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Simulation Study of Heat Exchanger Designed for Co2 Capturing Pilot Plant

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Abstract: Heat exchanger is heart of the any heat transferring system, which is utilized to transfer the heat from one fluid to the other. Based on the fact shell & Tube heat exchanger is selected for the required CO2 capturing pilot plant to minimize the cost and low pressure drop. Matlab code has been generated for numerical calculation of heat exchanger basic component dimensions. The geometry of the heat exchanger has been made in the solid works part and Assembly module. The assembly of heat exchanger has been imported in the Ansys workbench and simulated with Ansys Fluent module. Our requirement for the stripper inlet of fluid from the tube side is 90ºC and the fluid rejected from the stripper is nearly 120ºC. The tube side inlet of fluid is at 40-45ºC. This simulation study is carried out to achieve the temperature very close to the required inlet temperature in stripper for the desorption process of Co2 gas. From the results it has been observed that 80ºC temperature has been achieved at 5LPM flow rate of fluid mixture which is reducing the power consumption for heating the fluid with mild heating heater..

Keywords: Gearbox, Lubricant, gear pairs, Simulation, Fluent, Castor.

Introduction

Heat transfer is one of the key aspects of machineries, devices and industrial processes for maintaining their functionality and also for achieving better product quality. Hence, heat exchangers of different type sand sizes are used in these applications with the purpose of removing the extra process/device heat to maintain the desirable working temperatures. However, the size of a heat exchanger is a major consideration for any type of process/device as it decides the space requirements (i.e., the size) of the machine/device or the processing plant. Global warming is a very serious problem and anthropogenic CO2 emission is one of the biggest contributors to this phenomena. Most of the CO2 are emitted from different industries. For instances, coal combustion in a 500 MWe coal-fired power plant produces 8000–10000 tons of CO2 per day while a similar capacity natural gas combined cycle power plant produces about 4000 tons of CO2 per day. Through carbon capture and storage (CCS), the CO2 emitted from these sources can be prevented from entering the atmosphere. CO2 separation in carbon capture process can be achieved through different technologies: absorption, adsorption, membrane, and cryogenic among others. Among these technologies, absorption in which a liquid solution (solvent) is used to capture CO2 from the gas stream is the most matured and commercially-ready option. Different solvents categorized as chemical, physical and chemical-physical are applied in absorption processes.

Problem Statement

Heat exchanger is heart of the CO2 capturing unit. There is challenge with corrosive solvent amine to design high temperature difference. Required to design with the minimum energy utilization in the system.

Objective of Work

From problem statement the objective of work is to selecting the adequate Heat exchanger and achieves the required temperatures at the outlet of the heat exchanger. For that the Simulation study on the Heat exchanger is too carried out in the ANSYS workbench with fluent Module. The simulation study is carried out in several steps and with and with some basic knowledge of heat exchanger.

Literature Survey

(Jiang 2017) et al. worked on the energy consumption associated with absorbent regeneration which is the most critical challenge for the industrial implementation of chemi-sorption based CO2 capture processes. They investigated the techno-economic performance of the advanced NH3 process integrated with a 650MW coal-fired power plant, and evaluated it technical and energy performance using a rigorous, rate-based model in Aspen Plus. A sensitivity study was also performed to optimize the modelling parameters, i.e. the stripper pressure and the absorbent NH3 concentration, and minimize the regeneration duty. A very competitive regeneration duty of 1.86 MJ/kg CO2 was achieved for an optimized stripper pressure of 12 bar and an NH3 concentration of 10.2 wt%, with a total equivalent work of 0.164 MWh/t CO2 for absorbent pumping, NH3 regeneration and CO2 compression. They also used a validated economic model to estimate the capital investment of the advanced NH3 process and its corresponding economic performance. With its significant reduction in energy consumption, the proposed process was economically competitive with CO2 avoided cost was as low as US$40.7/t CO2. This was 34% and 44% less than the reference NH3 and monoethanolamine (MEA) processes, respectively. The advanced NH3 based flash stripper also had technical CO2 and economic advantages over other amine absorbents, such as MEA and pipe razine (PZ), as well as other advanced stripper modifications, such as inter-heating process, revealing its process viability in commercial application.

