



Design and Thermal Analysis of Polymer Composite Material of Shell and Tube Heat Exchanger

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ABSTRACT

Shell and tube heat exchanger is most commonly used in industries due to their good erection geometry, efficient service, simple maintenance and feasible improvements. Heat exchanger with shell and tube are often used in chemical engineering, power plants, waste heat recovery, oil refineries, and other large chemical process. It is suited for high pressure applications.

In this study tubes of shell and tube heat exchanger is replaced with different composite materials and analysed the properties of them. Heat exchanger is modelled in Ansys software. The composite material with various filler and matrix volume concentrations is used to develop the model. The composite material is developed with 0.6 matrix, 0.3 and 0.1 hybrid filler materials and the compositions are changed two more times. The model is simulated in ANSYS 19.2 and the properties of the composite material like heat transfer rate, overall heat transfer coefficient, Reynolds number and Nusselt number is found. The results are compared with conventional metallic materials like copper and titanium. The polymer matrix material used is High density polyethylene and E-Glass fibre, filler materials are hexagonal boron nitride.

Keywords: Reynolds number, Nusselt number, overall heat transfer coefficient, ANSYS19.2, High density polyethylene, E-Glass fiber, hexagonal boron nitride.

1. Introduction

The "key stone" of the industrial process is shell and tube heat exchangers, now a day's technology can be grown fast day by day, Shell and tube heat exchangers are broadly used in industries due to their good erection geometry, efficient service, simple maintenance and feasible improvements. Heat exchanger with shell and tube are often used in chemical engineering, power plants, and waste heat recovery. in this situation heat emission can be increases by this way life of a machinery or object can be decreases, because over heating can also causes the internal parts damage that's way now a day's cooling systems having huge demand, in this cooling systems heat exchangers are also playing vital role not only in industrial purpose some house hold purposes also used these things. In this much important thing in cooling systems are life and heat extraction of the heat exchanger, this is due to only when select the particular strong material to build this heat exchanger and here compared to conventional material like copper, titanium and stainless steel etc., By replacing those material with polymer composite these can increases life and light weight and corrosion free from chemicals also.

Here we mainly focused on the polymer composite materials with various filler material in polymer matrix. Evgin et.al [1] in this paper High density polyethylene, E-Glass fiber as matrix volume concentrations and hexagonal boron nitride is filler material, by adding this thermal conductivity of HDPE is increased, 10 vol% of hexagonal boron nitride Increases 0.386 to 0.76 w/mk. Jiaming Fan et.al [2] here ternary composite of HDPE/ E-Glass fiber with different compositions and in this HDPE/ (Al₂O₃) (E-Glass fiber) having a better performance of thermal conductivity is 54.8. Junjin Che et.al [3] here binary and ternary composite can be fabricated HDPE/ E-Glass fiber increases thermal conductivity of HDPE 0.44 to 1.6 W/mk. And ternary composite taken as HDPE/E-Glass fiber / Hexagonal boron nitride.

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HDPE/E-Glass fiber /Hexagonal boron nitride increase the thermal conductivity of 300% to 600% of original HDPE thermal conductivity. Chao Hu et.al[4] here experimentation can be done by with coating and without coating wise here the compassions taken are without Hexagonal boron nitride coating of HDPE/ Hexagonal boron nitride as 5,10,15,20% and results are by 25% of CF reached flexural tensile strength of HDPE/CF were improved by 70.62% and 40.38% compared to pure HDPE. Hai-zhe Wang et.al [5] Hexagonal boron nitride reinforcement of E-Glass fiber prepared by by chemical vapor deposition (CVD) by adding hexagonal boron nitride in E-Glass fiber strength of the material increases it is just about 0.5 wt%. Jiaming Fan et.al [6] HDPE reinforced with E-Glass fiber whiskers with 10 wt%, 20 wt%, 30 wt% and 40 wt%. The thermal conductivity of HDPE/ E-Glass fiber and HDPE/ E-Glass fiber at 40 wt% filler loading is 1.48 and 1.69 W/ (m K), which is 251.20% and 300.75% higher than that of HDPE, respectively. Geon-Woong Lee et.al [7] here composite prepared by hybrid filler in HDPE matrix with (0, 10, 20, 30, 40, 50) vol percent and here Single filler with 50 percent HBN achieves the highest thermal conductivity 3.66 w / mk. Xiujuan et.al [8] here polypropylene polymer hallow fiber heat exchanger can be fabricated and tested with poly propylene net used here without net and with neat heat transfer coefficient values are 757-1172 W/ (m2 K) and 1573-2627 W/ (m2 K) respectively. Xiangjie Chen et.al [9] here PHFHE is fabricated and here fibers can be taken with vary its number as 100,200 and 400 and by using these overall heat transfer heat exchanger values can be 758-1675 w/m2k, 369-1453 w/m2k and 296-1201 w/m2k respectively. Juan Cevallos et.al [10] in this nylon 12 carbon fiber is used as a material for webbed tube heat exchanger, for this counter flow heat exchanger used and this is a gas liquid heat exchanger. For this hot side methane gas is used with the 900c and cold side fluid is sea water with the temperature 350 C. thermal conductivity of a nylon 12 carbon fiber is 1.8 w/mk and the volume-specific heat transfer coefficient of 14 kw/m3k. Based on the literature review, the main property of heat exchanger is heat transfer coefficient this is depending upon the heat exchanging between the two materials as shell and tube. Here material plays a vital role here because high thermal conductivity materials having high heat transfer rate this will causes high heat transfer coefficient in heat exchanger. Polymer having high chemical and ware resistance, here by adding filler material in polymer can leads to improvement of various properties of a polymer material this can leads to equal or better option for metallic once. That's why polymer composite material can be taken as a tube material in heat exchanger and we have done simulation on it.

