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 diameterof7mmthanaluminium

Keywords:Condenser;Heattransfer;Computationalfluiddynamics;Thermalanalysis;Optimization

1. INTRODUCTION

Air conditioner is a home appliance, system, or mechanism designed to dehumidified and extract heat from an area. Its purpose in a building or an automobile, is to provide comfort during either hot or cold weather(Ansari*et al*., 2020). The purpose of air conditioning is to supply adequate volume of clean air containing a particular measure of water vapor and at a temperature fit for keeping up foreordained air conditions within a selected enclosure (Nirmala *et al*., 2015).

Thepurposeofairconditioningistosupplyadequatevolumeofcleanaircontainingaparticularmeasureof watervaporandatatemperaturefitforkeepingupforeordainedairconditionswithina selected enclosure. Its purpose in a building or an automobile, is to provide comfort duringeitherhot orcold weather.In systems involving heat transfer, a condenser is a device or unit used to condense a substancefrom its gaseous state to its liquid state, by cooling it. In so doing, the latent heat is given up bythesubstanceandwill transfer to thecondensercoolant. Condensers are used in air conditioning, industrial chemical processes such as distillation, steam power plants and other heat exchanger systems. Use of cooling water or surrounding air as the coolant is common in many condensers (Hindeling*et al*., 2012)

Heat generation can cause overheating problems and thermal stresses. It may leads 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 andchemical devices and plants, the enhancement of heat transfer is one of the key factors in thedesignof condenser.

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.

Mallikarjun and Anandkumar (2013) enhance and analyzed heat transfer by convection in condensers. They used copper for tube, aluminium1100, aluminium6063 and magnesium alloy for fins, and HCFC and 404R refrigerants. They observed that thermal flux is more in aluminium1100 fin material and R404 than other two materials. They also observed more heat transfer rate in theoretical thermal flux calculation in aluminium1100 fin and refrigerant R404 than others.

Babu and Srikanth (2016) designed an ac condenser and optimized for better materials, refrigerants and thickness to improve the heat transfer rate. The materials considered for tube is copper and for fins are Aluminium alloys 1100, 6063 and Magnesium alloy for different refrigerants HCFC and 404R. In their thermal analysis result, it has been found that, thermal flux and thermal gradientare more when Aluminium alloy 1100 is used for fin and refrigerant used is 404R.. It is also found that velocity of air also affects the cooling rate significantly. Increasing inlet velocity from 2.5m/s to 5m/s, yields no advantage but by increasing to 7.5m/s yields better results.

In the research work by Krishna and Kumar (2018), 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.

Prasad (2017) carried out a research on improving the heat transfer rate of AC condenser. The objective of the project was to make a 3D model of the condenser and study the CFD and thermal behavior of the condenser by performing the finite element analysis. CFD analysis was performed on the existing model of the condenser for velocity inlet to find out the mass flow, heat transfer rate and pressure drop. Also, thermal analysis was performed on the condenser assembly for thermal load. The assessment was carried out on an air cooled tube condenser where the materials considered are Al6061 and Al7075 and the refrigerants varied are R12, R134 and R407C. From the CFD analysis result, he found that heat transfer coefficient is higher when R134 is used and heat transfer rate is more when R22 is used than other fluids. For thermal analysis, he concluded that heat flux is higher when R22 and copper material are used.

Chouhan, Poshal, and Kumar (2017) 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 flow conditions such as inlet pressure and degree of sub cooling were the major parameters investigated. From their CFD result, it was observed that pressure drop value is increased at tube diameter 25mm by the fluid R22. From the thermal analysis, it was discovered that heat is more for copper when compare with aluminium material. They concluded thatfluid R22 and copper material are better.

Nirmal *et al.* (2015) optimized AC condenser using R404 to improve the heat transfer rate. In their research work, AC condenser was outlined and upgraded for better material and refrigerant to enhance the heat transfer rate. Thermal analysis was done on the condenser to enhance the condenser for better material. Examination was done utilizing blade materials (Al 1100 and Al6063), also by changing the cooling fluid HCFC to R404. From the result, they observed that utilizing fin material Al1100, heat flux is more. It was concluded from their result that by using Al1100, heat transfer rate increases with refrigerant R404.