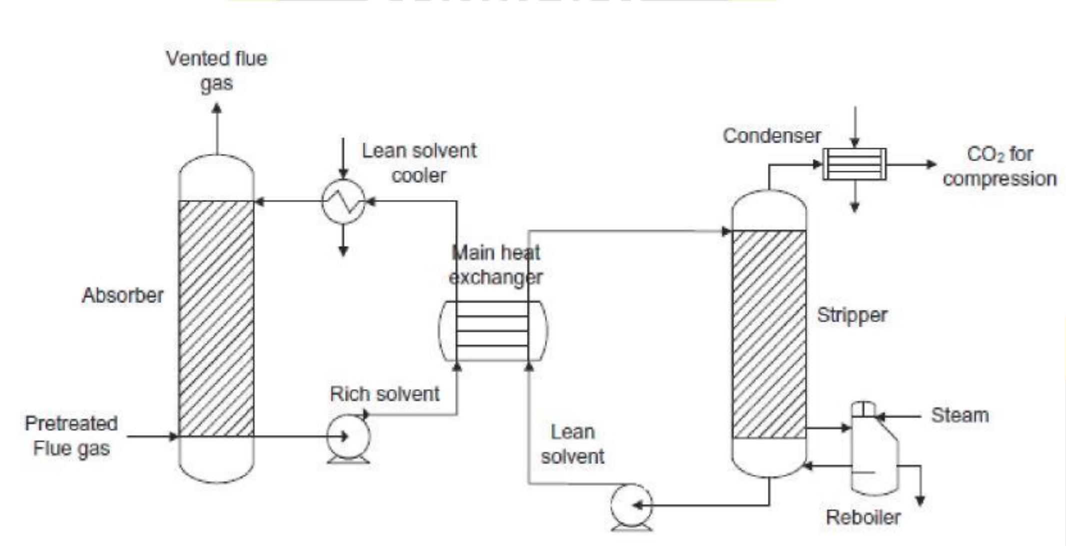

Figure 1 The conventional CO2 absorption and desorption process. (Jiang 2017)

(Kalatjari 2019) et al. setting up a dynamic pilot plant, and carried out capturing of CO2 using the aqueous Mono-Ethanol Amine at various concentrations and temperatures. They used four models of eNRTL-Bishnoi, Gabrielsen's approach, ASPEN eNRTL default and ASPEN-eNRTL Regressed-DRS for thermodynamic modeling and simulation of the pilot plant data. Using Gabrielsen's approach, the average absolute deviations for absorber and desorber columns were 10.2 and 10.3, respectively, using MEA (27 wt %); 10.2 and 9.4 using MEA (29 wt%) with high CO_2 feed gas. Moreover, using the different MEA concentrations with low CO_2 feed gas, the AAD% were 9.9 and 10.6 for the absorber and desorber columns, respectively.

(Lin 2019) Solvent selection is one of the promising ways to reduce energy use of amine scrubbing for CO_2 capture. The heat of CO_2 absorption is an important property of the solvent. Its effect on total energy use is not obvious: it directly increases the heat duty of regeneration, but indirectly reduces stripping steam and compression work. The optimum heat of absorption was quantified using the approximate stripper models developed in this work, including one of the most promising alternatives, the advanced flash stripper. Total equivalent work was used to indicate the overall energy performance. A wide range of lean loading, reboiler temperature, and compression efficiency was investigated. The optimum heat of absorption is 70–125 kJ/mol CO_2 at various conditions, which is generally higher than existing solvents with 60–80 kJ/mol. Operation at low lean loading and low reboiler temperature requires higher heat of absorption to boost the partial pressure of CO_2. The advanced flash stripper requires lower heat of absorption than the simple stripper to achieve minimum total equivalent work and was demonstrated as a flexible system that can be applied to a wide range of heat of absorption while still maintaining remarkable energy performance.

(Louis 2016)et al. tested four amines under challenging conditions (1–5 M at 120ºC) to confirm the behaviors. Due to recent interest in blended amine solvents (1º or 2º with 3ºor SH) for improved reaction kinetics, CO_2 absorption capacity and recoverability, four binary amine combinations. Blends containing low concentrations of 1ºor 2º amine show promise for use with carbon steel due to the formation of a siderite product layer and low corrosion levels. An increase in concentration of 1ºor 2ºamines, shows higher Fe ion concentrations initially as well as significant weight change to the coupon. However, the formation of more diverse product layers at longer time intervals reduces the Fe ion concentration in the bulk. Blends generally offer reduced corrosion compared to 1ºor 2º amines alone, another benefit towards deployment.

(Rashidi 2016)et al. investigated corrosion behavior of activated MDEA solution in the background of CO_2 bulk removal from ammonia plant, Kermanshah, Iran. The visual inspection reports demonstrated a consistent pattern of damage at the tubes' entrance of lean amine air-cooled heat exchanger, made from carbon steel. To provide information on the corrosion in tubes, a series of experiments was carried out at 85ºC, with different combinations of CO_2 loading (0.02, 0.25 and 0.6 mol/mol) using electrochemical techniques, weight loss coupons, chemical analysis, and surface analytical techniques. Results showed that the dominant process was the effect of erosion corrosion. It seems that impinging particles remove the semi-protective layer of $FeCO_3$ on the carbon steel surface, resulting in continuous exposure of fresh metal surface to the corrosive environment, and a higher corrosion rate.

