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Phase Heat Transfer and Pressure Drop inside Internally Helical-Grooved Horizontal Small-Diameter Tubes

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ABSTRACT

In this thesis analytical investigations are done to determine heat transfer and flow characteristics of water flowing through horizontal internally helical grooved tubes. Different materials used for tubes are steel and copper. The investigations are made by changing the pitch value 3mm & 3.5mm for helical grooves. The CFD and Thermal analysis are carried out for different refrigerants R32 and R410A for turbulent and laminar flows. CFD analysis is done to determine heat transfer coefficient, pressure drop, heat transfer rate and Thermal analysis is done to determine temperature distribution and heat transfer rate. Modelling is done in Creo 2.0 and analysis is done in Ansys.

INTRODUCTION

Heat exchanger devices are widely used in industries, air conditioning systems,refrigeration, etc. These devices have a major role in energy conservation; therefore,increasing the performance of heat exchangers helps save energy, costs and materials. Thetechnique to increase the heat transfer performance is called heat augmentation, which canbe applied to pipe surfaces and other surfaces which are used in heat exchangers to improvethermal performance. These techniques are categorized into 3 groups: passive, active andcompound technique.

Conventional resources of energy are depleting at an alarming rate, which makes future sustainable development of energy use very difficult. As a result, considerable emphasis has been placed on the development of various augmented heat transfer surfaces and devices. Heat transfer augmentation techniques are generally classified into three categories namely: active techniques, passive techniques and compound techniques. Passive heat transfer techniques (ex: tube inserts) do not require any direct input of external power. Hence many researchers preferred passive heat transfer enhancement techniques for their simplicity and applicability for many applications. Tube inserts present some advantages over other enhancement techniques, such as they can be installed in existing smooth tube that exchanger, and they maintain the mechanical strength of the smooth tube. Their installation is easy and cost is low. It relatively easy to takeout for cleaning operations too, The process of improving the performance of a heat transfer system is referred as the heat transfer enhancement technique.

REYNOLDS NUMBER (RE)

The Reynolds number was defined based on the inner diameter and flow velocity at the inlet of the test tube as

$$Re=\frac{\rho u\, d_i}{\mu}$$

Where ρ is the density of water, u is the flow velocity of water at the inlet of the test section, di is the inner diameter of the test tube, and μ is dynamic viscosity of water.

NUSSELT NUMBER (NU)

The Nusselt number was calculated as follows:

$$Nu = \frac{h_{avg}\ \ d_i}{k_1}$$

Where havg is the average heat transfer coefficient of water flowing inside the test section, and kl is thermal conductivity of liquid water. The average heat transfer coefficient was determined by using the following equation:

$$h_{avg}\ = \frac{Q_e}{A_{i(T_{avg\ ,wi} - T_{avg\ ,f})}}$$

Where tavg, f is the average temperature of water at the test section inlet and outlet, Tavg,wi is the average temperature of the inner wall, Ai is the actual inside surface area of the test section, and Qe is the electrical energy supplied to the test tube, which was obtained from:

Qe =VI

Where I and V are the current and voltage of the electric heater, respectively. The heat gained by the fluid inside the test tube (Qf) can be calculated as

$$Q_f = m_f c_p(T_{f,out}\ -\ T_{f,in})$$

LITERATURE SURVEY

In The Paper byNorihiro Inoue [1]Single-Phase Heat Transfer And Pressure Drop Inside Internally Helical-Grooved Horizontal Small-Diameter Tubes, in single-phase was carried out using 10 types of internally helical-grooved and smooth small-diameter tubes with an outside diameter of 4 mm. The results are listed below: (1) In the turbulent flow region, fin height had the greatest effect, helix angle had only a minor effect, and the number of grooves had almost no effect upon the pressure drop versus the mass flow rate of the 4-mm grooved small-diameter tubes. In the laminar flow region, except for fin height, the shapes of the internal grooves had scarcely any effect upon pressure drop. (2) In the turbulent flow region, the heat transfer coefficients of the 4-mm grooved small-diameter tubes were greatly affected by fin height. The heat transfer coefficients became the maximum when a helix angle was near 15°, and there is a different tendency in the experiments of the pressure drop. On the other hand, there is almost no effect of the number of grooves. In the laminar flow region, there were no large differences in the heat transfer coefficients between the internally helical-grooved tubes and smooth small-diameter tube. (3) New empirical correlations for the friction factor and heat transfer coefficient in the laminar and turbulent flow regions were developed based on the experimental values. (4) The performance assessment in consideration of both heat transfer and pressure drop was indicated by using Colburn's analogy.