Shafiudeen*et al.* (2018) designed and studied the flow analysis of condenser fins by using CFD. Condenser fin was designed with different materials and proper dimensions. The material used for fin was made with different materials (aluminium 1100 and aluminium 1050) and tube was copper. The refrigerants used are R12, R22 and R134a which are used for analysis on condenser using ANSYS. From their analysis result, it was discovered the heat transfer rate is higher when refrigerant R22 was used (heat flux is more). When the result was compared for fin material between aluminium 1100 and aluminium 1050, they discovered that aluminium 1050 is quite better.

Sriram and Sekhar (2016) modelled and performed a thermal analysis of an air cooled condenser for a home 1.5ton air conditioner. Thermal analysis was carried on the condenser by taking tube material as copper and varying the plate material. Analyisis was also carried out by varying the refrigerants (HC and HFC). In the analysis, they analyzed thermal properties like nodal temperature, thermal gradient and thermal flux. In their result, it was discovered that using plate material Al204 has higher thermal conductivities. It was also concluded that when comparing HC and HFC, using HFC is quite advantageous because its thermal conductivity is higher.

In the research work by Bhemesh and Venkastewarlu (2015), they designed, developed and utilized the high efficient heat transfer rate of an AC condenser. An optimization technique that can be useful in assessing the best configuration of a finned tube condenser was presented and heat transfer by convection in air cooled condenser was studied. Heat transfer carried out on the condenser to evaluate the material and refrigerants. Materials used for tubes are copper and aluminium 1100 and for fins are Al1050 and Al1100. The refrigerants varied are R13, R22 and R134. From the analysis result, it was observed that hear transfer rate is more when R22 is used. They also observed that using copper and Al1050 are better for both tube and fin material respectively.

Srividhya and Venkateswara (2013) designed an air cooled condensers. The material used for tube is copper and the materials used for fins are copper Al99 and Magnesium. Thermal analysis was done on COSMOS works. Varying working fluid used are HC and HCFC. Optimization was performed by changing the fin thickness. It was observed that using Al99 for fin material produces better result i.e. heat transfer rate is more. Also, by observing optimization result, it was concluded that using condenser with fin thickness of 1mm and fin material Aluminium gives better result.

Goswama and Babu (2019) carried out a thermal and CFD analysis on an ac condenser by varying the refrigerant. The assessment was carried out on an air cooled tube condenser of a vapour compression cycle for air conditioning system. CFD analysis was done to determine temperature distribution and heat transfer rate by varying the refrigerants and heat transfer analysis was done on condenser to evaluate better materials. From the result, they observed that heat transfer coefficient is more when R134A is used and from the thermal analysis, they observe that hear flux is more where R134a and copper material are used.

Ramesh (2017) worked on the heat transfer analysis of a condenser. Material used for coil is copper and aluminium 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. The fluid considered are HC and HCFC. The thermal analysis result shows that thermal flux is more when using aluminium for fin. From the optimization result, he observed that the optimum thickness value for decreased value is 1mm. He concluded that using condenser with fin thickness of 1mm and aluminium 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. 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 aluminium or copper. The aluminium 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 aluminiumwas 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.Final ly,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	Condenserconfiguration	Value
1	Condenserlength	100mm
2	Numberofturns	4mm
3	Tubethickness	1mm

Table2.PropertiesofMaterial

	Aluminium	Copper(C12200)
Thermalconductivity(W/mk)	235	385
Specificheatcapacity(J/kgK)	896	385
Density(kg/m^3)	2700	8940

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(TetraandHexahedralcells)havingboth triangularandquadrilateralfaces atthe boundaries.