(Abeykoon 2020) study aims to investigate the design procedure of a heat exchanger theoretically and then its performance will be analyzed and optimized using computational fluid dynamics. For the design purposes, a counter flow heat exchanger was considered and its length was theoretically calculated with the LMTD method while the pressure drop and energy consumption were also calculated with the Kern method. Afterwards, a computational model of the same heat exchanger was implemented with ANSYS and then this model was extended to six different models by altering its key design parameters for the optimization purposes. Eventually, these models were used to analyze the heat transfer behavior, mass flow rates, pressures drops, flow velocities and vortices of shell and tube flows inside the heat exchanger. Theoretical and CFD results showed only a 1.05% difference in terms of the cooling performance of the hot fluid. The axial pressure drops showed positive correlations with both the overall heat transfer coefficient and pumping power demand. Overall, the results of this study confirms that CFD modelling can be promising for design and optimization of heat exchangers and it allows testing of numerous design options without fabricating physical prototypes.

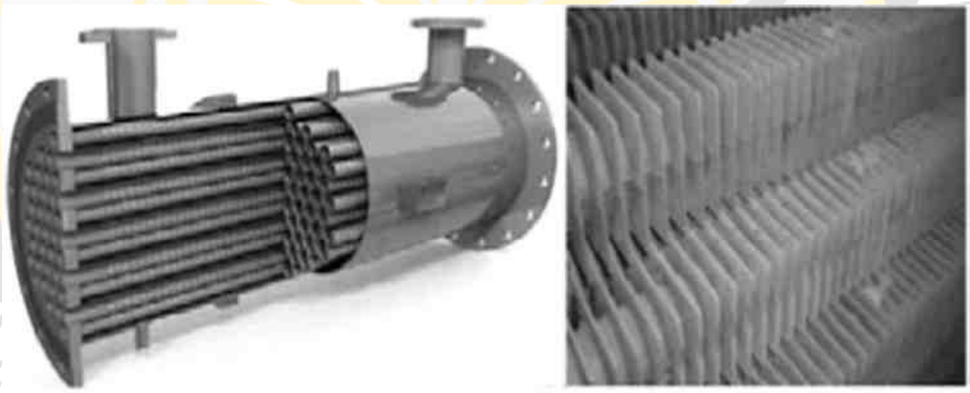

Figure 2 Different types of heat exchangers based on their construction: (a) – A single pass tubular (left), A plate (right).(Abeykoon 2020)

(García-Castillo 2019)et al. amidst the various design approaches available for the design of plate-fin heat exchangers for multi-fluid applications, are those based on the segmentation of the exchanger length into blocks that correspond to the enthalpy intervals in the Composite Curves. Such methods are characterized by three main features: identification of exchanger sections, surface selection from among the available types, and reconciliation of dimensions by pressure drop relaxation. The work presented in this paper introduces new concepts and removes some limitations in earlier approaches. In the first place, it reduces the number of block sections when the space between them is too short to fit intermediate headers along the length of the exchanger. Additionally, it introduces the concept of surface design as an aid to fulfill the heat transfer duties. Finally, it allows the design to meet fixed dimensions as design objective together with the heat duty within the limitations imposed by the pressure drop. The approach is demonstrated using a case study solved by different authors in the open literature. It is shown that the number of block sections is reduced from 3 to 2.

Methodology

- Selecting the appropriate type of heat exchanger for the system.
- Calculate heat transfer rate required for the heat exchanger.
- Design the heat exchanger.
- Create a model in the CAD Modelling Software.
- Prepare a Model for Finite Element Analysis in the Simulation Software.

- Prepare boundary conditions.
- Find out the optimum material properties and flow rate of fluids.
- Prepare a Model for fulfill the basic requirement of the pilot plant.

Experimental Process

- Shell and Tube type Heat Exchanger is found preferable due to lower pressure drop in the system and working pressure is also lower.
- Design a MATLAB Code by governing Eq.s
- Find the Heat Exchanger Dimensions for the Geometry and Simulation Studies
- Create Fluid Domain in ANSYS for CFD Simulation Studies.
- Defining Mesh and Name indication for identifying the position of the contour and Results.
- Defining the shell side and tube side flow
- Apply the Model condition, Cell zone condition, and Boundary Condition.
- Calculate the Initialize
- Run the Setup