2. Preparation of Specimen

For material preparation ANSYS 19.2 software used. In this software contain design modular package is there, by using this design modular we can design geometry for the specimen now we consider the model can be a weight of 1 kg, composite can be prepared by taking the whole composite into 1kg. In this composite we were taken three materials with the various different volume percentages, in this specimen different volume are taken like 0.6, 0.3 and 0.1 volume percentages. In this whole-body weight of specimen is 1kg then first material of weight contains 0.6kg, second material of weight contain 0.3kg and third material of weight contain 0.1kg. By taking that combination we can prepare a specimen. Here prepared material is a composite material then the first, second material is a matrix and third material is filler material.

2.1. Preparing by using different materials

Here three composite materials are prepared with different volume percentages of matrix and filler materials

2.1.1 Composite material 1(MAT 1): for this composite material matrix material is HDPE (high density polyethylene), E-Glass fiber and filler materials are hexagonal boron nitride, here we taken the volume percentages of the materials are 0.6, 0.3, 0.1 with respective HDPE, E-Glass fiber and hexagonal boron nitride. the material properties for composite materials are characterized by thermal and mechanical properties by using ANSYS 19.2

2.1.2 Composite material 2(MAT 2): for this composite material matrix material is HDPE (high density polyethylene), E-Glass fiber and filler materials are hexagonal boron nitride, here we taken the volume percentages of the materials are 0.5, 0.3, 0.2 with respective HDPE, E-Glass fiber and hexagonal boron nitride. the material properties for composite materials are characterized by thermal and mechanical properties by using ANSYS 19.2

2.1.3 Composite material 3(MAT 3): for this composite material matrix material is HDPE (high density polyethylene), E-Glass fiber and filler materials are hexagonal boron nitride, here we taken the volume percentages of the materials are 0.4,0.3,0.3 with respective HDPE, E-Glass fiber and hexagonal boron nitride. the material properties for composite materials are characterized by thermal and mechanical properties by using ANSYS 19.2

2.2. Characterization

above prepared composite materials can be characterized by thermal and mechanical properties by using ANSYS 19.2.

2.2.1 Thermal properties

here first we select the study state and transient state thermal analysis can be done for getting the thermal properties in this analysis firstly we design the geometry of composite material according to volume percentages what we were taken here, then mesh the geometry and here we gave fine meshing for getting accurate values after completing the meshing part then we'll move on to temperature assignment for the geometry to get heat transfer and calculate the total heat flux generated inside the geometry(composite material). Here we gave one side of the geometry as 700c and other side is 280c then run the study state analysis he can get the total heat flux by using this total heat flux we can calculate thermal conductivity of the geometry (composite) and we know the temperature difference by calculating $T_1 - T_2$ and the formulae for thermal conductivity is

$$k = \frac{q}{\Delta T} \quad \text{w/mK}$$

Then next density of the geometry can be calculated by using static and structural analysis in this consider the above geometry and fix all sides of the body with no displacement except top face of the geometry, in this geometry one load can be acted on the top surface of the geometry then there should be reaction loads can be generated by using those we can get the density of the material.