2.8 ApplyingLoads

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

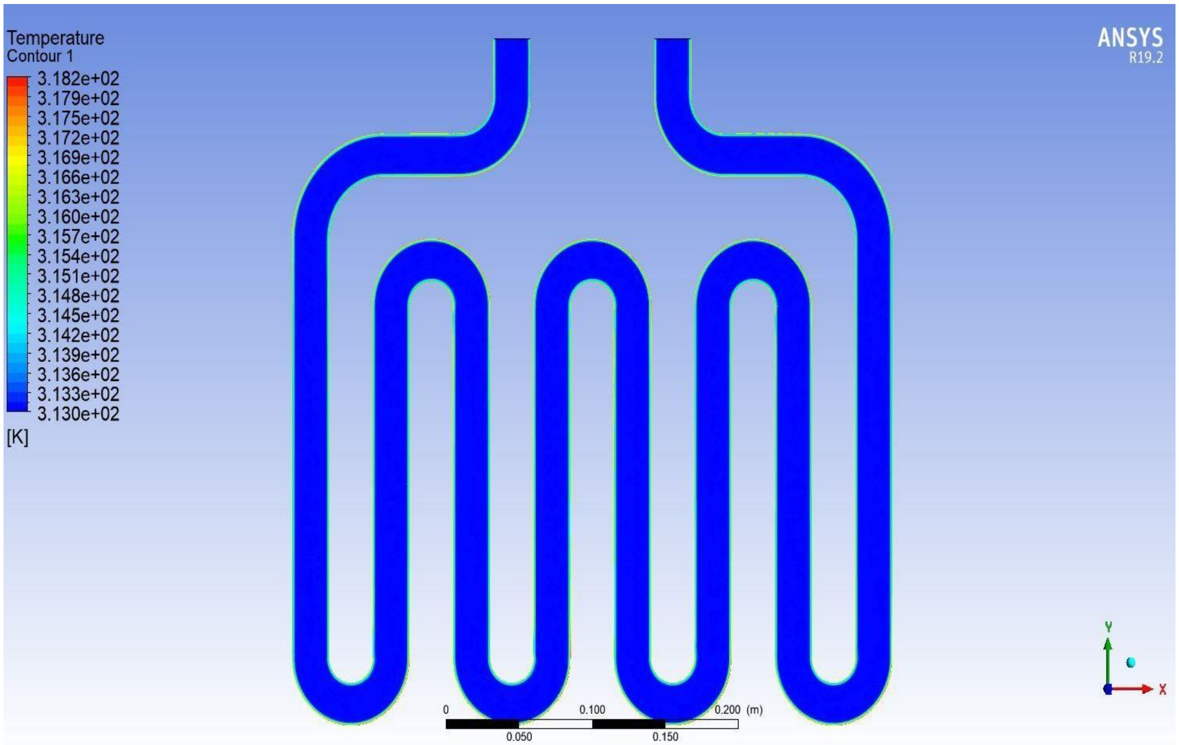

Figure2.Temperaturecontour

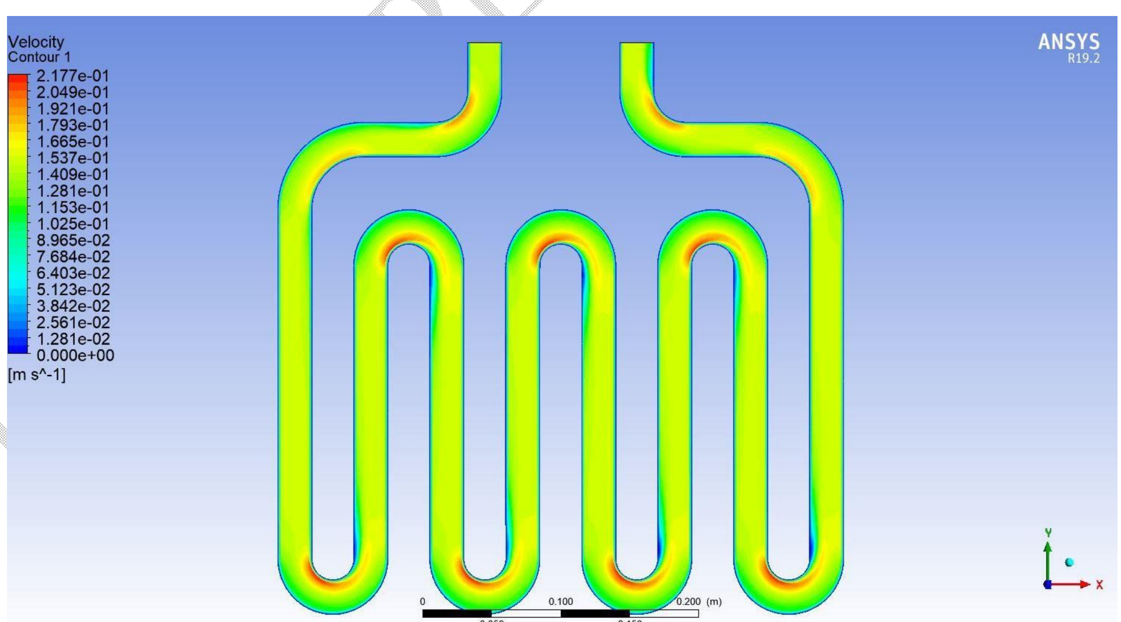

Figure3:Velocity contour

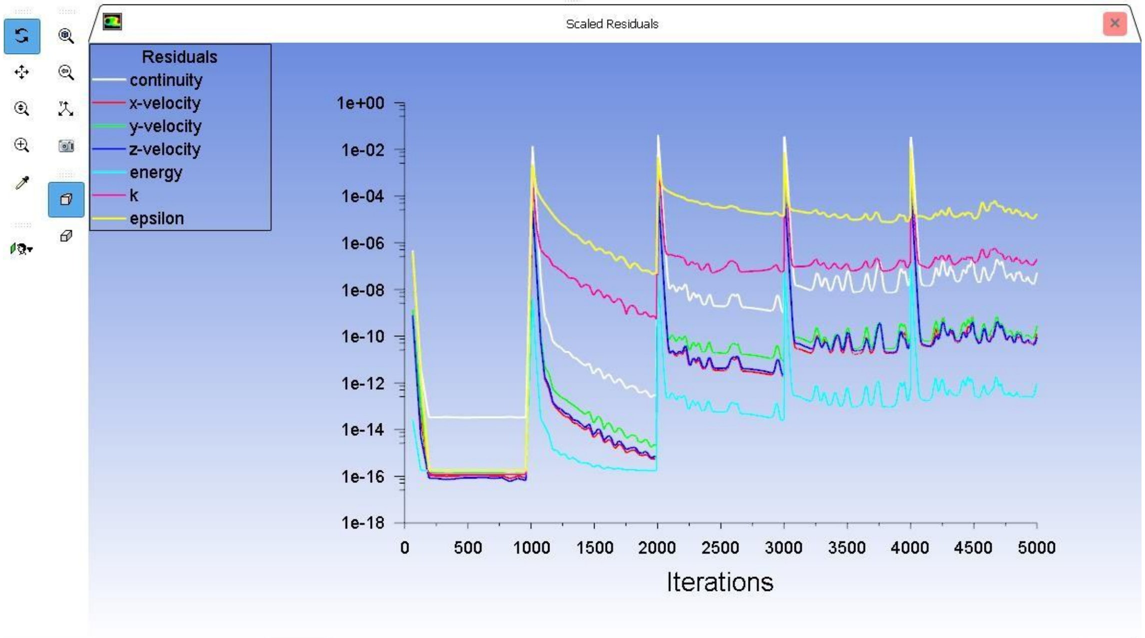

Figure4:iterationresidue

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 (^oC)	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	TubeDia meter (m)	Pressure (kPa)	Velocity (m/s)	MassFlow Rate (kg/sec)	TotalHeat 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

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.

