

Design and Analysis of S-Glass Heat Exchanger

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Abstract

This research work focuses on the composite material named S-Glass fibre Heat Exchanger, since the existing designs of heat exchangers are generally made up of metals which produce a critical amount of heat loss to the surrounding from the shell. These are also less corrosive resistant, have low life and high weight. To overcome these drawbacks, use of composite materials has become essential. There is a need to redesign it using composite materials which are lightweight, high strength material and more corrosion resistant.

Keywords: S-Glass, heat exchanger, composite material

INTRODUCTION

Heat exchangers are devices used to transfer heat between two or more fluid streams at different temperatures. In a heat exchanger, there is typically no external heat or work interaction involved. Heat is being transmitted by conduction through the exchanger materials (usually metallic wall) which separate the mediums being used [1]. Shell and tube heat exchanger fluids flow through and over tubes, on the other hand an air-cooled heat exchanger passes cool air through a core of fins to cool the liquid. Heat exchangers are often used in space heating, refrigeration, air conditioning, power stations, chemical plants, petrochemical plants, petroleum refineries, natural-gas processing, cryogenic, heat recovery, alternative fuel and sewage treatment. Common examples of heat exchangers are shell and tube exchangers, automobile radiators, condensers, evaporators, air preheaters, and cooling towers [2].

A heat exchanger consists of heat transfer elements such as heat transfer surface, and fluid distribution elements such as headers, manifolds, tanks, inlet and outlet nozzles or pipes, or seals. Usually, there are no moving parts in a heat exchanger. The heat transfer surface is a surface of the exchanger core that is in direct contact with both hot and cold fluids and through which heat is transferred by conduction is referred to as the primary or direct surface. To increase the heat transfer area, fins are connected to the primary surface to provide an extended, secondary, or indirect surface.

METHODOLOGY

In this research work we propose a redesigned heat exchanger with use of a composite material such as S-Glass. E-Glass heat exchanger is redesigned to make it efficient and effective.

Heat exchangers work on energy balance principle. In a heat exchanger, heat is transferred from hot fluid to cold fluid [3].

A set of working conditions include the parameters such as mass flow rate of hot and cold fluid, temperatures of hot and cold fluids at inlet and outlet, pressure within both shell and tube, fluid properties such as viscosity, specific heat capacity, and thermal

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conductivity. Shell and tube heat exchangers are the most widespread and commonly used basic heat exchanger configuration in the process industries. The reasons for this general acceptance are several, as the shell and tube heat exchanger provides a comparatively large ratio of heat transfer area to volume and weight. It provides a surface in such a form which is relatively easy to construct in a wide range of sizes.

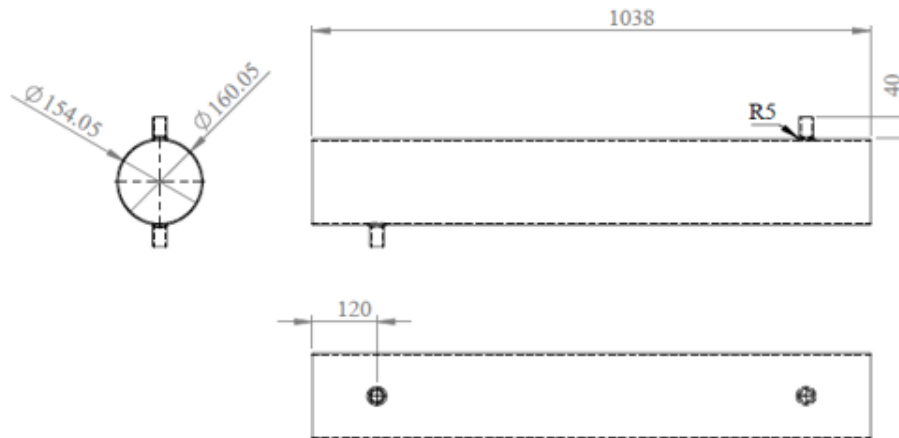


Figure 1. 3D Sketch of Heat Exchanger.