If an object to raise the temperature of 700 or above how much required amount of heat is called specific heat, here we considered 1 kg of specimen we add temperature differentiation on created geometry how much heat required to gain the temperature is calculated then we can get specific heat of specimen (composite).

$$Q = mc_p\Delta T$$

$$C_p = Q/m\Delta T \text{ Kj/Kg K}$$

2.2.2 Mechanical properties

here we taken standard ASTM E8 piece material dimensions for mechanical testing specimen and we designed according to the above standard dimensions for the testing in ANSYS 19.2. Here we used explicit dynamic analysis is used to calculate the stress and stain for the specimen(composite) based on the above obtained stress and strain values we calculated young's modulus and Poisson's ratio and tensile and compressive strengths of the material. In static and structural analysis, we considered a cantilever beam and we add fixed support at the one end and other end was an applied load, then the software can get the results of stress and strain values and buckling analysis for determine the compressive strength of the material.

2.2.3 Simulation

Here by using composite material replace the tubes with conventional metals like copper, aluminium and titanium. Here we designed a heat exchanger with assumed dimensions canbe given below

Table 1 dimensions of shell and tube

Name	Parameter
Shell length	1.30 m
Shell outer diameter	0.5m
Shell inner diameter	0.45m
Tube outer diameter	0.05m
Tube inner diameter	0.04m

Here ANSYS 19.2 fluent is used to determine the fluent flow analysis of heat exchanger with various tube composite materials with metallic shell. Over all designing can be elaborated with step by step below

3. Modelling and analysis of heat exchanger

3.1.1 Model design

model design can be done by using ANSYS 19.2 workbench, in ANSYS 19.2 Workbench design modeler is used to design the entire geometry of the heat exchanger with composite material temperature distribution

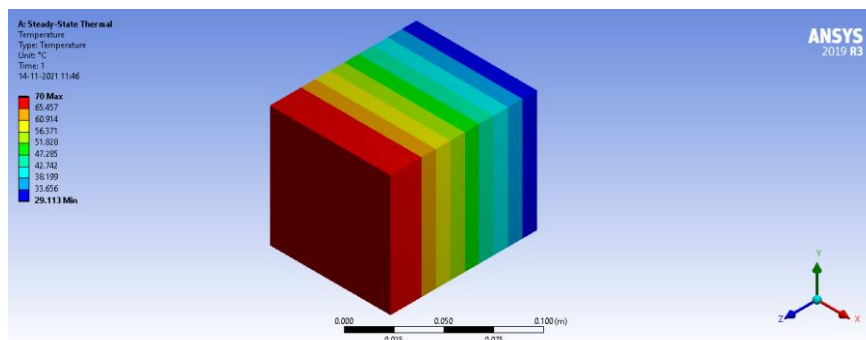


Figure 1 composite material temperature distribution

3.1.2 Meshing

this is the main step for getting accurate and exact values, depending upon the meshing results can be obtained accurately. There should be connected mesh in the geometry parts this can be done by using mesh methods like automatic and tetra/ hex dominant and edge sizing, face meshing, refinement. After completing the mesh, we should compulsorily check the geometry once weather it is fully connected meshed or not. After completing the meshing named selection can be given that is hot inlet, cold inlet, hot outlet, cold outlet, shell. And also check the parts with the fluent/ solid interface selection in this meshing model cell.

