Heat Transfer Rate of AC Condenser

ABSTRACT

Air conditioner system is made up of a condenser that removes unwanted heat in an enclosure through therefrigerant and transfers the heat outside. Improving the heat transfer of air conditioning condenser is still adifficult task because of the broader set of materials and various parametric designs involved. Due to this highcost,theexperimentalset-upcostcannot be modified,instead,simulationanalysis wasintroducedintheoptimization process in order to achieve a near-optimal solution. The aim of this research is to improve the heattransfer rate for air conditioning condenser by material and parametric design optimization. The system wasdesigned based on one basic parameter optimization: varying the condenser tube diameter. This variable waschanged in order to improve the heat transfer of the condenser. Simulations using Computational Fluid Dynamic(CFD) analysis and thermal analysis were carried out to have a better understanding and distinct visualization ofthe fluid flow and materials used, and to compare the results. The materials that were used for CFD analysis areR32andR290,andforthermalanalysisarecopper(C12200)andaluminum.Theanalysiswasdone usingAnalysisSystem (ANSYS) software. Different parameters were calculated from the results that were obtained and graphswereplottedbetweenvariousparameterssuchasheatflux,staticpressure,velocity,massflowrateandtotalheattransfer. From the CFD analysis, the result shows that R32 has more static pressure, velocity, mass flow rate andtotal heat transfer than R290 at a condenser tube diameter of 7mm. In thermal analysis, the heat flux is more forcopper(C12200)material at acondensertube diameterof7mmthanaluminum

Keywords:Condenser;Heatflux;Computationalfluiddynamics;Thermalanalysis;Optimization

1. INTRODUCTION

Air conditioner is an appliance, system, or mechanism designed to dehumidified and extract heat from an area. Itprovide comfort during either hot or cold weather(Ansari*et al*., 2020; Nirmala *et al*., 2015). And in systems involving heat transfer, a condenser condense a substancefrom its gaseous state to its liquid state, by cooling(Hindeling*et al*., 2012) because heat generation can cause overheating problems and thermal stresses that may lead to systemfailure. The removal of heat from these devices has been a critical challenge to thermal designengineers and researchers. Heat transfer in heat generating devices occurs by conjugate heatconduction and forced convection. Heat conduction is the transfer of thermal energy from moreenergetic particles to less energetic counterparts. This is largely influenced by the thermalconductivity ofthematerial.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 thedesignof condenser. And due to less time consumption, dependable output, and accurate results, simulation analysis wasintroducedintheoptimizationprocessinordertoachievenearoptimalsolution.Theadvanceintechnologyimprovementandtheintroductionofsimulationhasbroughtaboutgreatimprovement. Therefore, the solution is to ensure that there must be optimal design variables atwhichthe system will havemaximum performance.

Thermal flux is more in aluminum1100 fin material with refrigerant R404 than otheraluminum alloys materials (Babu and Srikanth, 2016; Nirmal *et al.,* 2015; Mallikarjun and Anandkumar 2013). 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 (Krishna and Kumar, 2018; Shafiudeen*et al.,* 2018; Chouhan *et al*., 2017; Prasad, 2017; Bhemesh and Venkastewarlu, 2015).Sriram and Sekhar (2016) 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 (2013) 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 (2019) 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 (2017) 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 aluminumhave 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 andparametricdesign optimization.

2. Methodology

In the research work, ANSYS 2019 R2 simulation software was used for the simulation ofCFD and thermal analysis. It was also used for obtaining the results generated. ANSYS isgeneral-purpose Finite Element Analysis (FEA) software package. Finite Element Analysis isanumericalmethodofdeconstructingacomplexsystemintoverysmallpiecescalledelements.The software is embedded with equations that govern the behaviour of these elements andsolvesthem all.