The heat exchanger is modelled in 3D. The 3D modelling of the heat exchanger is performed with SolidWorks software. Shell of exchangers was firstly designed, followed by a nozzle on the outer surface. Design of tubes and baffles was done together. All parts were assembled in SolidWorks assembly. Current building materials were analyzed and issues associated with them were noted before choosing a composite material (Figure 1). Different composite materials were studied and shortlisted on the basis of their thermal conductivity and structural strength. The general properties of shortlisted material were noted. The material was chosen using the Weighted Residual Method. A composite material S-Glass and E-Glass was selected. A composite material is classified as a material made up of two or more materials, which has better properties than the individual components when used separately. Unlike metallic alloys, each material retains its own chemical, physical, and mechanical characteristics. Reinforcement and a matrix are the two components. As compared to bulk materials, the key advantages of composite materials are their high strength and stiffness combined with low density, allowing for a weight reduction in the finished component.

Stainless steel and S-glass were subjected to theoretical calculations. Equivalent log mean area is considered and heat flux through a shell of stainless steel and S-glass was calculated. First step of ANSYS analysis is to import the SolidWorks 3D model into the ANSYS workbench by converting SolidWorks file to STEP format. Steady state thermal analysis was carried out for both stainless steel and S-glass and its results were coupled with static structural analysis. Finally, ANSYS Workbench results were analyzed and compared with theoretical values to validate the results.

The shell-and-tube heat exchanger is named for its two major components: round tubes mounted inside a cylindrical shell. Shell is the outer casing inside which the hot or cold fluid flows. Tubes are generally made of copper material. They are responsible to transfer heat between two fluids. Another component of shell and tube heat exchanger is Baffle. Baffles are required to direct the fluid inside the shell over the tubes for maximum heat transfer (Figure 2).

A shell and tube heat exchanger with single segmented baffles is designed. Single segmented baffles

are chosen as they are the most widely used; large data is available and hence can be theoretically designed. A water-water 1-2 pass shell and tube heat exchanger is designed considering the data. Hot fluid is considered to flow in the shell as a thumb rule says that fluid with low flow rate should always be in shell side; thus, satisfying the thumb rule.

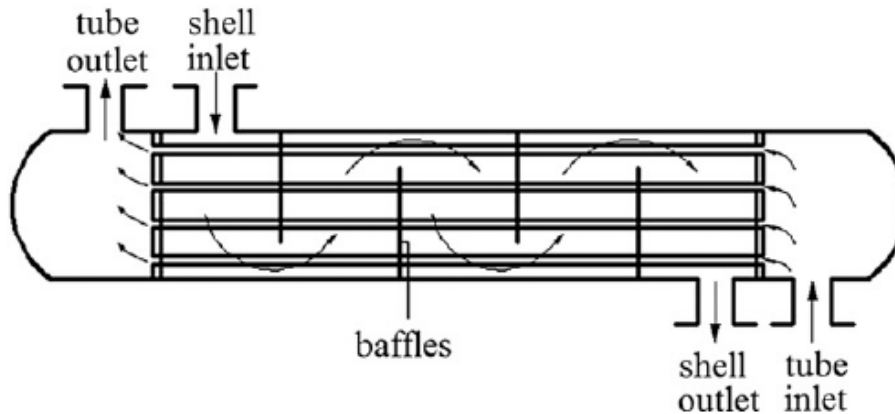


Figure 2. Heat Exchanger Working.

Theoretical Design Calculations for Heat exchanger Shell

A shell and tube heat exchanger with single segmented baffles is designed. Single segmented baffles are chosen as they are the most widely used, large data is available and hence can be theoretically designed. A water-water 1-2 pass shell and tube heat exchanger is designed considering the data in the following table (Table 1):

Table 1. Operating Parameters.

Shell-Side Fluid- Hot Water		
Property	Value	Unit
T_{hi}	90	$^{\circ}\text{C}$
T_{ho}	70	$^{\circ}\text{C}$
Density	1000	Kg/m^3
Flow rate	0.3	Kg/s
Tube-Side Fluid- Cold Water		
T_{hi}	30	$^{\circ}\text{C}$
T_{ho}	38	$^{\circ}\text{C}$
Density	1000	Kg/m^3
Flow rate	0.7533	Kg/s

Hot fluid is considered to flow in the shell as a thumb rule says that fluid with low flow rate should always be in shell side. A vice versa heat exchanger was also designed which was inferior with respect to hot fluid shell side design. Thus, confirming the thumb rule. With the above basic data, a shell and tube heat exchanger was designed by Theoretical method (Kern's method).