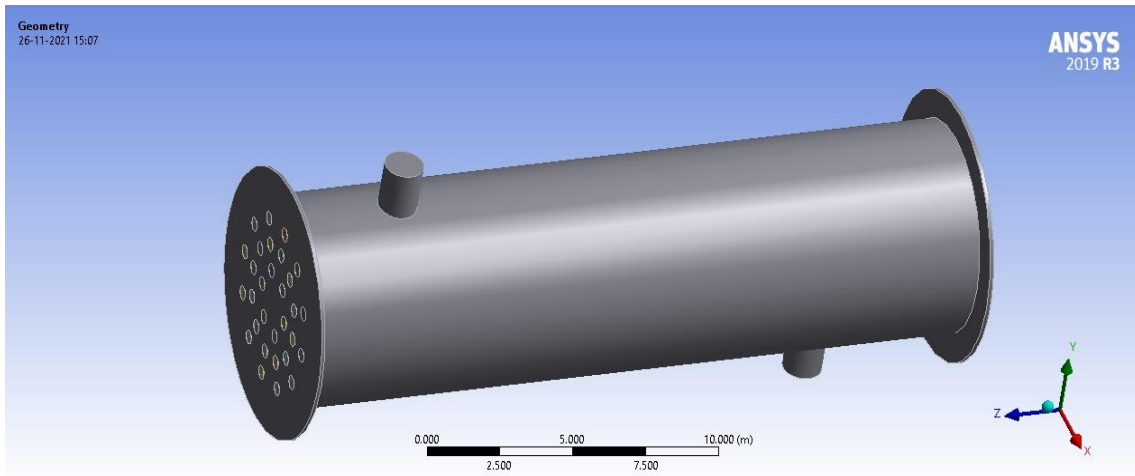


Figure 2 shell and tube heat exchanger model

3.1.3 Setup/Fluent

in this next step of meshing here all collected data can be go to this setup and it will open the ANSYS 19.2 Fluent. In this Fluent window is popup and here we check the double precision and then ok, this will open the interface of the ANSYS 19.2 Fluent, in this also step by step procedure is there firstly we select the check mesh and it will check the mesh quality of the geometry.

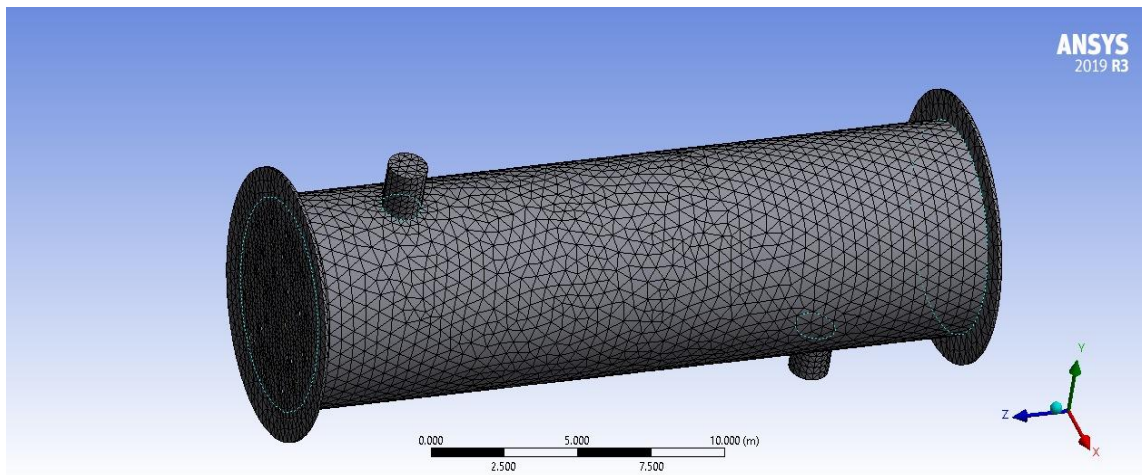


Figure 3 Meshing model of heat exchanger

Then select the model in menu this will pop up the window in this we should select the energy equation should on and then select the viscous nature of the fluent used in this analysis then we select the k-epsilon then select ok. Then next main step is select the fluent what is used for this analysis here we selected water as a fluid in the materials step, in this step we can also select the sold material in the material database after selecting the materials go to the cell zone conditions here, we assign the fluid/solid for the parts of the heat exchanger (ex: shell- copper, tube- aluminum, shell part- water, tubes part – water). After cell zone conditions boundary conditions are there, this is the most important step of the fluent, depending upon the boundary

conditions fluent can work or simulation can be done, here we give boundary conditions for the inlets and outlets of the geometry and as well as walls also. In this boundary conditions what we were taken can be shown below in a table

Table 2 Boundary conditions

Parameter	Value
Hot-inlet velocity (m/s)	0.1
Cold-inlet velocity (m/s)	0.1
Hot inlet temperature 0c	70
Cold inlet temperature 0c	28

After boundary conditions initialization is the next step, in this initialization step there are two methods are there those are standard and hybrid initialization is there if we select the standard initialization, we should select the part name in the given geometry weather it is a hybrid we should not give anything. after completing the initialization next step is run calculations here, we should give number of iterations (ex: 100,500,100....). Here we gave 100 iterations to calculate the results after it will converge at a particular time, but the results can vary slightly after 500 iterations.

After completing the calculations results step is there here, we can check the results obtained for the simulation, here graphic step is there for show the temperature distribution in the heat exchanger and pressure distribution and velocity distribution can show in a graphical view (contours/vectors) taking those pictures and represented below.