In The Paper by K. Aroonrat [2] Heat transfer and single-phase flow in internally grooved tubes, this study investigates heat transfer and flow characteristics of water flowing through horizontal internally grooved tubes. The test tubes consisted of one smooth tube, one straight grooved tube, and four grooved tubes with different pitches. All test tubes were made from type 304 stainless steel. The length and inner diameter of the test tube were 2 m and 7.1 mm, respectively. Water was used as working fluid, heated by DC power supply under constant heat flux condition. The test runs were performed at average fluid temperature of 25 °C, heat flux of 3.5 kW/m^2, and Reynolds number range from 4000 to 10,000. The effect of grooved pitch on heat transfer and pressure drop was also investigated. The performance of the grooved tubes was discussed in terms of thermal enhancement factor. The results showed that the thermal enhancement factor obtained from groove tubes is about 1.4 to 2.2 for a pitch of 0.5 in.; 1.1 to 1.3 for pitches of 8, 10, and 12 in., respectively; and 0.8 to 0.9 for a straight groove.

In The Paper by D. M. Graham [3] Heat Transfer and Pressure Drop During Condensation of Refrigerant 134a in an Axially Grooved Tube, R134a condensation experiments have been petfonned over a mass flux range of 75 to 450 kg/m2-s (55 to 330 klbm/ft2-hr) in an 8.91 rom (0.351") inside diameter, axially grooved, micro fin tube. At 75 kg/m2-s (55 klbm/ft2-hr), the axially grooved tube petfonns marginally better than a smooth tube, but worse than a similarly grooved tube with an 18 degree helix angle over a broad range of refrigerant qualities. Mass fluxes at 150 kg/m2-s (110 klbm/ft2-hr) and greater show broad quality ranges in which the axially grooved tube petfonns significantly better than both smooth and helically grooved tubes. Examination of a Froude rate parameter indicates that the axially grooved tube is able to maintain an annular film flow characteristic that results in more efficient heat transfer. Pressure drop characteristics of the axially grooved tube are similar to those found in an 18 degree helix angle tube.

In The Paper by M.J. Wilson [4] Refrigerant charge, pressure drop, and condensation heat transfer in flattened tubes, Horizontal smooth and micro finned copper tubes with an approximate diameter of 9 mm were successively flattened in order to determine changes in flow field characteristics as a round tube is altered into a flattened tube profile. Refrigerants R134a and R410A were investigated over a mass flux range from 75 to 400 kg m2 s1 and a quality range from approximately 10–80%. For a given refrigerant mass flow rate, the results show that a significant reduction in refrigerant charge is possible. Pressure drop results show increases of pressure drop at a given mass flux and quality as a tube profile is flattened. Heat transfer results indicate enhancement of the condensation heat transfer coefficient as a tube is flattened. Flattened tubes with an 18 helix angle displayed the highest heat transfer coefficients. Smooth tubes and axial micro fin tubes displayed similar levels of heat transfer enhancement. Heat transfer enhancement is dependent on the mass flux, quality and tube profile.

In The Paper byLeon Liebenberg [5] Refrigerant Condensation Flow Regimes in Enhanced Tubes and Their Effect on Heat Transfer Coefficients and Pressure Drops, Flow regimes influence the heat and mass transfer processes during two-phase flow, implying that any statistically accurate and reliable prediction of heat transfer and pressure drop during flow condensation should be based on the analysis of the prevailing flow pattern. Many correlations for heat transfer coefficient and pressure drop during flow condensation completely ignored flow regime effects and treated flows as either annular or non-stratified flow or as stratified flow. This resulted in correlations of poor accuracy and limited validity and reliability. Current heat transfer coefficient, pressure drop, and void fraction models are based on the local flow pattern, though, resulting in deviations of around 20% from experimental data. There are, however, several inconsistencies and anomalies regarding these models, which are discussed in this paper. A generalized solution methodology for two-phase flow problems still remains an elusive goal, mainly because gas-liquid flow systems combine the complexities of turbulence with those of deformable vapor-liquid interfaces. The paper focuses on the state of the art in correlating flow condensation in micro-fin tubes and proposes flow regime-based correlations of heat transfer coefficient and pressure drop for refrigerant condensation in smooth, helical micro-fin, and herringbone micro-fin tubes.