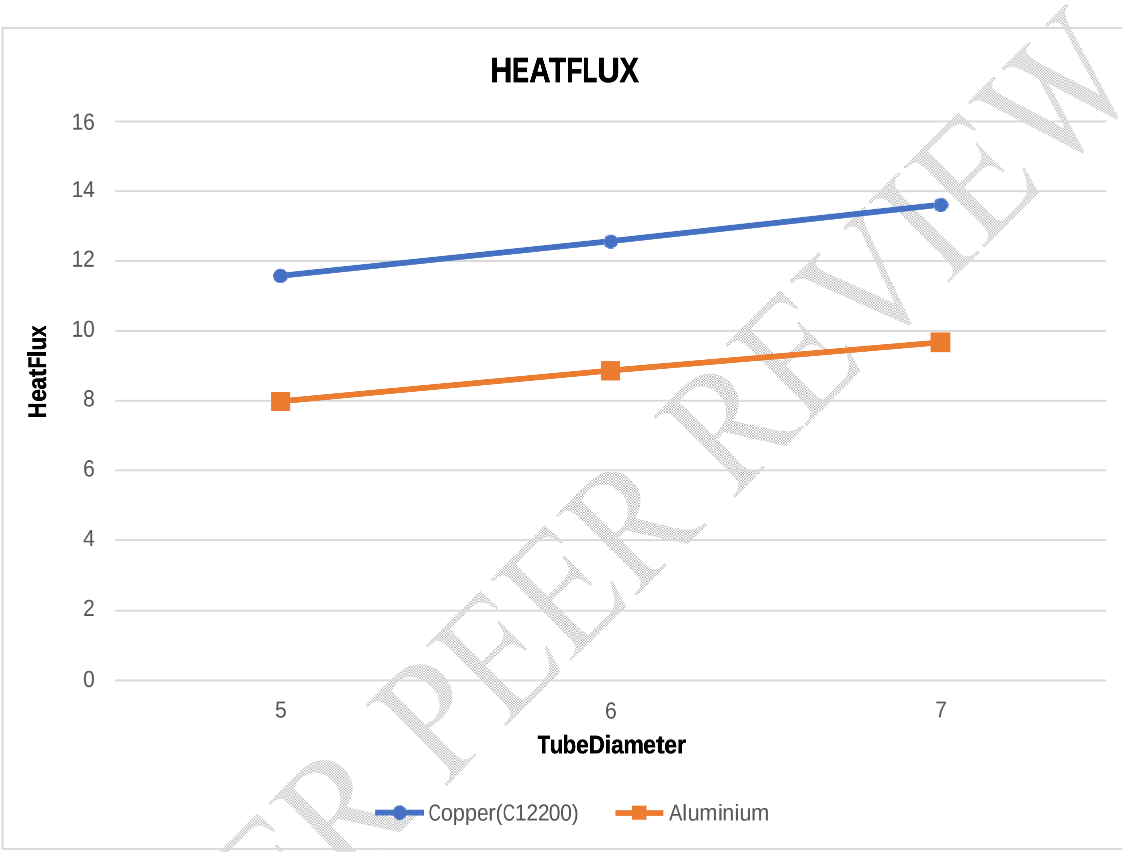

Fig. 5.Heatflux

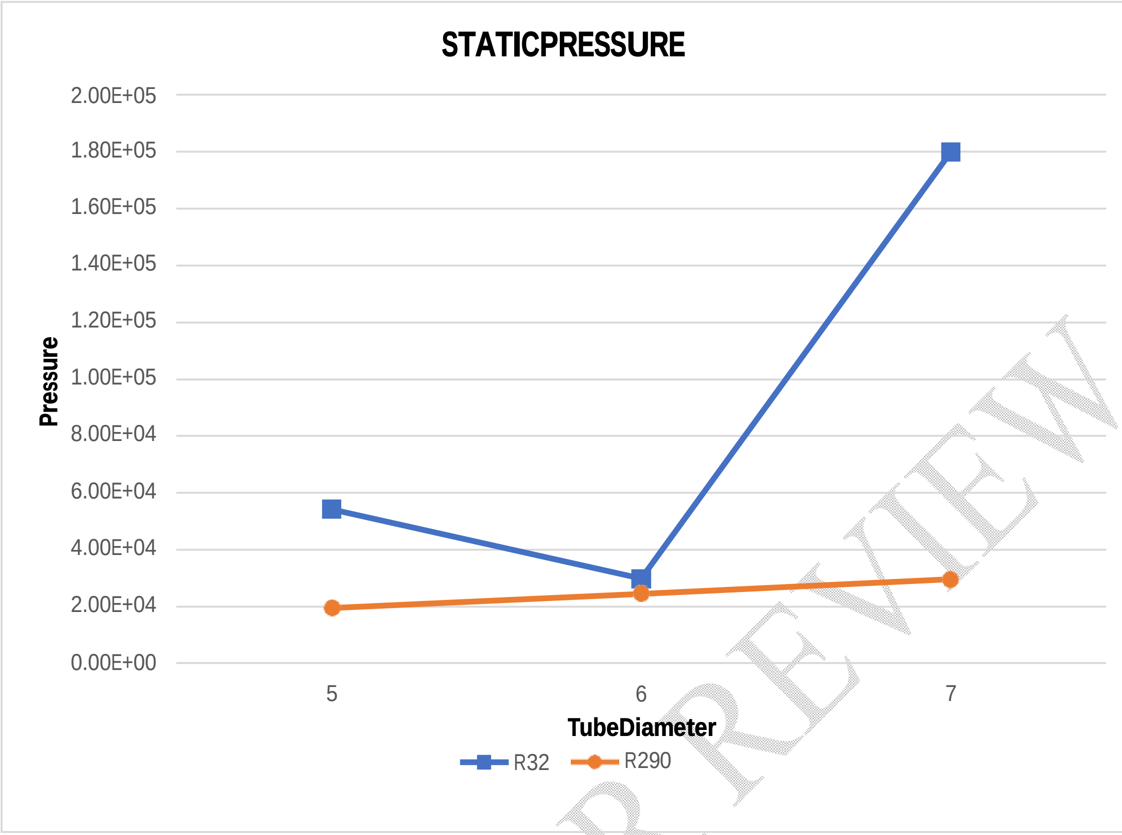

Figure6;Staticpressurecomparison graph

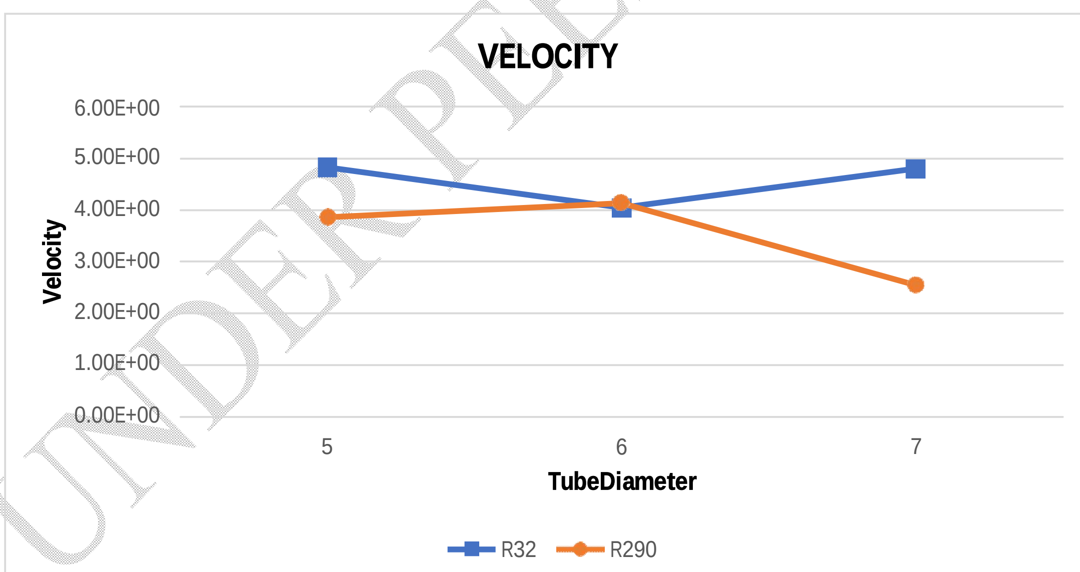

Figure7;Velocitycomparison graph