2.1 CFDAnalysisProcedure

Computational fluid dynamics (CFD) study of the system begins with the construction ofdesired geometry and mesh for modeling the dominion. Generally, geometry is simplified forthe CFD studies. Meshing is the discretization of the domain into small volumes where theequations are solved by the help of iterative methods. Modeling begins with the describing oftheboundaryandinitialconditionsforthedominionandleadstomodelingoftheentiresystem.Finally,it is followed by theanalysis of theresults, discussionsand conclusions.

2.2SolidModelingandFormulationofParameterofa Condenser

The solid modelling of the condenser was designed on SOLIDWORKS. The only geometricparameter that was varied in the condenser is the tube diameter. The number of rows, tubespacing and number of tubes were maintained at the values utilized for the configuration. Theformulationparameter used in designing the model can befound inTable 1.

2.3 MeshingoftheCondenser

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 alsodefinedto easily identifythe differentregion of inlet and outlet.

2.4 ProblemSetupandBoundaryConditionoftheCondenser

Themeshwasautomaticallycheckedandthequalitywasobtainedtoknowifitiscompatible.The type analysis was replaced with pressure-based type. The velocity was replaced withabsolute and the time was set to steady state. Then next comes the turbulence model section.Aswehavegonethroughdifferentpaperswhichsuggestedthek-epsilonmodeltobethemosteffective method for a heat exchanger evaluation. This model was selected based on its greateraccuracy in heat exchanger cases from model settings, turn on the energy equation. It alsoenablestheviscoussettingstok-epsilonrealizablesettingsandenhancewallfunctions.Incellzone, fluids selected were R-32 and R290; copper(C12200) was selected as material forsimulation. The properties of fluid flowing in the condenser are given below Table (2 and 3).Boundary condition was chosen for inlet and outlet. Boundary conditions are used accordingtothe needof themodel.Theinlet temperatures andvelocities areselected tothe setup.

2.5 SolutionoftheProblem

The CFD provides the solution of different fluid flow and heat flow problems based on thegivenboundaryconditionandsomeassumption.Secondorderupwindschemewasselectedinspatial discretization section for momentum, pressure, turbulent kinetic energy, energy andturbulent 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 1respectively. Solution initialization was hybrid method and solution was initialized from inletwith300k temperature.

2.6 ThermalAnalysisProcedure

Thermal analyses are used to determine the temperature distribution, thermal gradient, heatflow and other thermal quantities in a structure (Figure 1). The procedure for thermal analysis is dividedintothreedistinctive steps;

- Buildthe model.
- Applyingboundary condition andobtainthe solution.
- Reviewtheresults.

Table1.ParameterFormulation

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

	Aluminium	Copper(C12200)

Thermalconductivity(W/mk)	235	385
Specificheatcapacity(J/kgK)	896	385
Density(kg/m^3)	2700	8940

Table2.PropertiesofMaterial

Table3.PropertiesofRefrigerant

	R32	R290
Thermalconductivity(W/mk)	0.076	0.074
Specificheatcapacity(J/kgK)	988.1	960
Density(kg/m^3)	1305.8	1295

Fig.1. Model oftheCondenser

2.7 Meshing

Fromthestart,arelativelycoarsermeshwasgenerated.Thismeshconsistofmixedcells(TetraandHe xahedralcells)havingboth triangularandquadrilateralfaces atthe boundaries.

2.8 ApplyingLoads

The convection film coefficient and bulk temperature was specified at the surface of thecondenser.Sincethecoefficientdependsupontemperature,thenatableoftemperaturesalongwit hthecorrespondingvaluesateachtemperaturewasalsospecified.ANSYSthencalculatedthe appropriate heat transfer across the condenser surface. The heat transfer andflowcharacteristicsofacondensercanbeobservedfromthecontourdiagramsoftemperature,hea tflux, pressure, velocity, mass flow rate, and their iteration residues (Figure 2, 3, 4). The applying loads used can befoundin theTable 4.