Design of Heat Exchanger in Matlab

Matlab is the best utilizing software for solving the complex equations. This program contains a input and output parameters. Based on the output the number of tubes, Length of tubes, diameter of shell and diameter of tubes were found.
Heat exchanger design Matlab program has been given as following:

```
clc
clear
ms=0.085075;    %Mass flow rate on shell side kg/s
mt=0.07721;     %Mass flow rate on tube side kg/s
tsi=120;        %Temperature inlet on shell side C
tso=93;         %Temperature outlet on shell side C
tti=45;         %Temperature inlet on tube side C
tto=80;         %Temperature outlet on tube side C
rhos=1025;      %Density on shell side kg/m3
rhot=926.58;    %Density on tube side kg/m3
cps=3768;       %Sp.heat on shell side J/kgK
cpt=3287.1;     %Sp.heat on tube side J/kgK
mus=0.0008;     %Dynamic viscosity on shell side Pas
mut=0.001949; %Dynamic viscosity on tube side Pas
ks=0.4535;      %Thermal conductivity on shell side W/mK
kt=0.4098;      %Thermal conductivity on tube side W/mK
Ds=0.1          %Diameter of Shell m
do=0.01         %Outer Diameter of tubes m
B=0.25;         %Baffle spacing m
Pt=1.25*do;     %Tube pitch m
t=0.001;        %Tube wall thickness m
di=do-t-t;      %Inside Diameter of tubes m
De=1.1*[(Pt^2)-(0.917*do*do)]/do; %Equivalent shell
diameter m

%Empirical constants for 2 tube passes flow arrangement
n=2;
n1=2.207;
k1=0.249;
Npass=2;
Nt1=k1*((Ds/do)^n1);    %Number of tubes
Nt=round(Nt1)           %Number of tubes roundoff to
nearest integer
CL=Pt-do;               %Gap between two tubes m
as=Ds*B*CL/Pt;          %Free flow area on shell side m2
vs=ms/(as*rhos)         %Shell side velocity at free flow area
m/s
vt=(mt*Npass/Nt)/(3.14*di*di*rhot/4)    %Tube side velocity
m/s
Res=rhos*vs*De/mus;     %Shell side Reynolds number
Ret=rhot*vt*di/mut;     %Tube side Reynolds number
Prs=mus*cps/ks;         %Shell side Prandtl number
Prt=mut*cpt/kt;         %Tube side Prandtl number
hs1=ks*0.36*(Res^0.55)*(Prs^(0.33))*[(mus/0.000333)^0.14]
/De;
hs=round(hs1) %Shell side heat transfer coefficient W/m2K
ht1=kt*0.027*(Ret^0.8)*(Prt^(0.33))*[(mut/0.000777)^0.14]/
di;
ht=round(ht1) %Tube side heat transfer coefficient W/m2K
x=do/di;
Kw=16;          %Thermal conductivity of tube material
stainless steel W/mK
U1=[(x/ht)+(do*(log(x))/(2*Kw))+(1/hs)]^-1;
U=round(U1);    %Overall heat transfer coefficient W/m2K

R=[tsi-tso]/[tto-tti];
P=[tto-tti]/[tsi-tti];
F1=[[(R*R)+1]^0.5]*[log((1-P)/(1-(P*R)))];
F2=2-P*(R+1-((R*R)+1)^0.5);
F3=2-P*(R+1+((R*R)+1)^0.5);
F=F1/[(R-1)*log(F2/F3)]; %Correction factors for heat
transfer surface area.
```

Meshing

FEA software typically uses a CAD representation of the physical model and breaks it down into small pieces called finite "elements" (think of a 3-D puzzle). This process is called "meshing". The higher quality of the mesh (collection of elements), is a better mathematical representation of the physical model. ANSYS workbench simulation provides two forms of automated meshing: Fully automatic and manually directed automatic. Both forms employ a fault-tolerant philosophy and it meaning that, if a problem occurs, at least 12 attempts of automatic trouble-shooting are made before the meshed fails and tags the area of difficulty with a label. The Manual directed means that the user may specify meshing over rides on specific areas of a part or the baseline mesh

