Modeling and Simulation of Triple Concentric Tube Heat Exchanger Using Different Materials

ISSN (e) 2520-7393
ISSN (p) 2521-5027
Received on 3rd Dec 2020
Revised on 20th Dec, 2020
www.estirj.com

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Abstract: Tubular heat exchangers are very popular in various types of industries owing to the flexibility the designer must allow for a wide range of pressures and temperatures, especially in petroleum industries. The heat exchanger's thermal strength depends on what proportion heat is transferred from fluid to fluid. This research paper exhibits a comprehensive comparison between tube in tube heat exchanger (TTHE) and triple concentric tube heat exchanger (TCTHE) by simulation on ANSYS CFD and demonstrates that TCTHE has a greater heat transfer rate compared to TTHE because of greater heat transfer surface area and higher heat transfer coefficients, hence validating the experimental results. Furthermore, this paper also unveils the comparative analysis for the best suitable material for the heat exchanger tubes. Seven different types of materials are taken under consideration that are, Copper, Aluminum, Titanium, Stailnless-Steel-430, Stainless-Steel-304, Silver & Copper-Nickle-Alloy. The simulation results through ANSYS CFD suggests and declares mild steel as best possible tube material among the aforesaid materials

Keywords: *Heat Exchanger, Heat transfer, TCTHE simulation, Tube material*

1. Introduction

Heat exchangers are very useful systems transfer heat from high temperature fluid to low temperature fluid used in industries, heat exchangers are appliances used to move energy heat between two liquids at various temperatures. In the new time of supportability, the developing intensity to spare vitality and lessen natural effects has put more notable accentuation on the utilization of heat exchangers with better heat transfer proficiency. There are several types of heat exchangers are in operation in various industries like tube in tube heat exchanger (TTHE), triple concentric tube heat exchanger (TCTHE). Tube in tube heat exchangers are the same as double concentric tube heat exchanger and are based on two tubes which are basically concentric in nature with similar length and different diameter. TTHE have advantage to work in counter current flow, with good heat exchange, TTHE has a good resistance to high pressure it can be operating to high temperature. The double concentric tube heat exchangers are used as crystallizers, vaporizers, condensers, heat recovery exchangers, sub-coolers etc. in industries [1-3].

The triple concentric tube heat exchangers (TCTHE) are an improved graceful version of tube in tube heat exchanger by adding in-between tube. TCTHE are built-up by three concentric tubes of similar or different lengths. Beside tube in tube heat exchanger, triple concentric tube heat exchanger has some advantages as TCTHE has higher overall heat transfer coefficient and larger surface area for heat transfer per unit length [4-8].

2. Related Work

As Maulik Pancholi et al., (2017) presents results of analysis of the heat transfer to cool a petroleum product in two types of concentric tube heat exchangers: double and triple concentric tube heat exchangers. Water is used as cooling agent. The triple concentric tube heat exchanger is a modified constructive version of double tube heat exchanger by adding an extra intermediate tube. Overview and basic concepts of triple tube heat exchanger is presented which helps to contemplate over evaluation of different aspects of triple concentric tube heat exchanger [9]. As S. Rădulescu, L.I. Negoiţă, and I. Onuţu,2016 presented the heat transfer results of cooling of petroleum product through water as cooling agent in the two types of concentric tube heat exchangers: double and triple concentric tube heat exchangers. In their analysis it was attributed that triple concentric tube heat exchangers provide better rate of heat transfer as compared to the double concentric tube heat exchangers [2]Patel Dharmik A et al., (2017) Triple coaxial tube device consists of 3 tubes of various diameters connected concentrically. Triple coaxial tube device performs higher than double concentric tube heat exchanger. Most of the previous studies used two fluids for various arrangement. Cold fluids ensue tubing and outer annulus and hot fluid from inner annulus. totally different parameters were found that have an effect on performance of triple coaxial tube device [10]. Dilpak Saurabh et al., (2016) The present study would come with heat transfer CFD analysis for a triple tube device. Theoretical studies are performed for numerical simulations and warmth transfer analysis. Triple coaxial Tube Heat Exchanger's performance is to be assessed beneath variable operational conditions. Studies and experiments have already been conducted within the Triple Tube device for normal-hot-cold and cold-hot-normal configurations, within the gift study, CFD analysis is employed to validate experimental information specific to N-H-configuration [11]. García-Valladares et al., (2016) perform careful