Design of STHX by Kern's Theoretical Method

This method is employed as it is simple to use and the design is reliable. All the empirical equations in this section are as proposed by Donald Q. Kern [4].

Design of heat exchanger with this method is illustrated as follows:

Logarithmic Mean Temperature Difference LMTD is calculated as:

For one-shell pass and two-tube passes,

$$(\Delta T_{lm}) = \frac{(T_{Hi} - T_{Co}) - (T_{Ho} - T_{Ci})}{\ln \left(\frac{T_{Hi} - T_{Co}}{T_{Ho} - T_{Ci}} \right)} \frac{(T_{Hi} - T_{Co}) - (T_{Ho} - T_{Ci})}{\ln \left(\frac{T_{Hi} - T_{Co}}{T_{Ho} - T_{Ci}} \right)}$$

$$= 45.74^\circ\text{C}$$

It is assumed that $U = 785 \text{ W/m}^2\text{K}$

1. Heat Load is given by:

$$(Q) = m \times C \times (\Delta T)$$

$$= 0.3 \times 4.1963 \times (90 - 70) = 25.18 \text{ kW}$$

2. Area is given by:

$$A = \frac{Q}{U \Delta T_{lm}} = \frac{25180}{785 \times 45.74} = 0.71 \text{ m}^2$$

3. Choose 21.34 mm OD, 16.04 mm ID, 1.068 m long Copper tubes.

Allowing for tube-sheet thickness of 3 mm:

Take $L = 1.038 \text{ m}$

4. Area of one tube $= \pi d L = 0.0696 \text{ m}^2$

Number of tubes N is given by:

$$N = \frac{\text{Area}}{\text{Area of one tube}} = \frac{0.71}{0.0696} = 10$$

5. Bundle Diameter D_b is given by:

$$D_b = d \left(\frac{N}{0.249} \right)^{\frac{1}{2.207}} = 113.733 \text{ mm}$$

6. Fixed U-tube Head is used.

Bundle diametrical Clearance $= 10 \text{ mm}$

Shell diameter $(D_s) = D_b + 10 = 113.73 + 10 = 123.73 \text{ mm}$

Nearest Standard Pipe size of 160.05 mm is considered as Shell Diameter with thickness of 3 mm.

7. Tubes per pass $= N/2 = 5$

8. Choose 32% baffle cut

Baffle Spacing $= 50.8 \text{ mm}$,

Number of Baffles $= 16$.

DESIGN AND ANALYSIS

The SolidWorks CAD software is a mechanical design automation application that lets designers quickly sketch out ideas, experiment with features and dimensions, and produce models and detailed drawings. Parts are the basic building blocks in the SolidWorks software. Assemblies contain parts or other assemblies, called subassemblies. A SolidWorks model consists of 3D geometry that defines its

edges, faces, and surfaces [5]. The SolidWorks software lets you design models quickly and precisely. SolidWorks uses a 3D design approach.

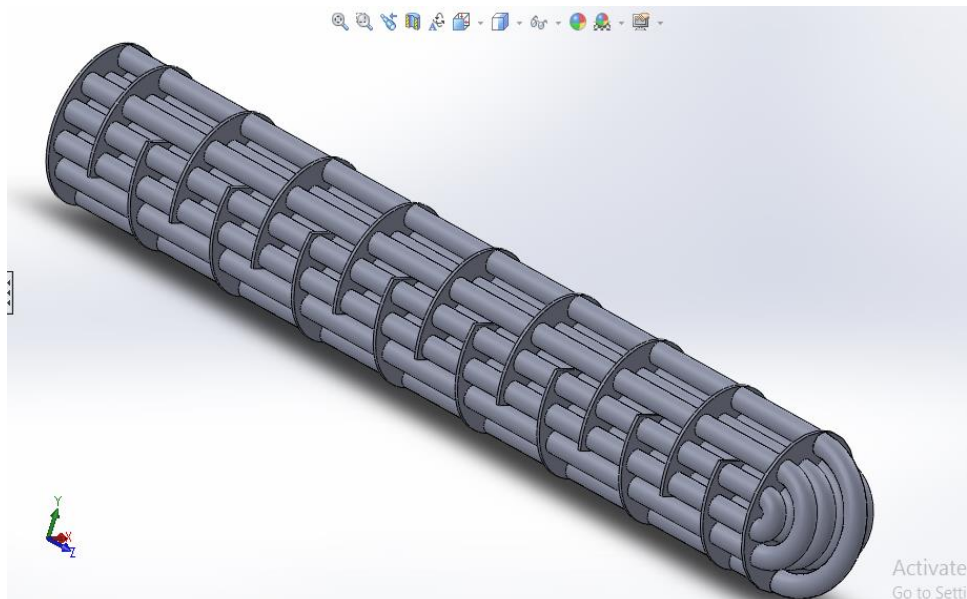


Figure 3. 3D Model.