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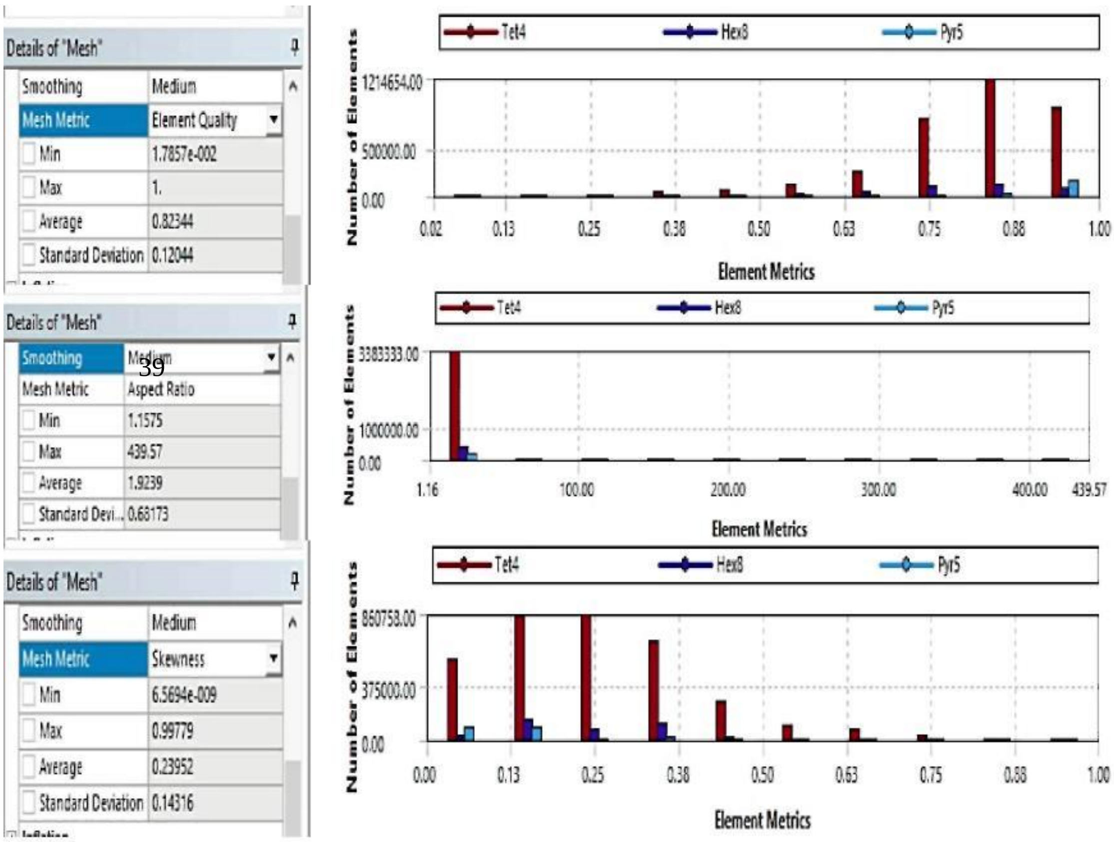
density on entire parts that differ from other parts within the assembly, either for accuracy or efficiency purposes. Here in current work the fully automatic meshing of gearbox is done. The element chose for meshing by ANSYS is ten nodes tetrahedral shown in Figure 6.4 this element are good for meshing in curvature area.

Numbers of node and element use for meshing are listed in Table 1 below.

Table 1 Mesh Information for Ansys



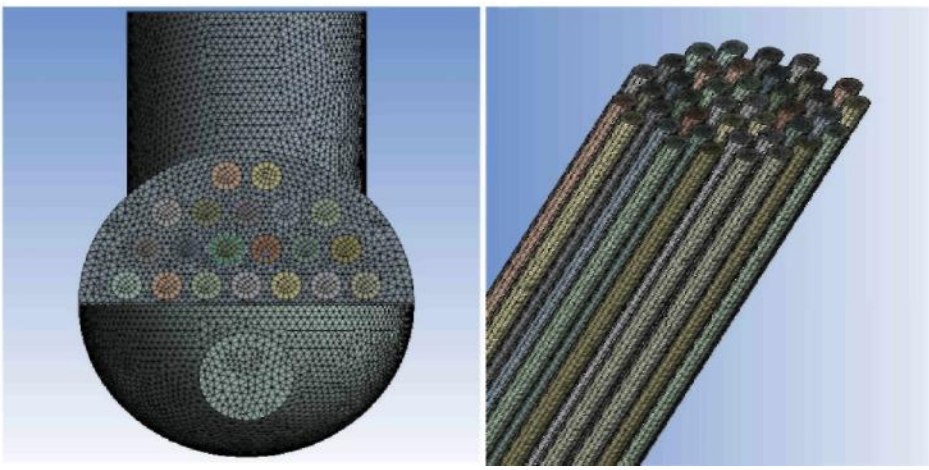


Figure 2 Meshing Model of Heat Exchanger

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Sampling points for Parameters

Figure 3 shows the location of the temperature sensor to capture the actual data from the particular location. This will help to collect the data from the particular location and resolve the temperature contour reading complexity. These sensors are necessary because of minor difference observation at the location to observe the temperature behavior.