In The Paper by Bilen et al. [6] studied the relationship between different types of geometries of grooved tubes and surface heat transfer using fully developed turbulent flow where air was used as working fluid. Three types of groove geometries, i.e., circular, trapezoidal, and rectangular were considered during their experiment. Parameters such as tube length, diameter, and Reynolds number were fixed. The ratio of tube length to diameter was fixed to 33 and the test was performed at a Reynolds number range of 10,000 - 38,000. From the experimental results using smooth tube as the comparison, heat transfer enhancement showed 63% for circular groove, 58% for trapezoidal groove, and 47% for rectangular groove. Circular and trapezoidal grooved tubes were found to have better heat transfer than rectangular grooved tube because they can provide more surface are swept by fluid hence reducing the occurrence of the recirculation. Better surface sweep can avoid the sharp vertical corner and produce a better flow thus decreases the negative effect of the recirculation region on the heat transfer. The comparison between circular and trapezoidal grooved tubes was also done. The results showed that the heat transfer enhancement between these two tubes with different geometries is almost same. However, the number of groove in trapezoidal grooved tube is 20% less than circular grooved tube.

In The Paper by M. M. Rahman [7] A CFD Simulation Study of Heat Transfer Augmentation through Enhanced Tube, This paper presents the outcomes of a computational fluid dynamics (CFD) simulation study of heat transfer augmentation through enhanced copper tube. The study was carried out by constructing the model of a 0.5 m long 40 inner grooved copper tube through SOLIDWORKS followed by importing the model into GAMBIT environment for healing, meshing, and boundary conditions and zone setting. The model was subsequently run in FLUENT for four different cases. The simulation results were compared with experimental results found in literature. A moderate agreement was observed between the results obtained through this simulation work compared to published experimental results. Heat transfer augmentation through enhanced tube is also compared with smooth tube and it is found that enhanced tube could enhance heat transfer in the rage of 649.67 - 917.22%. Relationship between heat transfer coefficient and mass flow rate was also observed and it is found that they are directly proportional to each other.

3D MODELING AND ANALYSIS OF HELICAL - GROOVED HORIZONTAL SMALL - DIAMETER TUBES

The outer and inner diameters of tube are 20mm and 16mm respectively. The diameter of the helix is 2.5mm and the pitch values are varied by 3mm and 3.5mm.

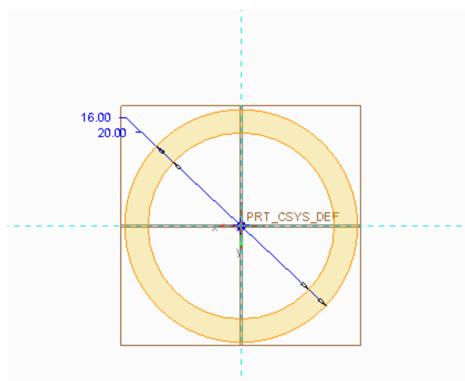

Fig: Sketch

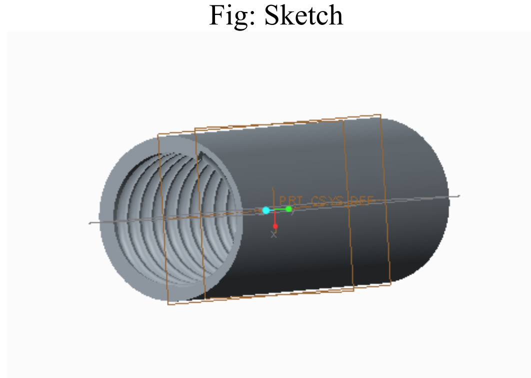

Fig: 3D model of tube with helical grooves

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VELOCITY CALCULATIONS

Material properties R32
Density (ρ)=1212.9kg/m^3
Viscosity (μ) = 276.7kg/m-s
Thermal conductivity=187.4w/m-k
V= velocity
di=inner diameter
di = 20mm