As you design a part, from the initial sketch to the final result, you create a 3D model. You can also create 2D drawings of 3D assemblies(Figure 3). When designing a model using SolidWorks; you can visualize it in three dimensions, the way the model exists once it is manufactured [6–10].

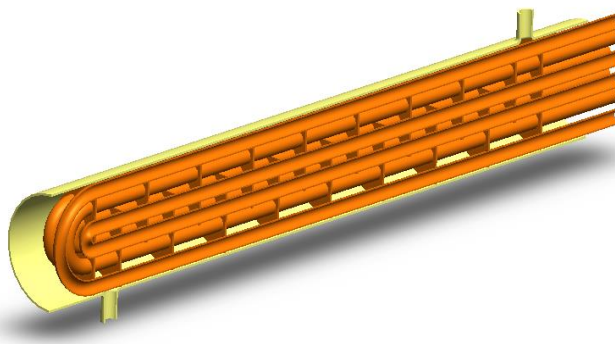


Figure 4. Sectional View of Heat Exchanger.

RESULT

The cost of the material used to insulate the heat exchanger to prevent heat loss to the atmosphere is higher in stainless steel heat exchangers than in S-glass heat exchangers(Figure 4).

The critical insulation thickness for S-glass and stainless steel is 54 and 604 mm, respectively, suggesting a 91.05% reduction in insulation thickness. The S-Glass composite shell was found to be 3.106 times lighter than the stainless steel shell. As a result, the S-Glass heat exchanger is found to be an effective and long-term solution in industry with a low overall cost (Figures 5 and 6).