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numerical simulations of a single-pass and double-pass star parabolic trough collector's thermal and fluid dynamic behaviour area unit performed. The management equations inside the receiver tube were resolve iteratively throughout a separate manner, alongside the energy equation within the tube walls and cover wall and thus the thermal analysis within the star concentrator. the implications of employment at the ends on heat transfer area unit numerically studied, showing that the double pass can improve the thermal efficiency compared to the sole pass [12]. Sampath Emani et al., (2016) presents the impact of shear stress on the formation of deposits caused by significant oil residues. The inspection is based on a computational fluid dynamics approach based on a three-dimensional study. Simulation of the fouling process using asphalt precipitation and chemical reaction routes. The rate of asphalt section deposition and coke formation was foreseen by point volume model and thermal cracking thanks to chemical reactions severally [13]. Fayi Yana et al., (2016) study a LNG (Liquefied Natural Gas) vehicles, the benefits of high thermal potency and fewer pollution are the transport of urban pollution disposal. Another advantage of LNG vehicles is that the LNG fuel's cold energy for air con is recycled. supported the 2 fluid models, the warmth transfer characteristics of the cold energy recovery device are simulated numerically in LNG vehicles. The results will give a benchmark for planning the warmth money changer for cold energy recovery in LNG vehicles [14]. Rohit, Khedkar et al., (2014), has investigated TiO2-water nanofluid heat transfer characteristics as a fluid during a focused tube device. the warmth money dealer is created from a one thousand millimetre long copper focused tubing. Nanofluids are the mixture of base fluid water and nano-range TiO2 particles. the typical heat transfer rates for nanofluids as a cooling media are as curtained to be beyond those for the water that's conjointly used as a cooling media, and this will increase with nanofluid composition concentration. The results of this study are of technological importance for the economical style of focused tube heat exchangers so as to boost cooling performance in low heat flux cooling systems [15]. Pierre Peigné et al., (2013) did experimental tests conducted on a replacement wood-based air-heating system for energy-efficient dwellings are presented. The experimental results show that the rise within the average variety of Nussels mistreatment the loose-fit, spiral tape with and while not core-rod is 230 % and 340 percent over the corresponding plain tube, severally and a triple concentrate tube device integrated into the chimney of a room-sealed wood pellet stove to heat the total house [16]. Nano fluids are colloidal mixtures of Nano metric metallic or ceramic particles in a base fluid, such as water, ethylene glycol or oil., possess immense potential to enhance the heat transfer character of the original fluid due to improved thermal transport properties. Nano fluids have been found to possess enhanced thermo-physical properties such as thermal conductivity, thermal diffusivity, viscosity, and convective heat transfer coefficients compared to those of base fluids like oil or water based on this concept D Han et al., (2018) did experimental work, experimental set-up consisted of a double-tube device with cold-side nano fluids employed in turbulent regimes with Sir Joshua Reynolds variety starting from 20000 to 60000 aims to research through an experiment the result of Al2O3/water nano fluids on the development of warmth transfer among the double tube device at variable recess temperature. At totally different recess temperatures, Al2O3 nanoparticle with concentration of 0.25 p.c and 0.5 p.c by volume concentration was used. [17]. Many theoretical studies were done on the concept that triple concentrate tube heat exchangers consisting of 2 elements as Panel et al., (2013) presents the primary a part of the study and discusses mathematical modelling. The model includes the derivation and potential solutions of the governing differential equations for each counter-flow and parallel-flow arrangements. within the second a part of the study, that is underneath its approach for publication, the results of many case studies are bestowed [18]. Datta et al., (2013) developed an reiterative technique and reported for correct estimation of warmth transfer coefficients in an exceedingly voluted triple tube device. supported the experimental temperature rise of milk in an exceedingly voluted triple tube device, correct values of film heat transfer coefficients and overall heat transfer coefficients supported the surface space of the innermost tube and therefore the within area of the centre annulus are obtained from initial principles. 3 totally different milk flow rates were used, leading to 3 numbers of Sir Joshua Reynolds. The represented procedure may be applied with minor modifications to any device [19]. Many researchers addresses numerical and experimental investigation of a thermal energy storage unit involving a heat-driven phase transition process as a scientist Longjian et al., (2013) did investigation and presents ,thermal energy storage unit includes a multiple concentrate tube stuffed within the middle channel with phase transition material (PCM), with hot heat transfer fluid (HHTF) flowing outer channel throughout the charging method and cold heat transfer fluid (CHTF) flowing inner channel during discharging process. Graphical results as well as fluid temperature and solid and liquid section interface of PCM versus time and axial position mentioned [20]. Nema et al., (2013) developed A laptop model for precise milk temperature management as tormented by fouling. It will accurately calculate the steam temperature increase needed to keep up the specified temperature of milk sterilization. with none management, the results with steam control are compared with the results and this procedure has been found satisfactory to regulate the temperature of the milk outlet. The represented procedure is applied with minor modifications to any device [21]. live fluid temperature variations on the warmth money handler length and friction issue variations and Nusselt variety with Reynolds number Sanjaywere investigated by Singh, Mishra and Jha(2014) investigate Triple concentrate tube device thermo-hydraulics with two-thermal communications were conducted through an experiment below stable conditions. Water was responded to the tubing, the inner annulus, and therefore the outer annulus at totally different temperatures. Experiments for the amount of Reynolds starting from 2800 to 11,000 predicament within the inner annulus were conducted in the slightest degree attainable flow arrangements. Experimental results validations were additionally applied with the results established. [22].

Furthermore, most of the researchers had carried out experimental analysis of heat transfers in the double and triple concentric tube heat exchangers by considering the flow directions. However, comparison of different materials has not been done and less attention has been given to the validation of experimental work through Ansys-fluent. Therefore, prime aim of this research is to validate the experimental results through ANSYS FLUENT simulation and was to select suitable material for heat exchanger tube.

3. Methodology

The heat transfer analysis for the designed heat exchanger was carried out on ANSYS 16.0 and the results were obtained according to given boundary conditions provided at the inlet. This research includes eight simulations at different boundary conditions at inlet of the heat exchanger to show the variations of the values at the outlet of the heat exchanger. During the simulation, the complete transfer of heat in the heat exchanger was observed including all points of interest. By doing fine meshing, accurate values for the heat transfer was found. The law or method on which the ANSYS given the results was according to the Fourier's Law of Heat Transfer.

3.1 Simulation of Experimental Work

Ansys FLUENT was used for conducting computational fluid dynamic analysis, Simulation was carried out by 3 steps:

- Development of CAD Model
- MASHING
- ANALYSIS

Modeling of TTHE and TCTHE was done on Ansys Design Modeler according to geometrical parameters as instated in Table 1[2].

Table 1: Geometrical parameters for Heat Exchangers

S.No	Size	TTHE (mm)	TCTHE (mm)
01	Inside diameter of inner tube	26	12
02	Outside diameter of outer tube	28	14
03	Inside diameter of outer tube	40	40
04	Outside diameter of outer tube	42	42
06	Outside diameter of intermediate tube	-----	26
07	Inside diameter of intermediate tube	-----	28
08	Length of inner tube	1193	1193
09	Length of intermediate tube	------	1193
10	Length of outer tube	1193	935

3.1.1 Development of Model Geometry

The geometry (CAD Model) of Heat Exchanger was planned in ANSYS Design Modeler. The geometry of two containers of dia 26mm and 40 mms with thickness of 2mm individually appeared in Figure 1 (a), and three concentrated tubes of measurement 12mm, 26mm, and 40mm with thickness of 2mm separately appeared in Figure 1(b).

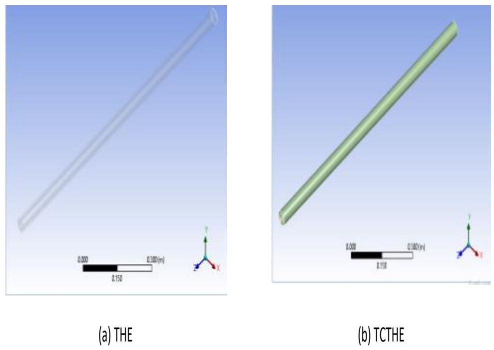

Fig. 1: CAD models of Heat Exchangers

3.1.2 Mashing Model: After defining the geometry, the meshing was performed for TTHE and TCTHE as shown in Figure 2 and Figure 3, respectively. For accuracy and stability of numerical computation, the mashing quality should be high.