After taking the contours reports step is there in this section, we can get the results of the simulation like temperature of inlet and outlet and difference and mass flow rate and heat transfer rate and surface heat transfer coefficient and total heat transfer coefficient. Obtained results can be shown below

Mathematical formulae used for this calculation

$$\theta_1 = t_{hi} - t_{co}$$

$$\theta_2 = t_{ho} - t_{ci}$$

Here θ_1 is temperature difference of hot inlet and cold outlet

θ_2 is temperature difference of hot outlet and cold inlet

$$\Delta T_m = LMTD = \frac{\theta_2 - \theta_1}{\ln\left(\frac{\theta_2}{\theta_1}\right)} \text{ } ^\circ\text{C}$$

Here ΔT_m is logarithmic mean temperature difference (LMTD)

$$Q = mc_p \Delta T \quad W$$

$$\text{here } \Delta T = t_{hi} - t_{ho} \text{ } ^\circ\text{C}$$

$$Q = UA \Delta T_m$$

$$U = \frac{Q}{A \Delta T_m} \text{ } W/m^2K$$

$$U = \frac{1}{\frac{1}{h_i} + \frac{d_i \ln\left(\frac{d_o}{d_i}\right)}{2k} + \frac{d_i}{d_o} + \frac{1}{h_o}} \text{ } W/m^2K$$

$$\text{Raynolds number } R_e = \frac{\rho V D}{\mu}$$

$$\text{Nusselt number } N_u = \frac{h L}{k}$$

4. Results And Discussion

Here we represent the obtained characterization of the composite material here we considered three various compositions of the composite materials. Firstly, we can show the individual properties of the material what we were used in this paper.

Table 3 Mechanical properties

Material	Density ρ kg/m ³	Young's modulus E M.Pa	Poisson's ratio	Tensile strength M.Pa	Compressive strength M.Pa
Hexagonal boron nitride	2270	19500	0.21	83.3	225
E-Glass fibre	2710	72000	0.21	1950	580.15
HDPE	958	1080	0.3	250	250

Table 4 Thermal properties

Material	Density, ρ (kg/m ³)	Specific heat, Cp(j/kgK)	Thermal conductivity, k (w//mK)
Hexagonal boron nitride	2270	770	52
E-Glass fibre	2710	805	1.35
HDPE	958	1780	0.481

Here we were calculated the thermal and mechanical properties of the composite material for the various composition with the different volume percentages. Here all are calculated by using ANSYS 19.2 software for thermal properties study state thermal analysis and for mechanical properties static and structural and explicit dynamic analysis are carried out.

Material properties with various compositions can be given below. Here composition assignment can be

0.6HDPE/0.3 E-Glass fiber /0.1 Hexagonal boron nitride-material 1(MAT 1)

0.5HDPE/0.3 E-Glass fiber /0.2 Hexagonal boron nitride-material 2(MAT 2)

0.4HDPE/0.3 E-Glass fiber /0.3 Hexagonal boron nitride-material 3(MAT 3)

Table 5 Thermal properties of composites

Material	Density ρ (kg/m ³)	Specific heat Cp(j/kgK)	Thermal conductivity k (w//mK)
MAT 1	1439.724	1342.469	5.5676
MAT 2	1314.218	1433.842	5.7273
MAT 3	1589.147	1223.171	7.5481

For mechanical properties stress and strain analysis can be done in static and structural analysis in ANSYS 19.2 here stress and strain graphs can also show according with mechanical properties

Table 6 Mechanical properties of composite materials

Material	Density	Young's modulus	Poisons ratio	Compressive load N	Tensile strength M.Pa
MAT 1	1439.724	161.12	0.30	201	761.89
MAT 2	1314.218	115.53	0.27	112.3	775.74
MAT 3	1589.147	314.91	0.32	416	765.79

Here Among all three materials material 3 is having high thermal conductivity when compared to other two materials, because here for the result purpose material 3 simulation results can be shown below remaining material values can be tabulated