Material properties R410A
Density (ρ)=134.7kg/m^3
Viscosity (μ) = 346.4kg/m-s
Thermal conductivity=151.3w/m-k
V= velocity
di=inner diameter
di = 20mm

Reyonlds number of turbulent-6000(R32)

$$Re = \frac{\rho v d_i}{\mu}$$

$$6000 = \frac{121.9 \times v \times 20}{276.7}$$

V=68.439m/s

Reyonlds number of turbulent-6000(R410A)

$$Re = \frac{\rho v d_i}{\mu}$$

$$6000 = \frac{1349.7 \times v \times 20}{346.4}$$

V=76.99m/s

Reyonlds number of laminar-1800(R32)

$$Re = \frac{\rho v d_i}{\mu}$$

$$1800 = \frac{121.9 \times v \times 20}{276.7}$$

V=20.53m/s

Reyonlds number of laminar-1800(R410A)

$$Re = \frac{\rho v d_i}{\mu}$$

$$1800 = \frac{1349.7 \times v \times 20}{346.4}$$

V=23.098m/s

CFD ANALYSIS OF HELICAL - GROOVED HORIZONTAL SMALL - DIAMETER TUBES

LAMINAR FLOW
PITCH DIAMETER - 3.0 mm
REFRIGERANT-R32

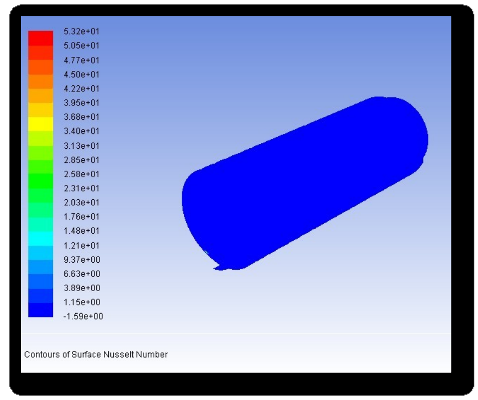

Fig: Nusselt number