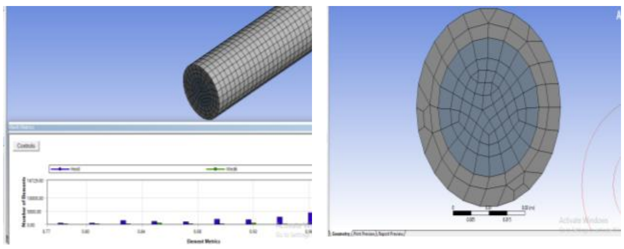

Fig. 2: Mesh Model of TTHE Heat Exchanger

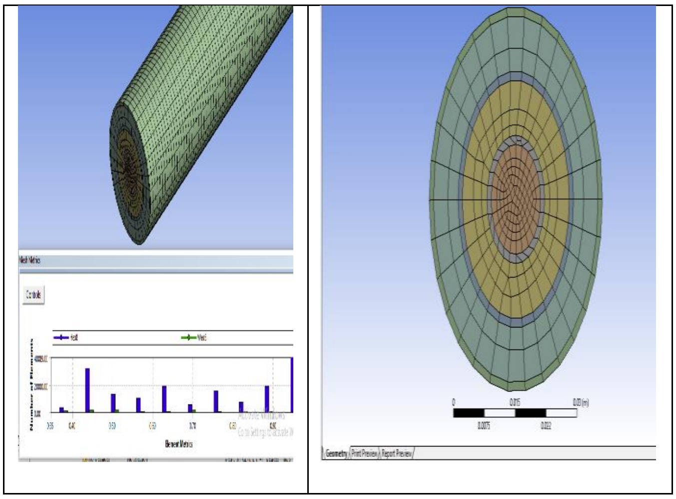

Fig. 3: Mesh Model of -TCTHE Heat Exchanger

3.2 Simulation Setup

Boundary conditions set to normal atmospheric temperature and pressure. Moreover, initial conditions were applied to inlet and outlet, such as flow rate, initial Temperature, flow velocity, etc. The type of the fluid has Laminar and Steady flow, and the type of the fluid was defined such as liquid or air. Since the objective was to determine out heat transfer, the energy equation was used in ANSYS. The Fluent solves the energy equation as given in eq (1) as follows:

$$\frac{\partial}{\partial t}(\rho E) + \nabla.(\mathrm{v}(\rho E + \rho)) = (\nabla.(\mathrm{k_{eff}}\nabla T - \sum_i hJ + (\mathrm{T_{eff:}}.\ \mathrm{V})) \text{ --------------eq (1)}$$

Through ANSYS fluent Solver Copper was selected as tube material ,and in tubes fluid flow for TTHE is in such arrangement that cold fluid (water) in outer tube and hot fluid(petroleum product) in inner tube, while for TTCHE cold fluid(water) in inner and outer tube and hot fluid(petroleum product) in intermediate tube .we get almost same result which are in experimental work .Input parameters like mass flow and inlet temperatures prescribed in experimental work i.e. Table 2.

Table 2: Input Parameters Like Mass Flow And Inlet Temperatures Prescribed In Experimental Work

	TTHE						TCTHE				
No. Det.	V_H	V_C	$T_{H,in}$	$T_{H,out}$	$T_{C,IN}$	$T_{C,OUT}$	V_{C1}	V_{C2}	$T_{h\ out}$	$T_{C1\ out}$	$T_{C2\ out}$
01	180	290	60.0	52.3	12.1	14.6	110	120	52.1	14.5	14.7
02	120	220	60.4	50.4	12.6	15.1	100	100	50.3	14.9	15.2
03	150	250	60.2	51.4	11.3	14.0	100	100	51.2	13.9	14.2
04	150	250	70.3	59.8	10.9	14.2	100	100	59.6	14.0	14.4
05	150	250	86.4	72.4	11.3	15.5	100	110	72.3	15.4	15.6
06	120	210	70.4	58.3	13.4	16.6	90	100	58.2	16.4	16.7
07	50	140	60.5	45.4	17.2	18.8	90	100	45.0	18.7	19.0
08	50	140	60.5	46.4	19.3	21.4	90	50	46.2	20.8	22.4

3.3 Computation and Monitor Solution

After the giving input parameters like copper as tube material ,and in tubes fluid flow for TTHE is in such arrangement that cold fluid (water) in outer tube and hot fluid(petroleum product) in inner tube, while for TTCHE cold fluid(water) in inner and outer tube and hot fluid(petroleum product) in intermediate tube, the calculation begins, and it takes a few minutes to give the required results. It takes some time because of the calculations running in the background within iterations. The results can be monitored easily on the screen where the graphical results are also shown as well. .

4. Results and Discussion

The transfer of the fluid flow across the tubes of the heat exchanger can be visualized by vectors. The variation can be seen according to the change of color (from Blue to Red color). Effect of variation in temperature of heat exchanger can be visualized.

4.1 Simulation Data

The combined contours of temperature at 8 different cases for THE and TCTHE as shown in figure 4 & figure 5, respectively. we get almost same result which are in experimental work. Input parameters like mass flow and inlet temperatures prescribed in experimental work for TTHE and TCTHE as shown in table 1 and table 2 respectively.

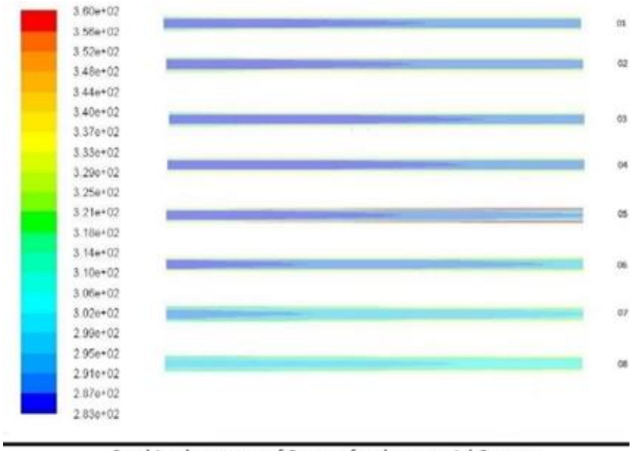

Fig 4: Combined contours of 8-cases for Copper TTHE material Copper

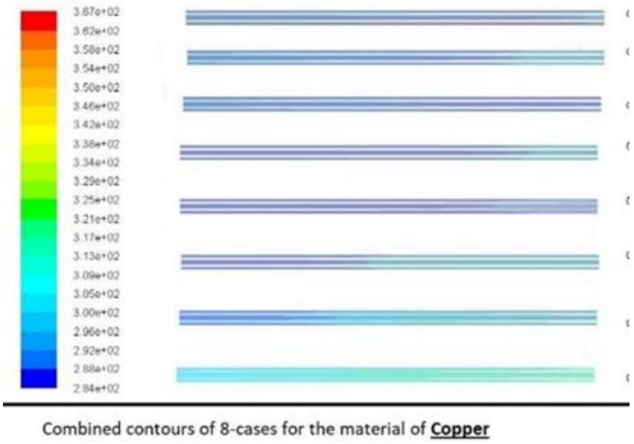

Fig 5: Combined contours of 8-cases for TCTHE material Copper

Table 3: Comparison between Experimental Results and Simulated Results of TTHE.