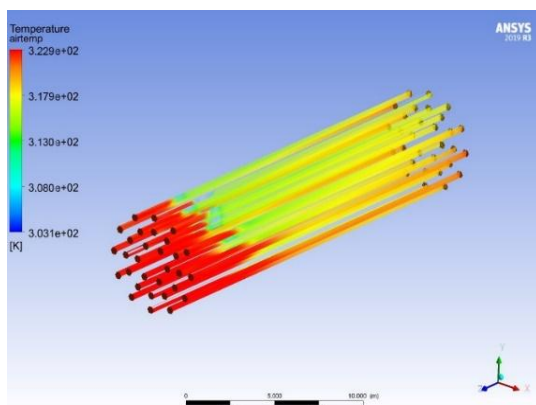


Figure 4 temperature of tubes for copper material

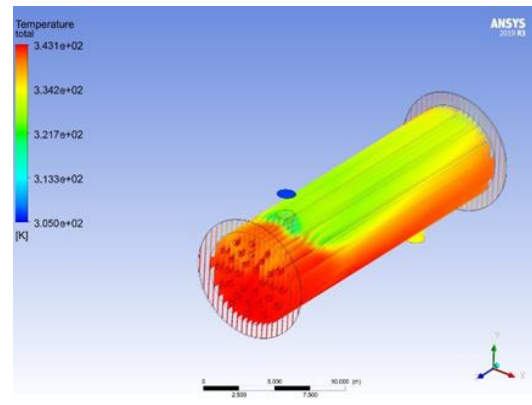


Figure 5 temperature of shell for copper material

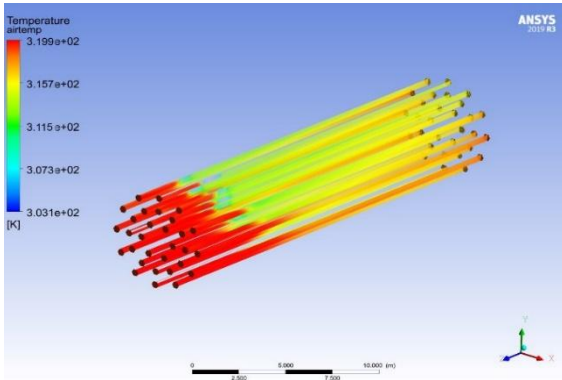


Figure 6 temperature of tubes for Titanium material

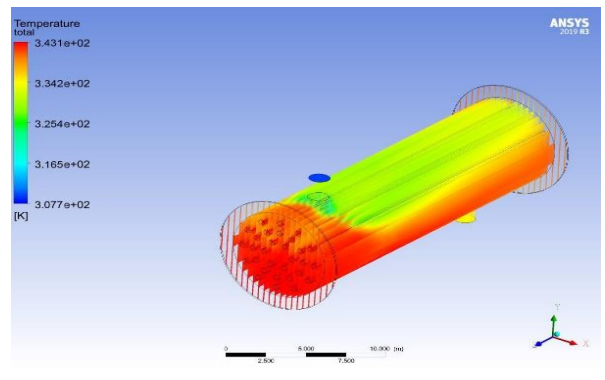


Figure 7 temperature of Shell for Titanium material

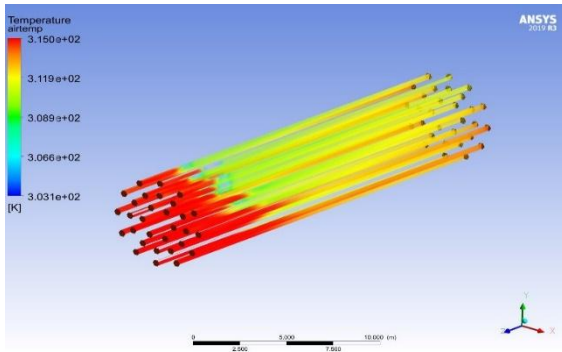


Figure 8 temperature of tubes for mat1