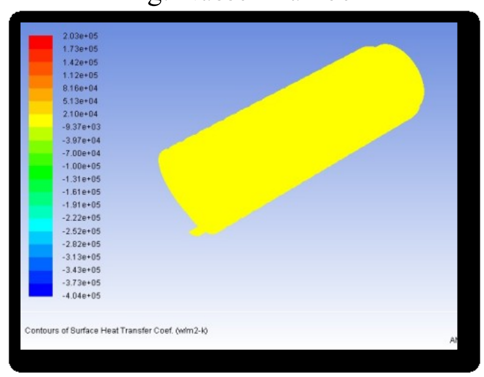

Fig: Heat transfer coefficient

REFRIGERANT-R410A

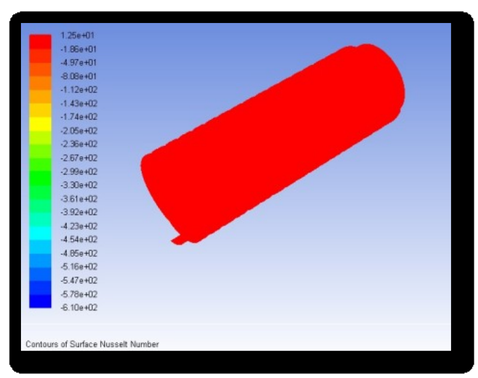

Fig: Nusselt Number

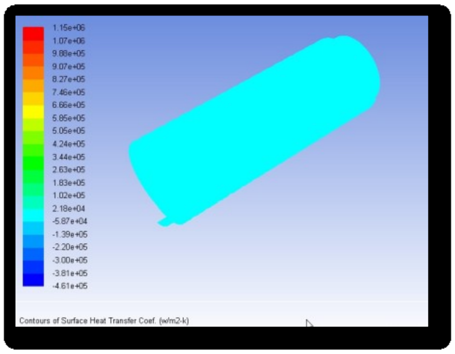

Fig: Total Heat Transfer Coefficient

TURBULENT FLOW

REFRIGERANT-R32

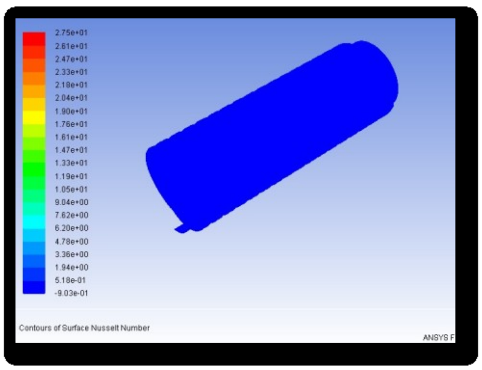

Fig: nusselt number

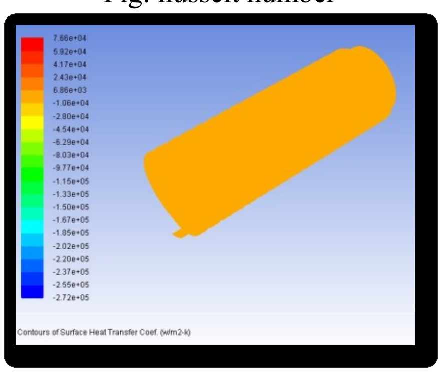

Fig: total heat transfer coefficient

REFRIGERANT-R410A

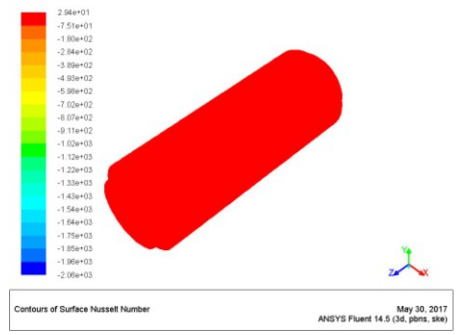

Fig: nusselt number

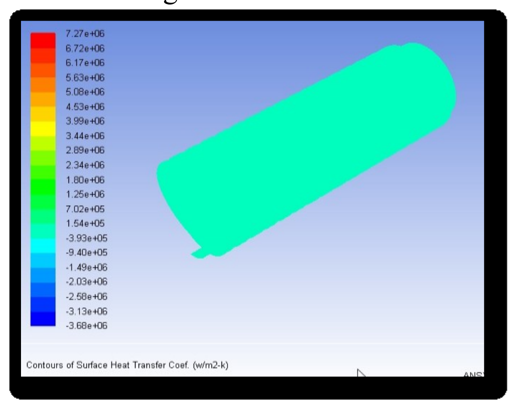

Fig: total transfer coefficient

THERMAL ANALYSIS

PITCH – 3mm
TURBULENT FLOW
REFRIGENT-R32

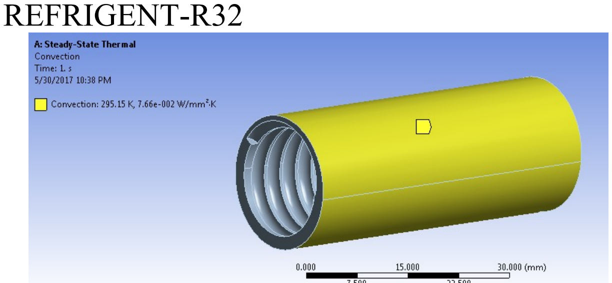

Fig: convection

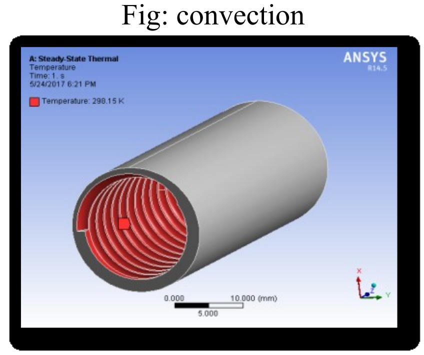

Fig: temperature

MATERIAL- COPPER

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Material properties of Copper
Thermal conductivity: 385 W/mK