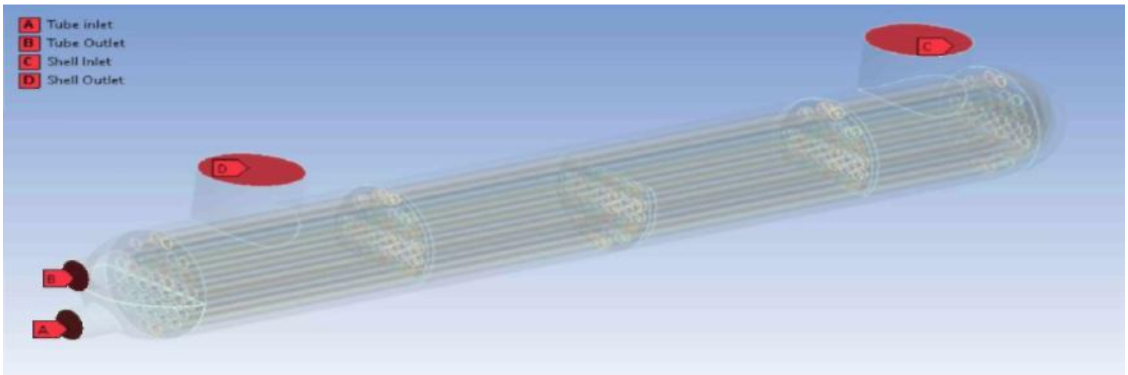

Figure 3 Sensor Location in the Simulation Study

Material property

Materials in the Workbench are imported from material library available in ANSYS database. If the material is not available in material library then it is required to define manually. An aqueous amine property for hot side is taken at average bulk temperature of 100ºC. All Properties except Conductivity are readily available from catalogs of Water-MEA solvent. Conductivity of only pure MEA is available. So conductivity of aqueous MEA mixture is found by weighted average of the mixture properties.

Conductivity of 50%Water-MEA mixture = 0.5*Conductivity of Water + 0.5*Conductivity of MEA

Aq. Amine pure Hot side					
	Density (kg/m3) @20	Sp.heat(J/kgK) @100	Viscosity (cP@100)	Viscosity (PaS@100)	Conductivity @ 80C
MonoEthanolAmine MEA	1017	3181.96	2	0.002	0.23
Water	1000	4186	0.2814	0.0002814	0.677
50-50% Water-MEA	1025	3768	0.8	0.0008	0.4535

Figure 4 Aq. Amine Pure at Hot Side Properties

Similarly, aqueous amine properties for cold side are taken at average bulk temperature of 60ºC. And properties of CO2 gas are taken at 60ºC. The property for cold side fluid of 10%CO2 + 90% (Water+MEA) mixture is obtained by weighted average.

Property of 10%CO2 + 90% (Water+MEA) = 0.1*property of CO2 + 0.9*property of (50%water+50%Amine)

Aq. Amine + CO2 cold side					
	Density (kg/m3) @20	Sp.heat(J/kgK) @100	Viscosity (cP@100)	Viscosity (PaS@100)	Conductivity @ 80C
50-50% water-MEA	1025	3558	2	0.002	0.4535
CO2(gas)	40.8	849	1.495	0.001495	0.01663
10% CO2 + 90% (Water+MEA)	926.58	3287.1	1.9495	0.0019495	0.409813

Figure 5 Aq. Amine + Co2 at Cold Side Properties

Due to very low flow rate the shell and tube heat exchanger requires 2 tube passes for heat transfer. The shell diameter is 0.1m, tube diameter is 0.01m and baffle spacing is 0.25m with 25% baffle cut. The number of tubes is 40, i.e 20 tubes in 2 pass configuration. The tube length is 0.7896m ~0.8m. The required Heat load is 8.65KW and exit temperature of hot fluid is around 91ºC.

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Boundary condition

The boundary condition in Preprocessor is very important for getting approximate result nearer to actual condition. In present work the boundary condition is define as domain in pre processer. The first domain is defined as Shell and second is Tubes. The Tube has cold side flow and Shell has a hot side flow of fluid. This flow effect of fluid domain is transferring to the heat for that energy generation option is required to turn on.

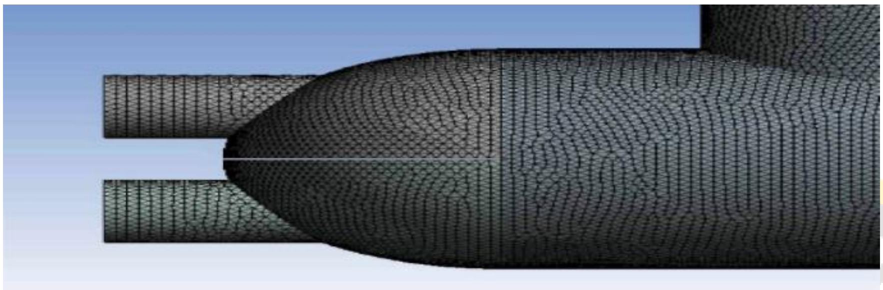

Figure Error! No text of specified style in document. **Meshing of Shell & Tube Heat Exchanger**

Figure 7 shows the fluent setup model for the simulation study in which energy is on due to heat transfer in the fluid and fluent k-ε model has been selected for solving the heat transfer study by selecting the standard mode and remaining Model constants setting adopt as default.