TTHE RESULTS FOR OUTLET TEMPERATURE						
EXPERIMENTAL-RESULTS			SIMULATION-RESULTS			
	OUTtER	INNER	OUTTER		INNER	
Case#	Th out	Tc out	Th out	Th out	Tc out	Tc out
	C	C	K	C	K	C
01	52.3	14.6	324.545	51.54503	289.9762	16.97621
02	50.4	15.1	323.1682	50.1682	290.2921	17.29207
03	51.4	14	323.9234	50.92342	289.4728	16.4728
04	59.8	14.2	331.9928	58.99282	290.1695	17.16948
05	72.4	15.5	345.0494	72.04938	292.2054	19.20539
06	58.3	16.6	331.498	58.49795	292.6912	19.69123
07	45.4	18.8	317.8209	44.82089	295.4162	22.41616
08	46.4	21.4	318.5922	45.59222	297.2677	24.26771

Table 4: Comparison Between Experimental Results And Simulated Results Of TCTHE

				TCTHE RESULTS FOR OUTLET TEMPERATURE					
EXPERIMENTAL-RESULTS				SIMULATION-RESULTS					
INTER:		INN:	OUT:	INTERMEDIATE		INNER		OUTER	
Case#	Th,out	Tc1,out	TC2,out	Th,out	Th,out	Tc1,out	Tc1,out	Tc2,out	T
	C	C	C	K	C	K	C	K	C
01	52.1	14.5	14.7	324.9393	51.93926	288.5739	15.57392	287.9596	1
02	50.3	14.9	15.2	321.9798	48.97976	289.2145	16.21452	288.819	1
03	51.2	13.9	14.2	323.6212	50.62115	288.0935	15.09345	287.6788	1
04	59.6	14	14.4	341.9374	68.93741	288.9804	15.98039	288.6885	1
05	72.3	15.4	15.6	344.6222	71.62224	290.1223	17.12229	289.0665	1
06	58.2	16.4	16.7	329.8661	56.86612	291.13	18.13004	290.2427	1
07	45	18.7	19	312.7052	39.70519	293.2275	20.22754	292.6554	1
08	46.2	20.8	22.4	313.9613	40.96126	295.1995	22.19951	296.8146	2

4.1.1 TTHE Simulation Data for The Change of Different Tube Materials

The simulation results were analyzed, and it was found that using petroleum product as heating fluid or main fluid in tube in tube heat exchanger and triple concentric tube heat exchanger, whereas the water was used as coolant fluid. The flow of fluid was in counter direction. The graph-01 and 02 denote that both Experimental work results and simulation work results are almost same for both TTHE & TCTHE. It was also observed that heat transfer rate in TCTHE is high for all cases.

4.1.2 TCTHE Simulation Data for The Change of Different Tube Materials

We are at the knowledge that heat transfer efficiency of TCTHE Is more than TTHE, so in this regard heat exchanger tube material of TCTHE were changed and results were captured. The calculated results were saved through ANSYS report, simulation for 8-different materials were done at different boundary conditions accordingly. The simulation of these 8 changed tube materials i.e. Copper,Allumanium, Mild-Steel ,Titanium,Stailnless-Steel-430,Stainless-Steel-304,Silver & Copper Nickle-Alloy is shown below in Fig-06,-07,08,09,10,11,12,13 respectively .