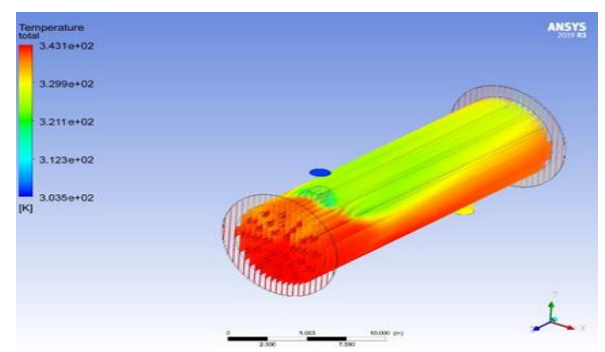


Figure 6 temperature of shell for mat1

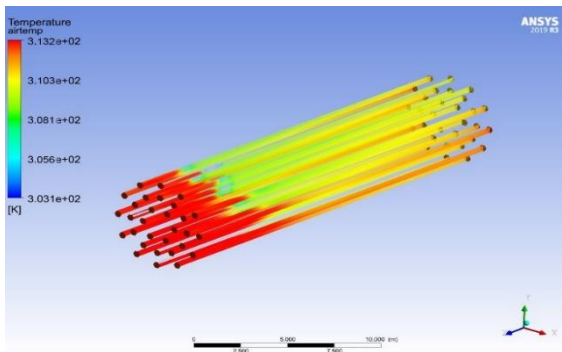


Figure 10 temperature of tubes for mat2

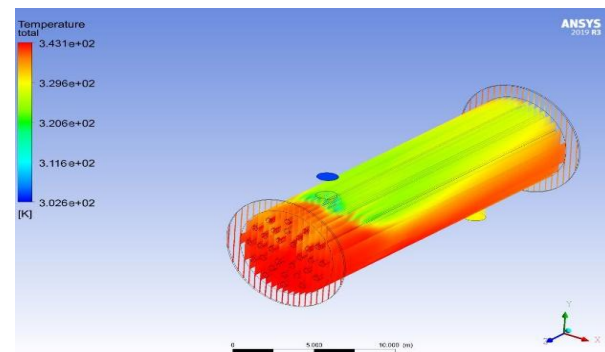


Figure 11 temperature of Shell for mat2

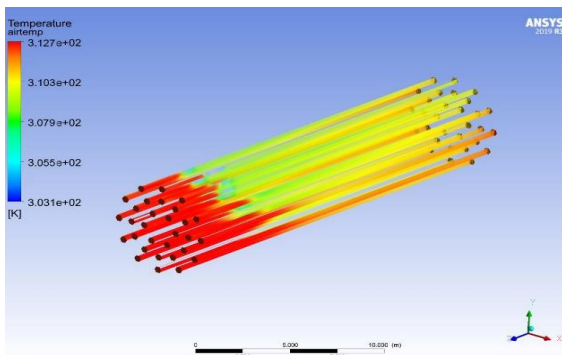


Figure 12 temperature of tubes for mat3

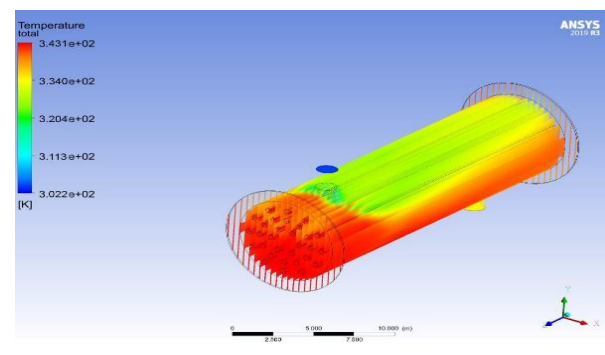
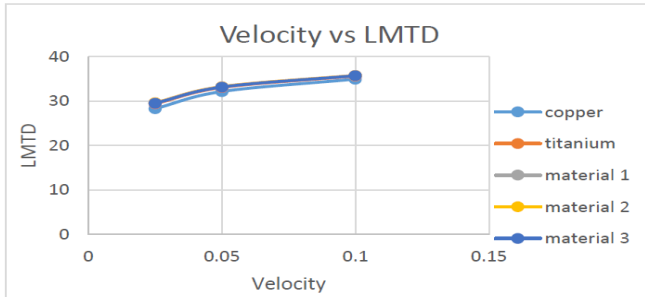
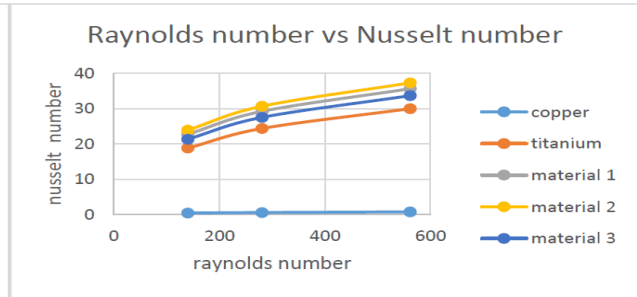