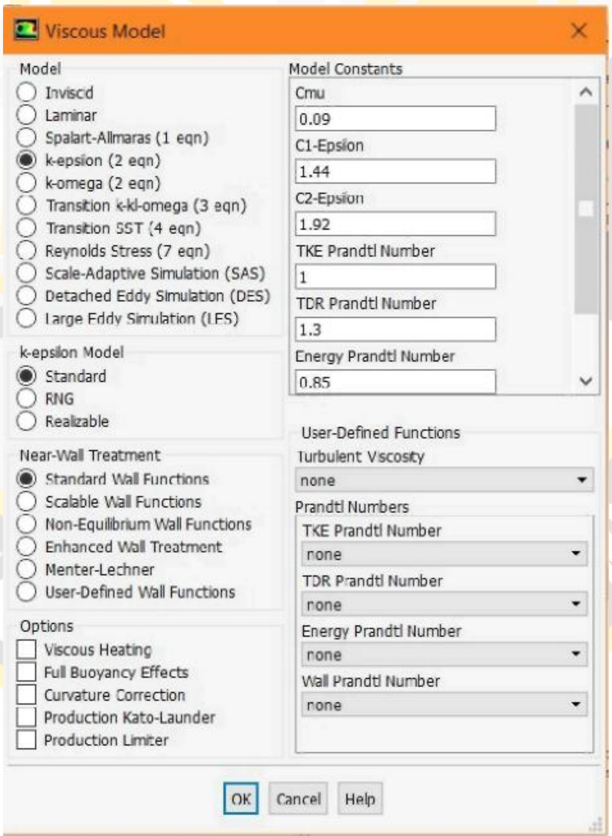

Figure 7 Realizable k-epsilon Model with standard wall function

1.1. Solution

The solution is the processer in which the problem is solve for given boundary condition. Method used for solving the model is Ansys Fluent Phase Coupled SIMPLE with least squares cell based as shown in Figure 8.

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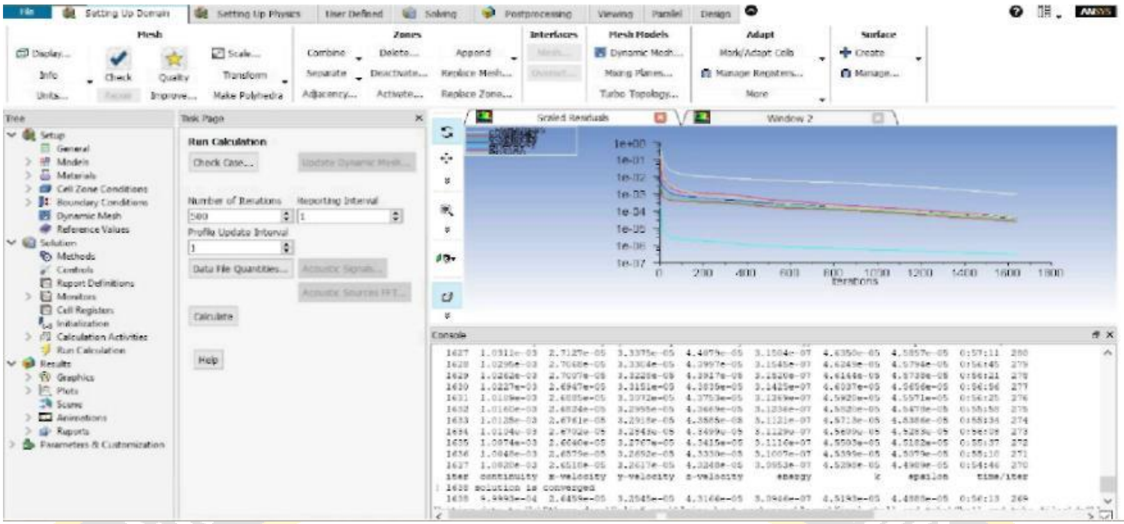


Figure 8 Convergence of Heat Exchanger model

Result & Discussion

Figure 9 shows the Temperature contour plot in Heat Exchanger. It shows the high temperature at the inlet surface of shell side. Fluid temperature is applied by heat hot fluid temperature due to reboiling by assumption from the design points, which is equivalent to 393ºK. Heat Exchanger is quite difficult to simulate and also it required lots of skill to apply the cell zone and boundary condition. The red zone indicates the high temperature at the shell body.