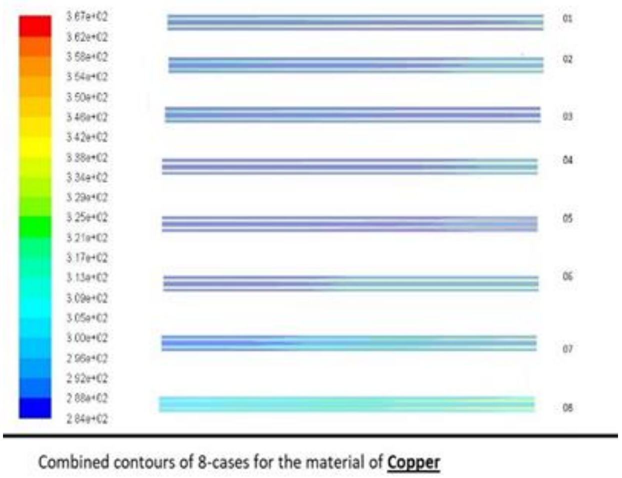

Fig 6: Combined contours of 8-cases for TCTHE material Copper

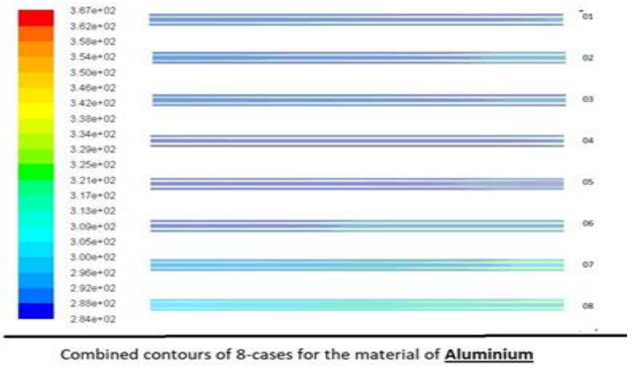

Fig 7: Combined contours of 8-cases for TCTHE material Aluminum

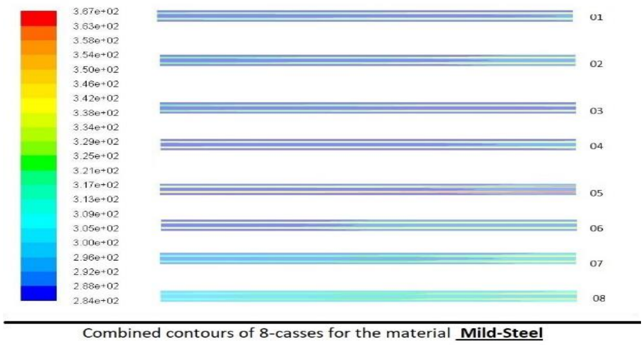

Fig 8: Combined contours of 8-cases for TCTHE material Mild Steel

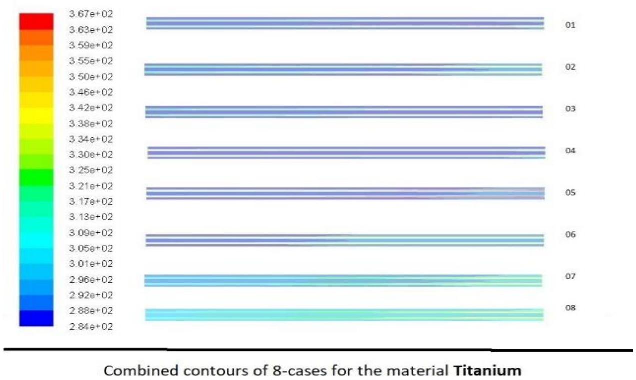

Fig 9: Combined contours of 8-cases for TCTHE material Titanium

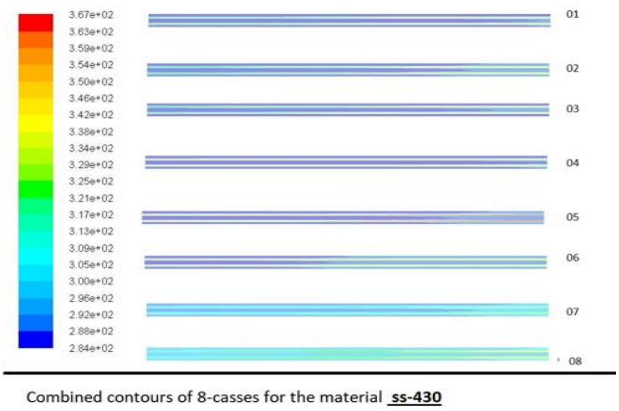

Fig 10: Combined contours of 8-cases for TCTHE material SS-430

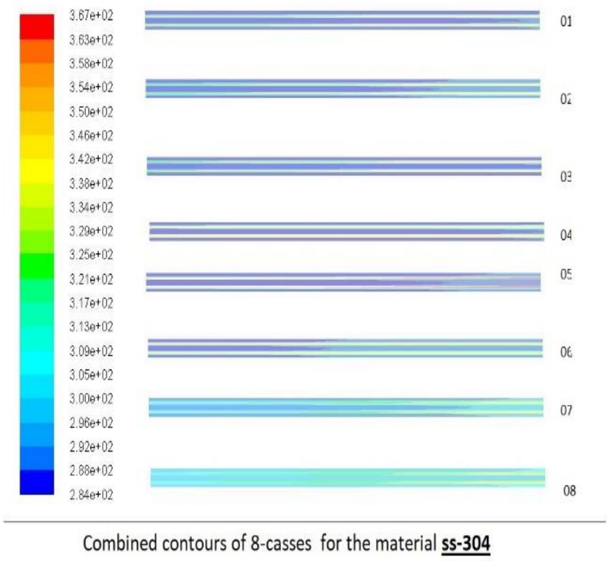

Fig 11: Combined contours of 8-cases for TCTHE material SS-304

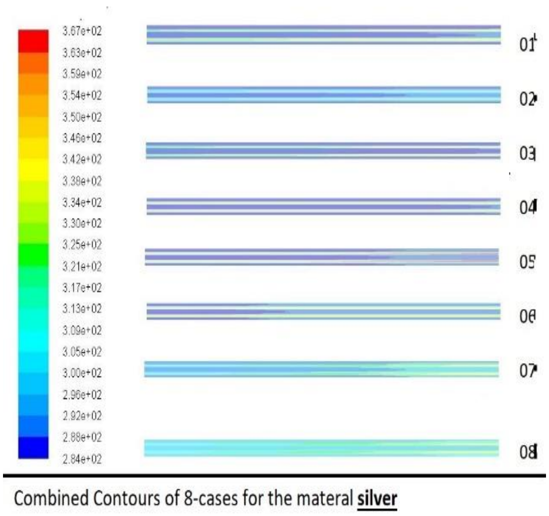

Fig 12: Combined contours of 8-cases for TCTHE material Silver

4.2 Heat transfer rate of Petroleum Product for both TTHE, &TCTHE tube material Copper (Validation of Experimental-work)

The simulation results were analyzed, and it was found that using petroleum product as heating fluid or main fluid in tube in tube heat exchanger and triple concentric tube heat exchanger, whereas the water was used as coolant fluid. The flow of fluid was in counter direction. The figure 13 and 14 shows the both experimental work results and simulation work results are almost same for both TTHE & TCTHE. It was also observed that heat transfer rate in TCTHE is high for all cases.

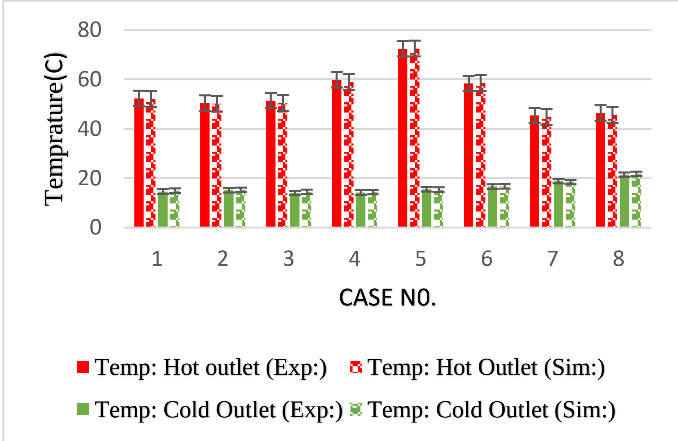

Fig 13: Comparative study of experimental results and simulation results of TTHE.