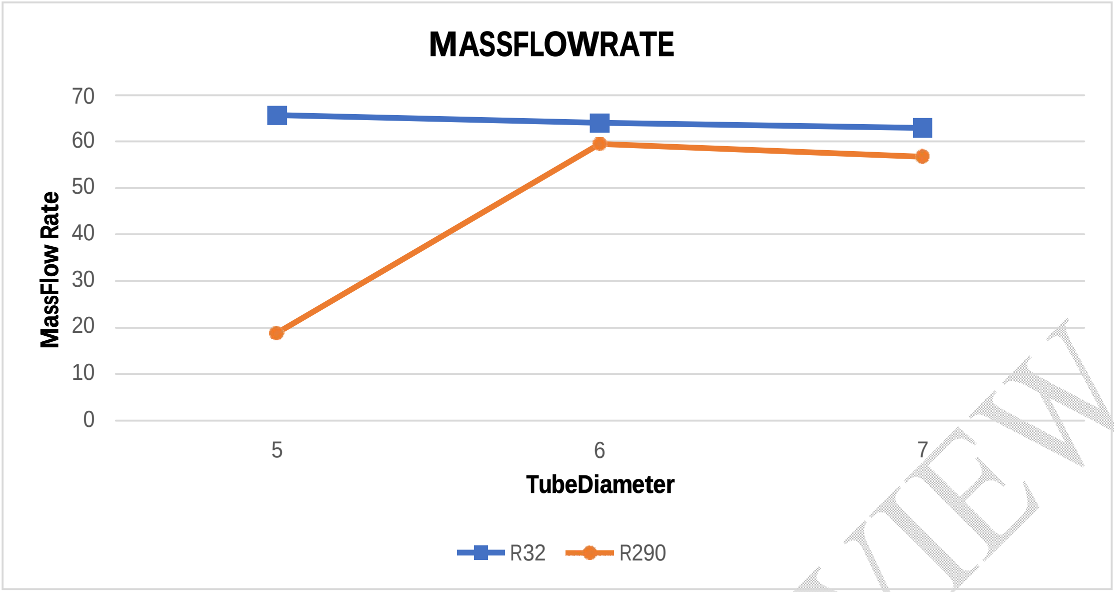

Figure8;Massflowratecomparison graph

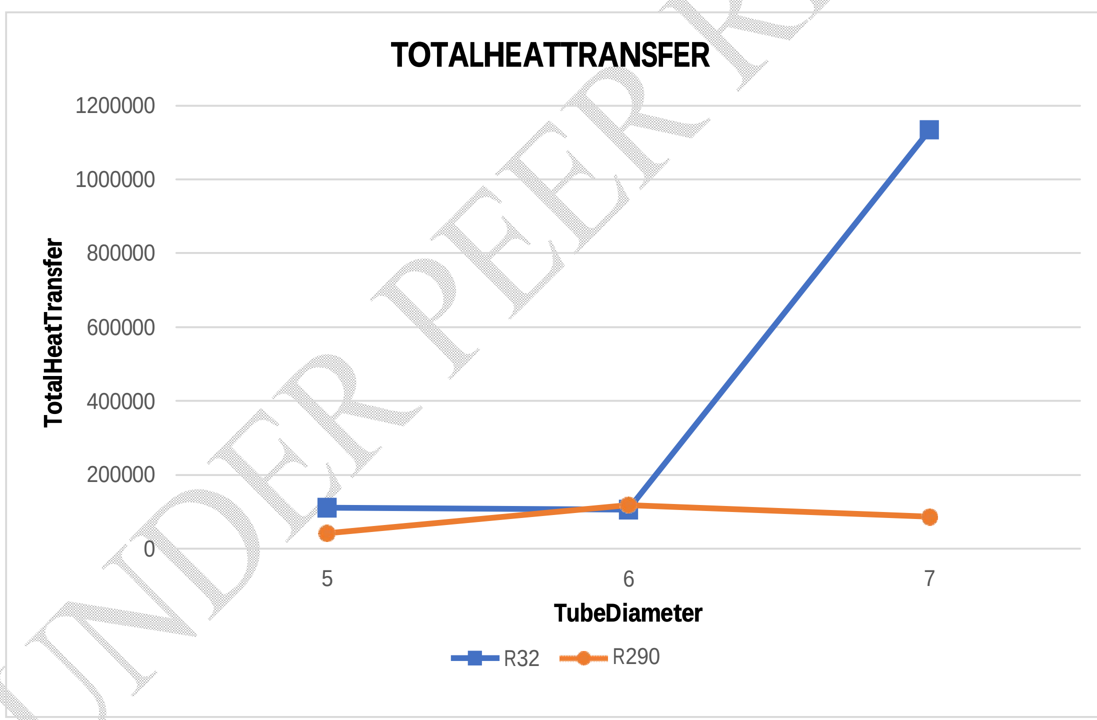

Figure9;Heattransfercomparison graph

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)andaluminiuminorderestablishbettermaterialandCFDanalysiswasalsoperformedonthetubefortworefrigerantsR32 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 thanaluminium

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

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