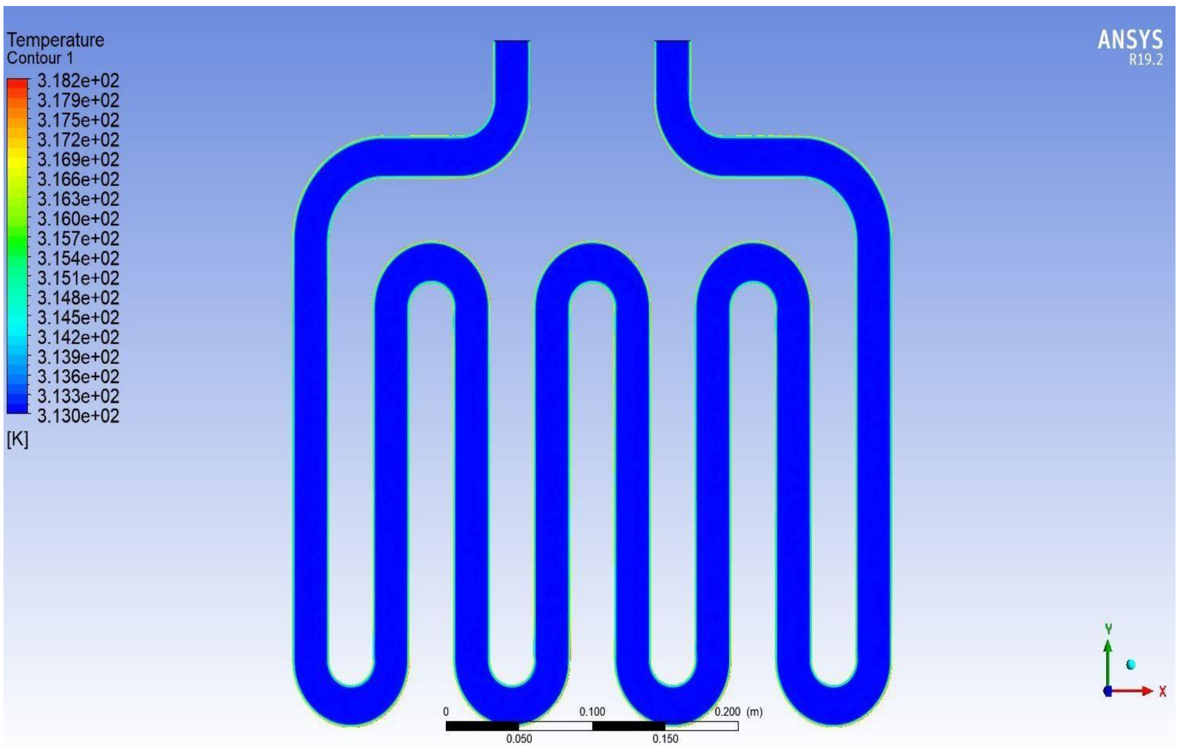

Figure2.Temperaturecontour

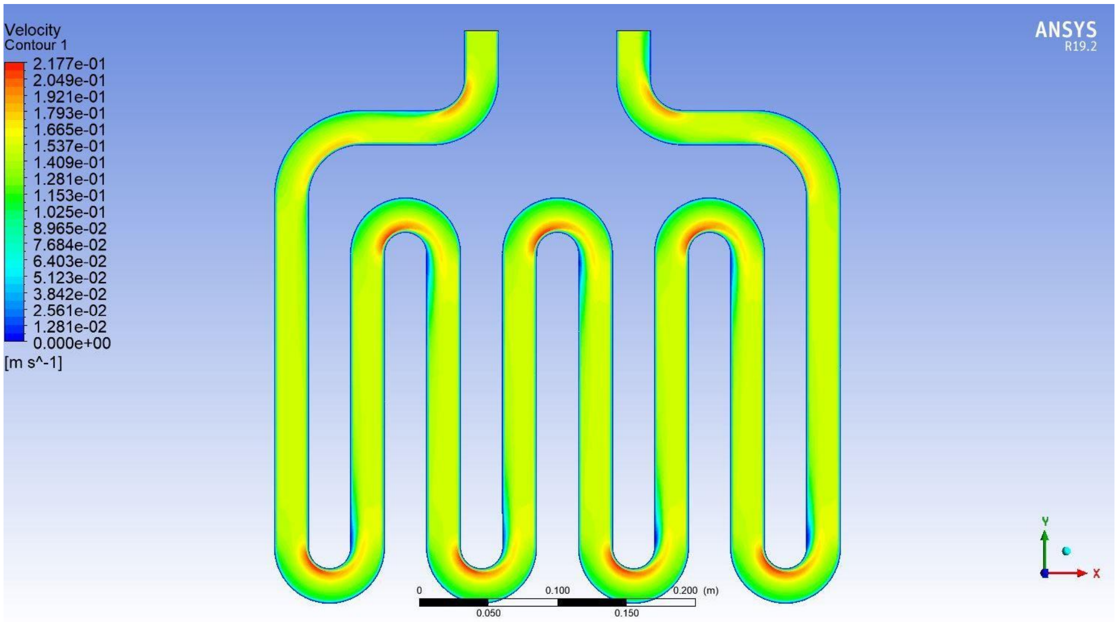

Figure3:Velocity contour

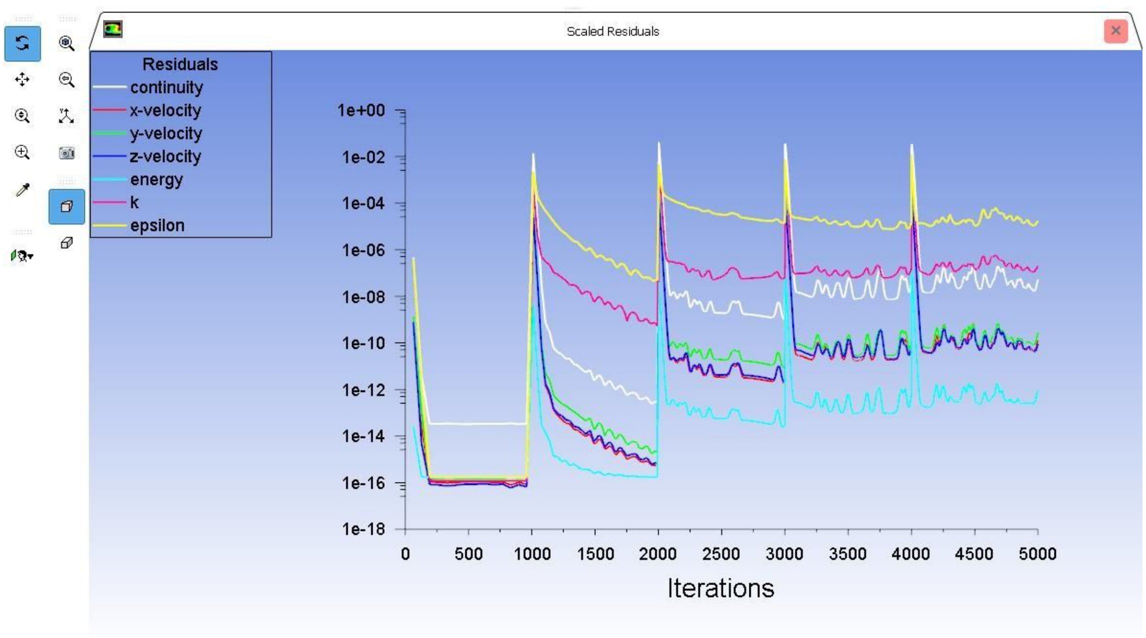

Figure4:iterationresidue

Table4.Applying loads

S/N	Parameter	Value
1	Typeofload	Thermal

2	Areatemperature	313K
3	Bulktemperature	303K
4	Filmcoefficientvalue	0.0024w/m^2

3. RESULTANDDISCUSSION

The results obtained from calculations for CFD analysis and Thermal analysis using softwareANSYS to show the performance of the air conditioner by comparing the refrigerant and thecondenser material at various tube diameter are shown in Table 5 and 6.