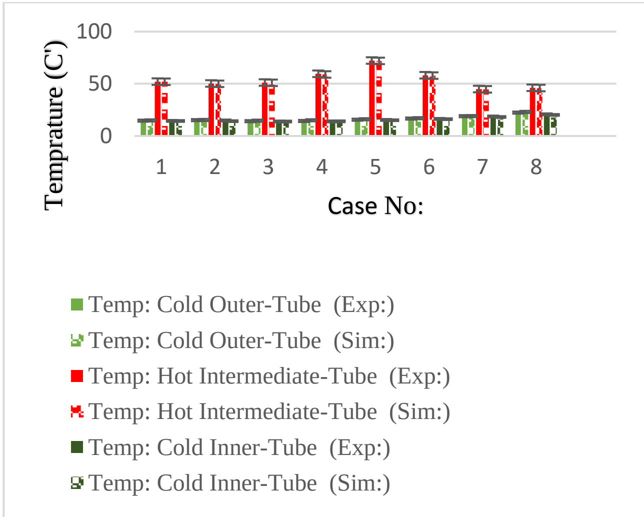

Fig 14: Comparative study of experimental results and simulation results of TCTHE

4.3 *Heat Transfer Rate of Petroleum Product for TCTHE At Different Tube Material*

The simulation of these 8 changed tube materials i.e. Copper, Aluminum, Mild-Steel ,Titanium,Stailnless-Steel-430,Stainless-Steel-304,Silver & Copper Nickel-Alloy is shown in Fig-06,-07,08,09,10,11,12,13 respectively .graphical representation as shown in figures 15,16,17,18,19,20,21 & 22 of these data is below which will help to reached at conclusion ,which material is best for heat transfer rate for TCTHE.

4.3.1 Heat Transfer Rate of Petroleum Product For TCTHE for Different Tube Material at Case-01-08

The simulation results were analyzed and it was found that using Copper, Aluminum, Mild-Steel ,Titanium,Stailnless-Steel-430,Stainless-Steel-304,Silver & Copper Nickel-Alloy as tube material for the fluids like petroleum product as heating fluid or main fluid in triple concentric tube heat