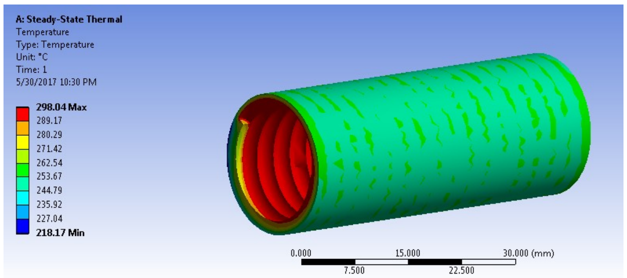

Fig: temperature

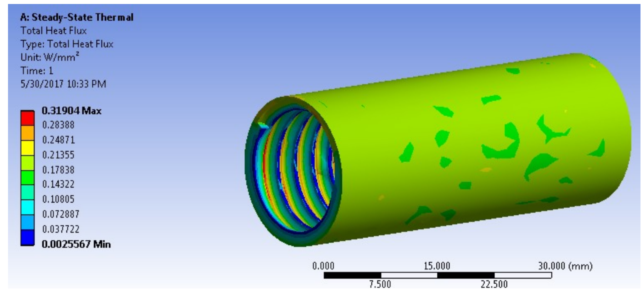

Fig: total heat flux

RESULTS & TABLES
CFD ANALYSIS

Pitch - 3.0mm

Flow	Refrigerant	Pressure (Pa)	Nusselt Number	Total Heat Transfer Coefficient (W/m^2 K)	Total Heat Transfer Rate (W)
Laminar	**R32**	5.17e+08	5.32e+01	2.03e+05	-2.6828841
	R410A	1.12e+08	1.25e+01	1.15e+06	-12.126785
Turbulent	**R32**	8.65e+08	2.75e+01	7.66e+04	-22.590287
	R410A	3.36e+08	2.94e+01	7.27e+06	21.159

Pitch - 3.5mm

Flow	Refrigerant	Pressure (Pa)	Nusselt Number	Total Heat Transfer Coefficient (W/m^2 K)	Total Heat Transfer Rate (W)
Laminar	**R32**	5.17e+08	5.32e+01	2.03e+05	-2.6828841
	R410A	1.27e+08	1.25+01	1.15e+06	-12.126785
Turbulent	**R32**	8.65e+08	2.75e+01	7.66e+04	-22.590287
	R410A	3.41e+08	2.94e+01	2.24e+06	21.159402

THERMAL ANALYSIS

Pitch – 3mm
Turbulent Flow
Refrigent-R32

	Temperature(k)	Heat flux(w/mm^2)
Steel	289	0.1661
Copper	298.04	0.31904

Refrigent-R410A

	Temperature(k)	Heat flux(w/mm^2)
Steel	298	0.32761
Copper	298	1.8227

Laminar Flow
Refrigent-R32

	Temperature(k)	Heat flux(w/mm^2)
Steel	298	0.23738
Copper	298	0.65422

Refrigent-R410A

	Temperature(k)	Heat flux(w/mm^2)
Steel	298	0.30421
Copper	298	1.46642

Pitch – 3.5mm
Turbulent Flow
Refrigent-R32

	Temperature(k)	Heat flux(w/mm^2)
Steel	298.17	0.091989
Copper	298.15	0.10829

Refrigent-R410A

	Temperature(k)	Heat flux(w/mm^2)
Steel	298.16	0.224432
Copper	298.15	0.34256

Laminar Flow
Refrigent-R32

	Temperature(k)	Heat flux(w/mm^2)
Steel	298.15	0.39014
Copper	298.16	0.77677

Refrigent-R410A

	Temperature(k)	Heat flux(w/mm^2)
Steel	298.12	0.65422
Copper	298	1.46642

CONCLUSION

Analytical investigations are done to determine heat transfer and flow characteristics of water flowing through horizontal internally helical grooved tubes. Different materials used for tubes are steel and copper. The investigations are made by changing the pitch value 3mm & 3.5mm for helical grooves. The CFD and Thermal analysis are carried out for different refrigerants R32 and R410A for turbulent and laminar flows.

By observing CFD analysis results, the change in pitch value does not affect Nusselt Number, Pressure and Heat transfer rate. Heat transfer coefficient is more when pitch 3mm is used for helical grooves. By comparing the results between turbulent and laminar, the values are more for turbulent flow. Nusselt number and Heat transfer coefficient are more when refrigerant R410A is used but heat transfer rate is more when R32 is used.

By observing thermal analysis results, the heat flux values are more for turbulent flow and when R410A and Copper for tube is used since the heat transfer coefficients are more from CFD analysis. With high heat flux, heat transfer rate will be more.

So it can be concluded that using R410A, Copper material for tube with turbulent flow yields better results.

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