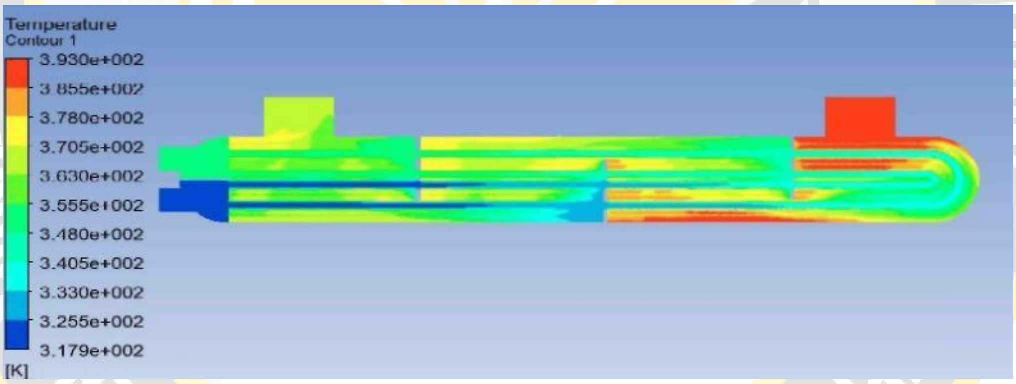
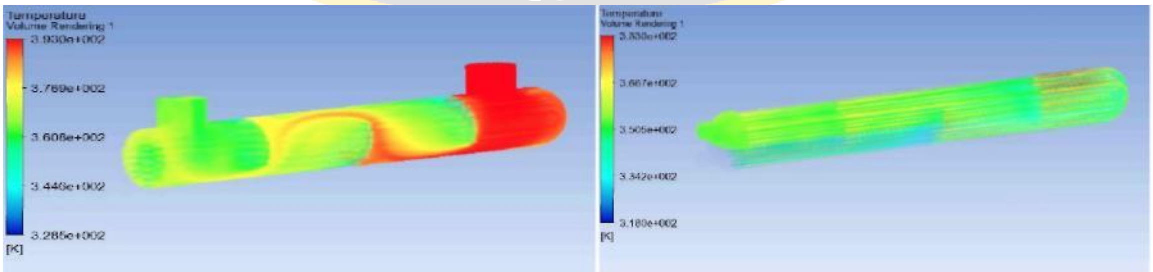
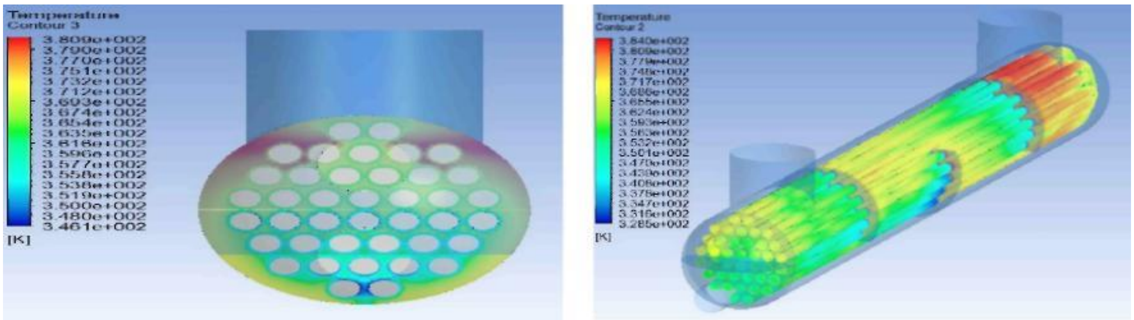


Figure 9 Temperature contour plots for Heat Exchanger

Figure 10 shows the temperature contour plots for Shell & Tube Heat Exchanger. From the Figure 10 it has been observed that the high temperature had been developed between inlet and outlet of shell side flow and increase in tube side flow from inlet to outlet.



(a) (b)



(c) (d)

Figure 10 Temperature Contour plots for Heat Exchanger in (a) Shell side (b) Tube side (c) Side View of HE (d) Tube wall Temperature

Conclusion:

For the longer life of the gears temperature plays an important role in the rotating system. For the continuous utilization of the Heat Exchanger heat generation has been increasing continuously and it is required to observe and select the proper heat exchanger with maximum utilization of heat. From the temperature output of the tube side it has been achieved upto 80ºC temperature at outlet and with mild heating it is ready to supply in the stripper to save the power consumption. Also at the shell side the fluid is getting cold by rejecting heat inside the heat exchanger it save the energy to getting cold from 120ºC-90ºC to 40ºC as per our requirement.

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