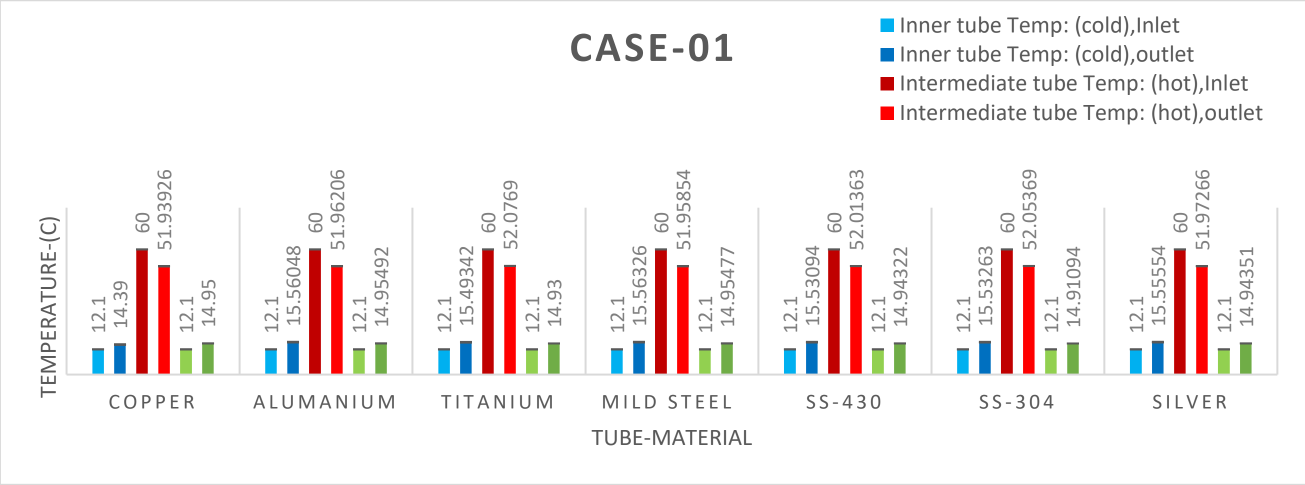

Fig 15: Case-01

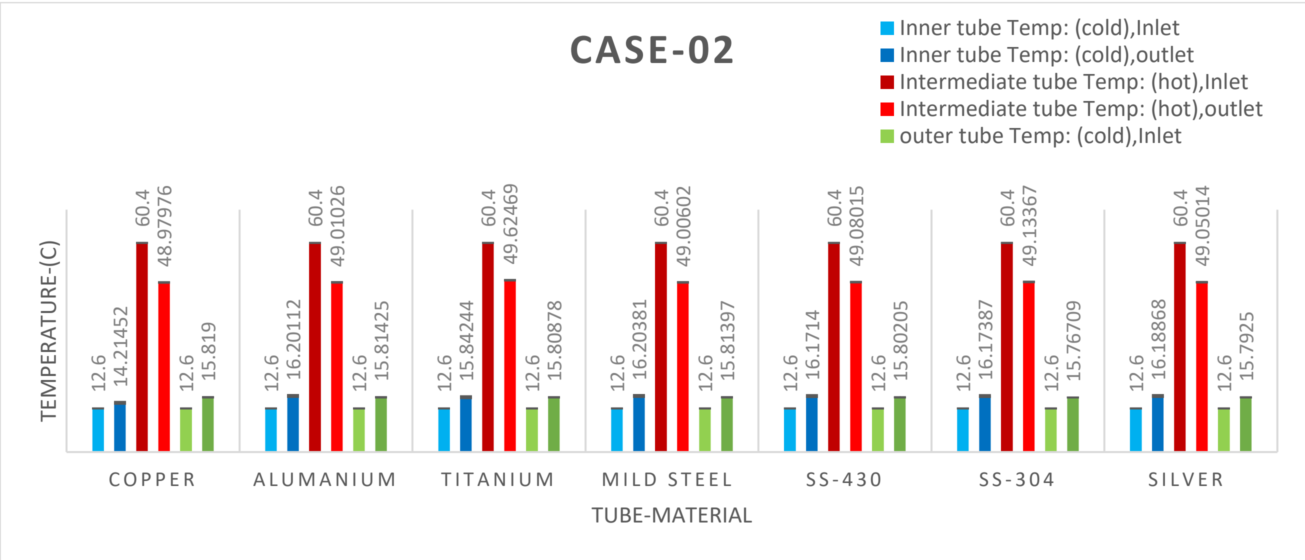

Fig 16: Case-02

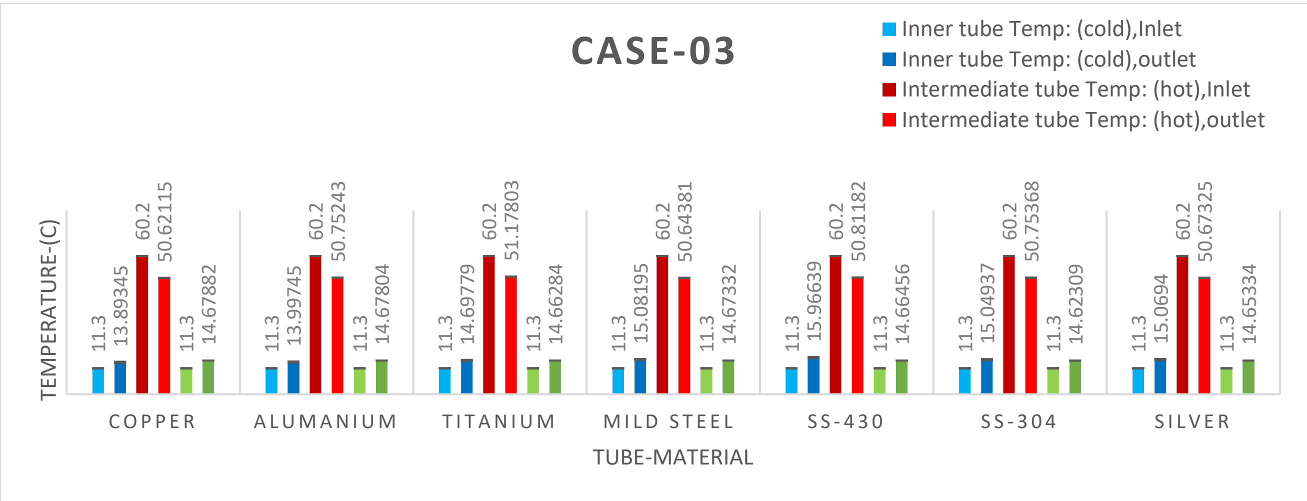

Fig 17: Case-03

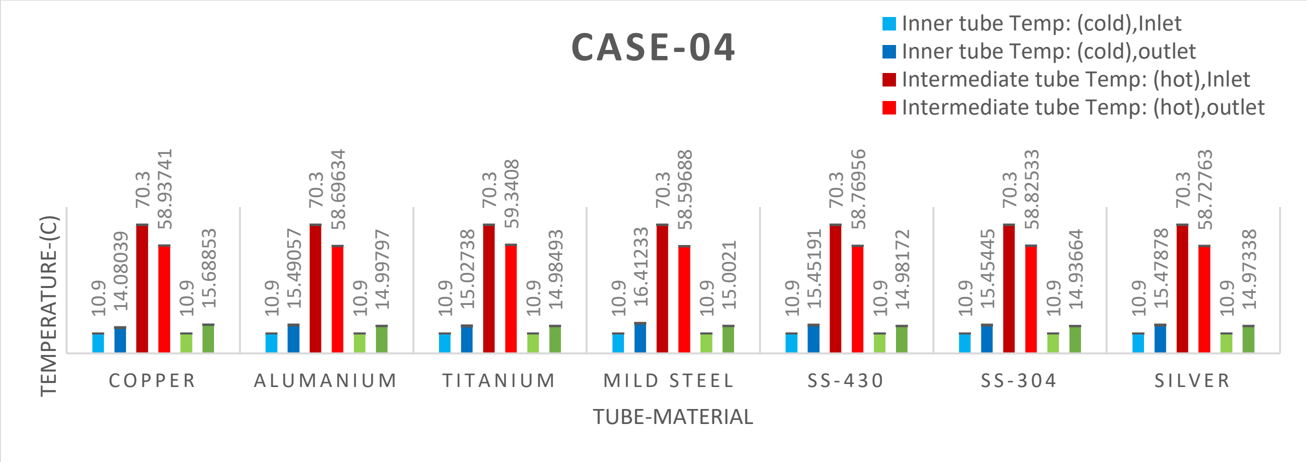

Fig 18: Case-04

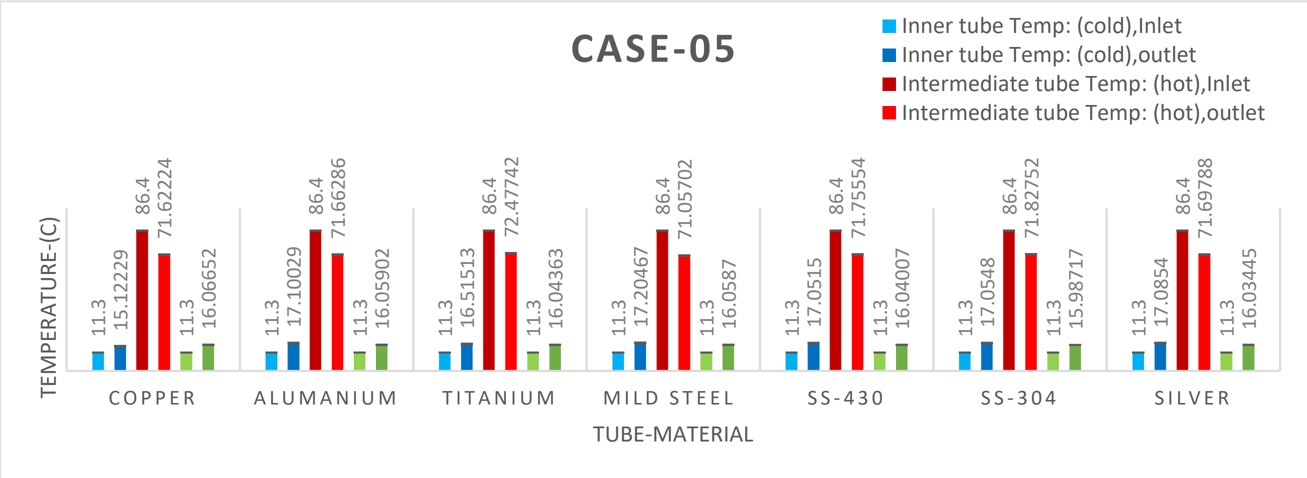

Fig 19: Case-05

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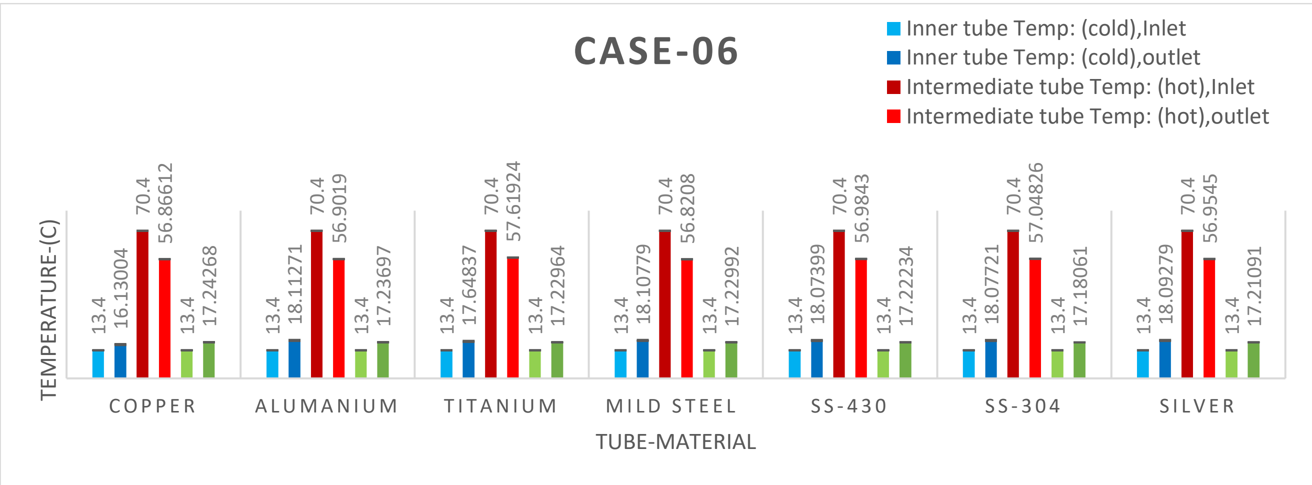

Fig 20: Case-06

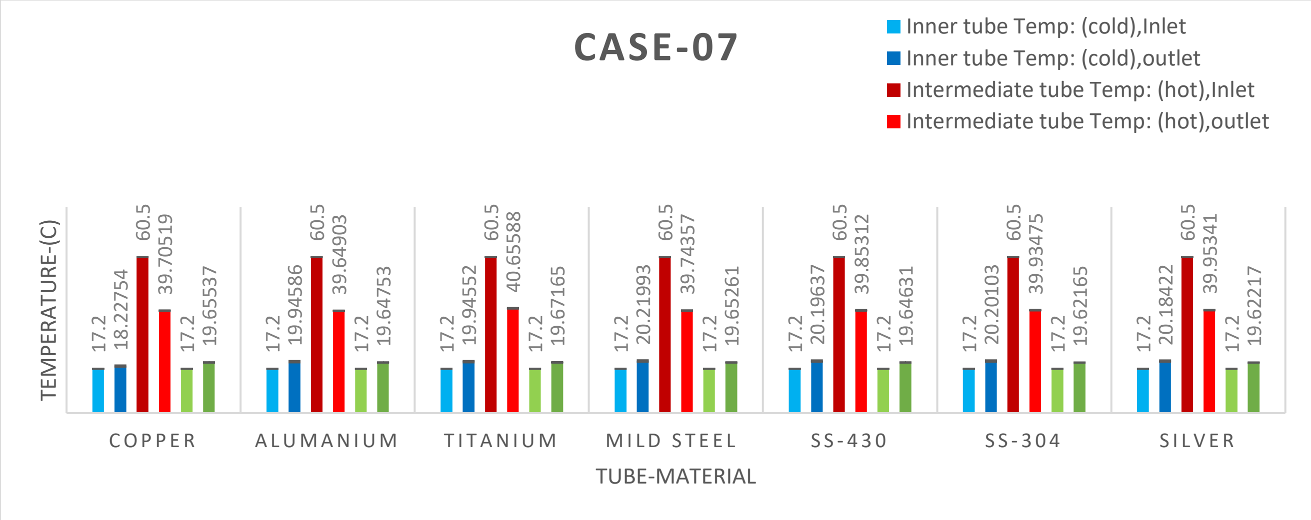

Fig 21: Case-07

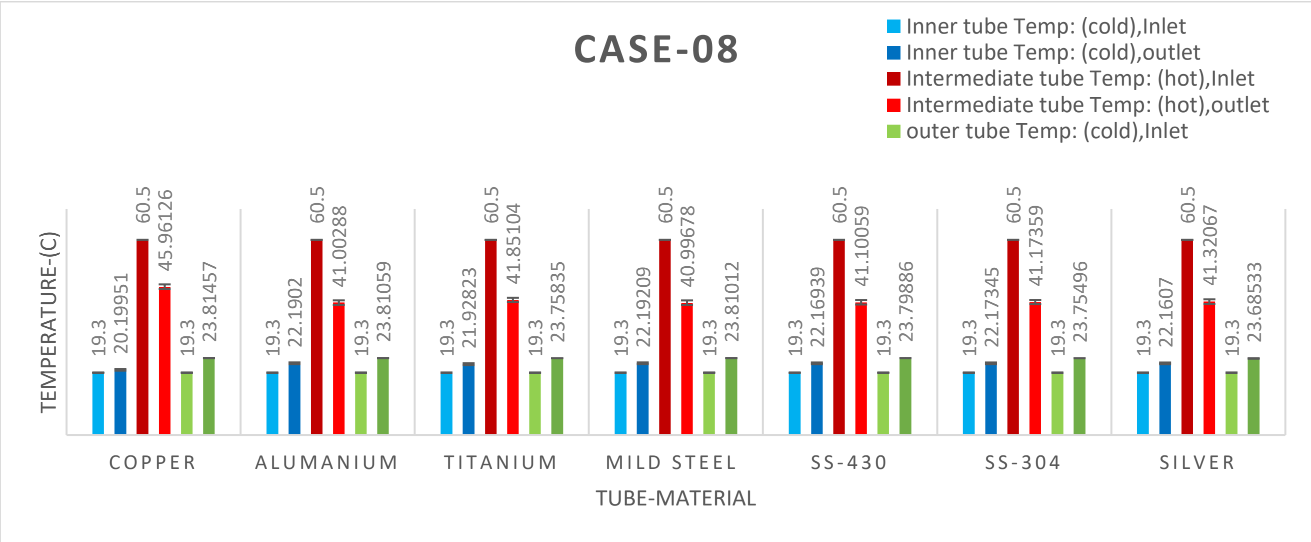

Fig 22: Case-08

5. Conclusion

This research paper exhibits a comprehensive comparison between tube in tube heat exchanger (TTHE) and triple concentric tube heat exchanger (TCTHE) by simulation on ANSYS CFD and demonstrates that TCTHE has a greater heat transfer rate compared to TTHE because of greater heat transfer surface area and higher heat transfer coefficients, hence validating the experimental results. Furthermore, this paper also unveils the comparative analysis for the best suitable material for the heat exchanger tubes. Seven different types of materials are taken under consideration that are, Copper, Aluminum, Titanium, Stailnless-Steel-430, Stainless-Steel-304, Silver & Copper-Nickle-Alloy. The simulation results through ANSYS CFD suggests and declares mild steel as best possible tube material among the aforesaid materials

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