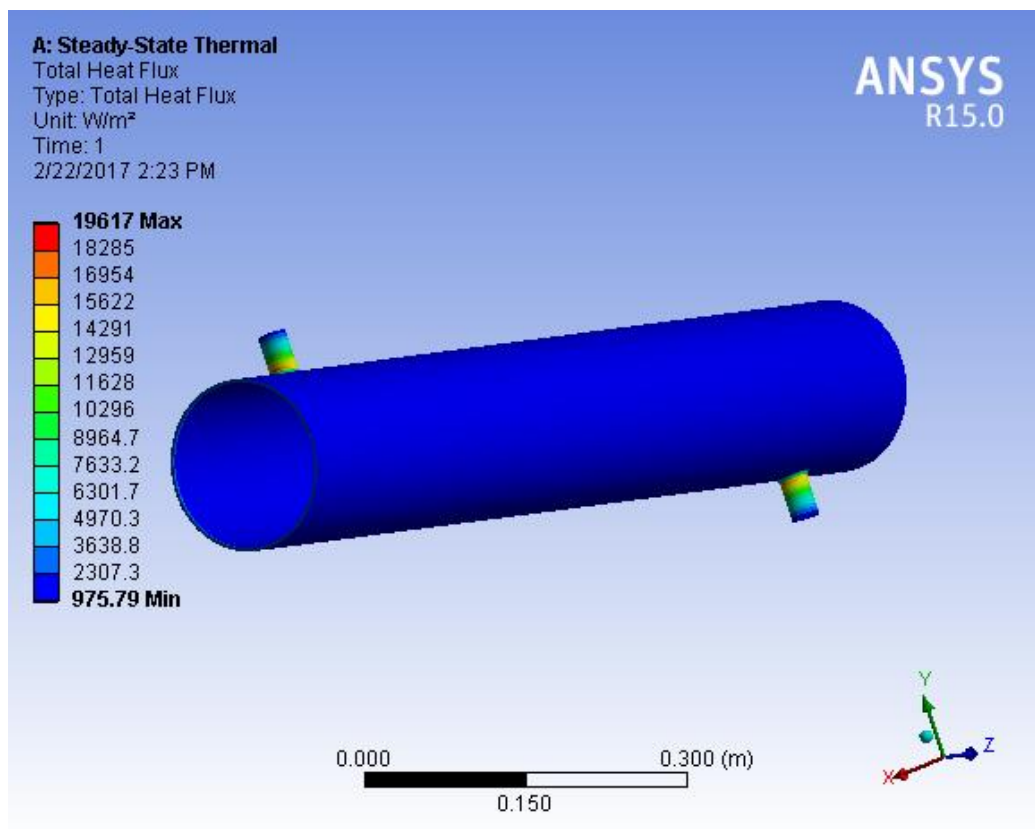


Figure 5. Heat transfer through stainless steel casing.

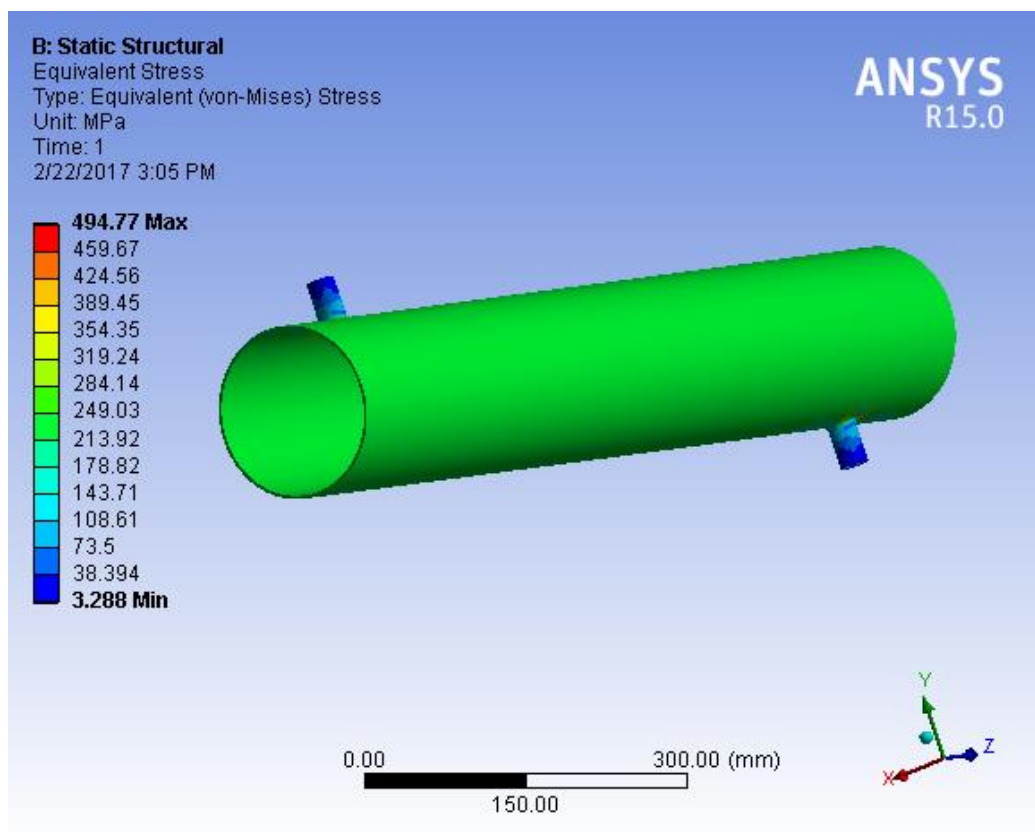


Figure 6. Stress distribution of heat exchanger casing.

CONCLUSION

The simulation in the ANSYS software shows that the heat flux from the shell has decreased significantly. S-Glass has a 29.88% lower heat loss than stainless steel, according to a finite element report. Theoretical calculations indicate that S-Glass reduces heat loss by 29.507% as compared to stainless steel. The S-Glass composite shell was found to be 3.106 times lighter than the stainless steel shell. The outer surface temperature of the shell for the S-Glass material is 32.84°C, according to the Flow analysis data. The heat exchanger has a 0.33 efficiency. The critical insulation thickness for S-glass and stainless steel is 54 and 604 mm, respectively, suggesting a 91.05% reduction in insulation thickness.

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