Figure 13 temperature of Shell for mat3

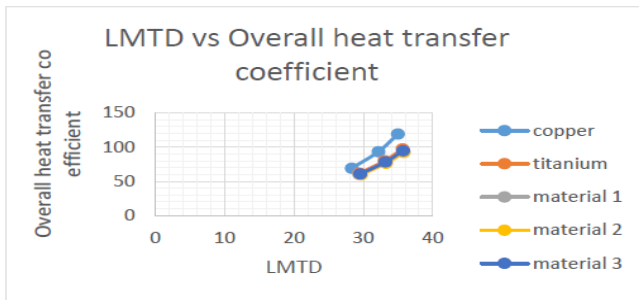
Here results can be calculated with different velocities and we obtained logarithmic mean temperature difference (LMTD) for material1 and material 2 and material 3 and here material 3 has 34.73^oc it is nearer value for copper and titanium. And we plotted graph between them according to velocities what we are given. Then next we calculated Reynolds number and Nusselt number with respective velocities for materials 1, 2 and 3 and we obtained best and nearer value for material 3 is 561.797 and 33.68 respectively. And we plotted graphs for calculated results along with copper and titanium materials. And finally, we calculated overall heat transfer for material 1,2 and 3 and as well as copper and titanium also we are shown results in



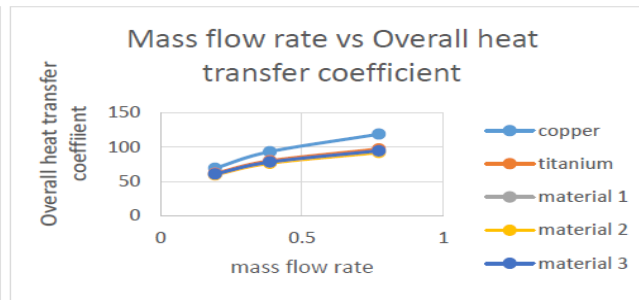
Graph 1 Graph 1 LMTD vs Velocity



Graph 2 Re vs Nu



Graph 3 LMTD vs U



Graph 4 mf vs U

graphs, here we plotted graphs between overall heat transfer and LMTD, mass flow rate what we obtained from used velocities used in this experiment.

Table 7 Temperature distribution in Shell and Tube

Material name	Inlet cold Temp °C	Inlet hot Temp °C	Outlet cold Temp °C	Outlet hot Temp °C	LMTD °C	Weight of Heat exchanger(KG)
copper	28	70	56.75	31.88	34.96	4.5435
titanium	28	70	46.85	34.56	35.65	6.0583
Material 1	28	70	41.85	30.36	35.77	3.7435
Material 2	28	70	40.05	29.53	35.80	3.6521
Material 3	28	70	39.55	29.11	34.73	3.4673

Table 8 simulation result at velocity 0.1 m/s

Material name	LMTD 0c	Reynolds number Re	Nusselt number Nu	Overall heat transfer coefficient (U) w/m2k
copper	34.96	561.797	0.723	98.92
titanium	35.65	561.786	30	97.31
Material 1	35.77	561.759	35.66	93.14
Material 2	35.80	561.768	37.32	91.91
Material 3	34.73	561.757	33.68	94.60

6. Conclusion

In this paper we are briefly studied that the replacement of the shell and tube heat exchanger tubes with the composite material, here we consider the ternary polymer composite material as a tube material. For this composite we were taken various compositions with different volume percentages of filler and matrix materials those are high density polyethylene (HDPE) and E-Glass fiber (EG) and Hexagonal Boron Nitride (HBN). Here we considered the HBN volume composition (0.6/0.3/0.1) and (0.5/0.3/0.2) and (0.4/0.3/0.3) HDPE/EG/HBN respectively. After preparing the material we were characterized the material properties of the taken composite material after that by using these properties we were designed shell and tube heat exchanger by using ANSYS19.2 software. This can be simulated as fluent analysis in ANSYS 19.2. After simulation we can get the required properties of heat exchangers like heat transfer rate and overall heat transfer coefficient and Reynolds number and Nusselt number of the heat exchanger, here we compared our results with the conventional metallic materials like copper and titanium. Log mean temperature difference (LMTD) for copper is 34.96, titanium is 35.65 and Mat 3 is 34.73. From the results LMTD is good for Mat 3 compared to all other materials. By comparing the values of overall heat transfer coefficient of copper, titanium and material 3 is 98.92 and 97.31 and 94.60 respectively. Here Mat 3 is nearer value for copper and titanium. We conclude that these are also good material for heat exchanger tubes to avoid corrosion, chemical reactions and long life when compared to metallic once. From the results we observed that material 3 is having the highest thermal conductivity and this is happened because the composite material 3 is having the highest composition of hexagonal boron nitride (HBN) percentage with compared to remaining composites used in this project. As copper and Titanium are metals and the composite materials used here are polymer materials the weight of all three composite materials is comparatively lower to the metals. By replacing with these composite materials with copper the cost of the production will also decrease.

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