Table5:ThermalAnalysis ResultTable

Material	TubeDiameter (mm)	Temperature (^{o}C)	HeatFlux (w/mm^2)
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

Table6:CFDResult Table

Fluid	TubeDiameter (m)	Pressure(kPa)	Velocity (m/s)	MassFlowRate (kg/sec)	TotalHeatTransfer (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

The comparison of heat flux for the two materials at different tubediameters (Fig. 5) shows that copper with 7mm tube diameter has more heat flux value thanaluminium.This is gratified with the statement of Fourier's Law of Conduction "The rate ofheattransferinconductionisproportionaltothethermalconductivityofthematerial(K.W/m^2)"given by Joseph Fourier in 1822. And comparison between refrigerant and tube diameter for R32 and R290 refrigerant (Fig. 6, 7, 8, and 9) shows that the R32 has more static pressure,velocity,mass flow rateand total heat transfer than R290.

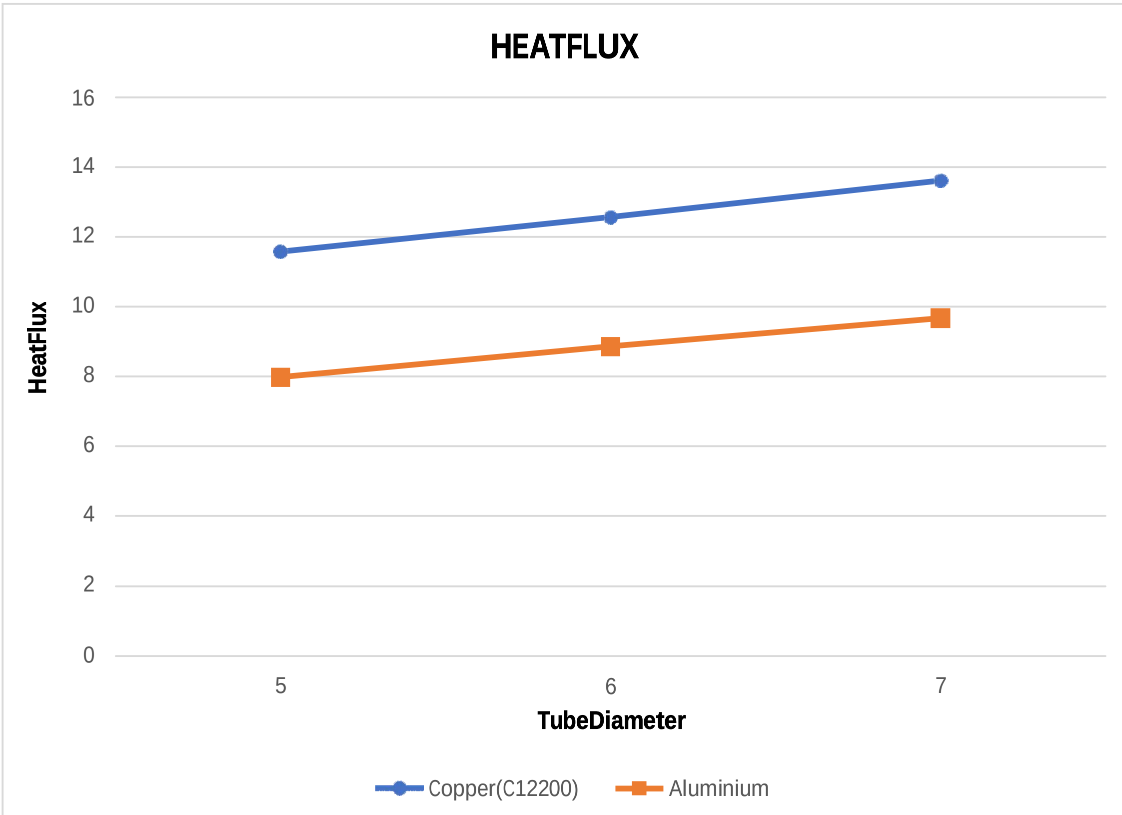

Fig. 5.Heatflux

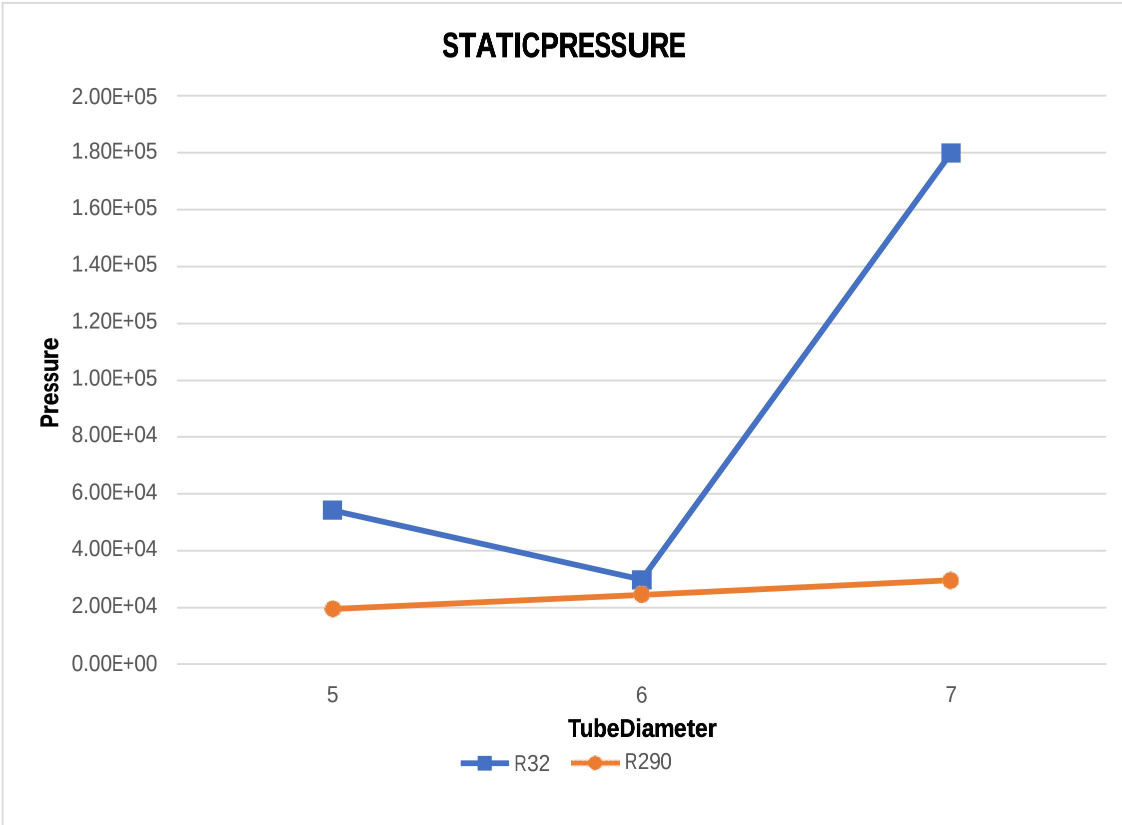

Figure6;Staticpressurecomparison graph

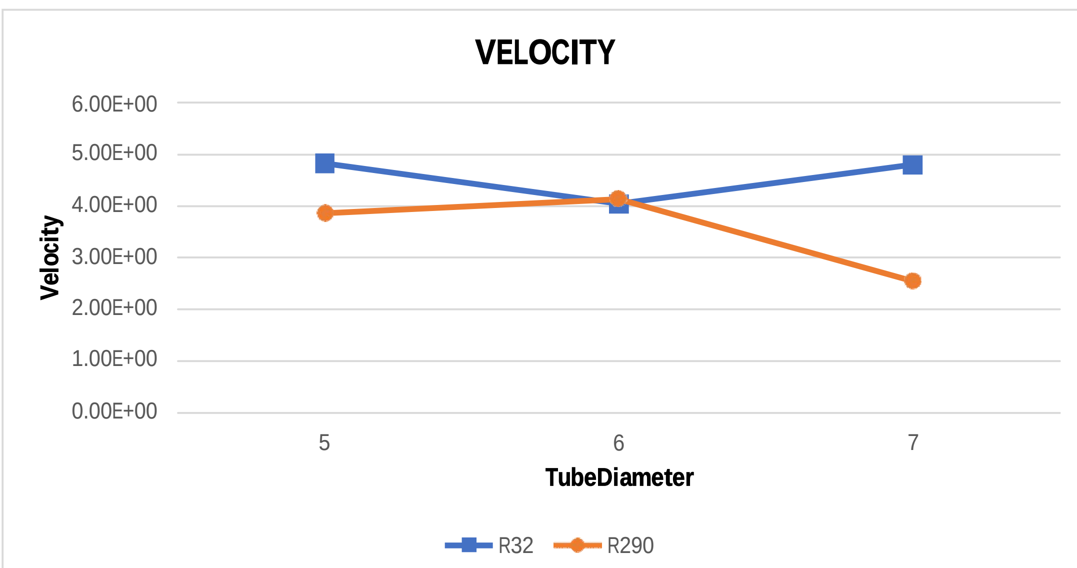

Figure7;Velocitycomparison graph

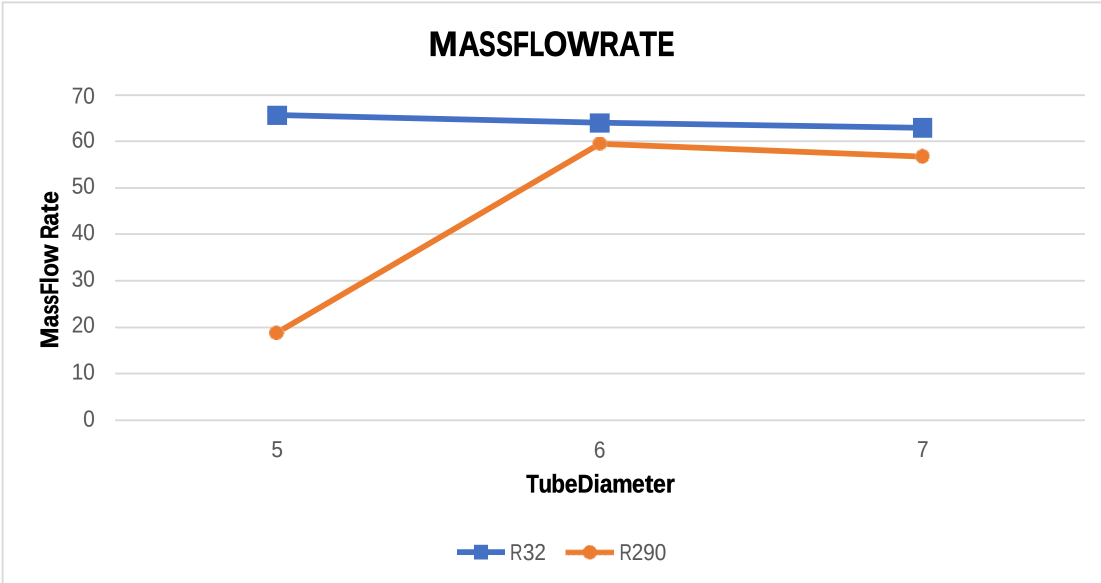

Figure8;Massflowratecomparison graph

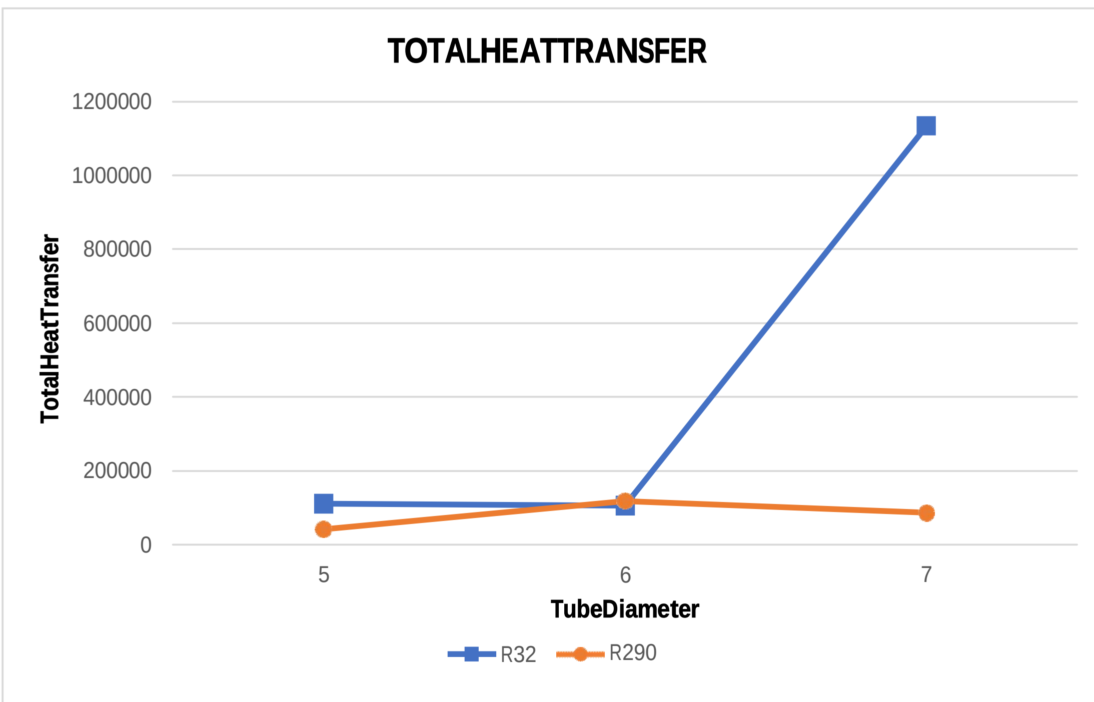

Figure9;Heattransfercomparison graph

4. CONCLUSION

In this research, an air conditioning condenser was designed and optimized for better materialand refrigerant and to improve the heat transfer rate by carrying out simulation analysis. Thecondenser was modelled using Solid Works software and simulation analysis was performedon the condenser using Analysis System Software in order to optimize the condenser foraccurateresults.Thermalanalysiswascarriedoutoncopper(C12200)andaluminuminorderestablishbettermaterialandCFDanalysiswasalsoperformedonthetubefortworefrigerantsR32 and R290 at different tube diameters 5mm, 6mm and 7mm to determine the heat transferrate.

(i) From the CFD analysis results, it was observed that the static pressure, velocity magnitude,massflow rateand heat transfer ratearemorewhen R32 was used.

(ii) From the thermal analysis results, using copper (C12200) material, thermal flux is more thanaluminum

(iii) By observing the trends of the results obtained, it was concluded that using copper (C12200)andR32at7mmtubediameterimprovestheheattransfer.Thisisinductivebecauseanincreaseindiameter significantlyexpands theheattransferarea.

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