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Strength Analysis of Tube to Tube Sheet Joint in Shell and Tube Heat Exchanger

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ABSTRACT

This paper aims at strength analysis of a typical tube to tube sheet joint in shell and tube heat exchanger. In the present work the joint between tube and tube sheet joint in shell and tube heat exchanger is designed and analyzed using ANSYS 9.0 software for the combination of admiralty brass and steel as tube and tube sheet materials respectively. Contact analysis is performed to analyze the gap between tube and tube sheet element. Stress concentrations at various parts of tube and tube sheet at various stages of loading and unloading are obtained and displayed pictorially. The value of stress at interface of tube and tube sheet joint is also obtained. The value thus obtained is compared with the result value obtained by executing readily available computer code. Further the Pull out load of tube to tube sheet joint of shell and tube heat exchanger is calculated using mathematical calculations and the obtained value is compared with the pullout load obtained in laboratory. It is found that there is no much difference between the pullout load obtained by mathematical calculation and that of experimental results

It is finally observed that controlling parameters in tube to tube sheet expansion joint are loading pressure, Clearance for tube thickness, Stress-Strain data of materials used in assembly to get required residual pressure, it is also observed that some parameters that affect the tube to tube sheet joint strength such as loading pressure, Clearance for tube thickness, Stress-Strain data of materials used in assembly to get required residual pressure are to be monitored and it should be seen that those values which affect the joint strength of a tube to tube sheet joint should be kept within permissible limits to get a good and leak proof joint and resulting in better working conditions of a plant without causing any damage to the work area.

Keywords: Strength Analysis; Tube to Tube Sheet Joint; Shell and Tube Heat Exchanger; ANSYS 9.0

1.0 INTRODUCTION

Heat transfer between different fluids at different operating conditions involves proper design selection, constructional configurations of heat exchangers and material selections, which have different physical and chemical properties. In indirect and non-mixing fluid heat transfer, varieties of components with intended functional purposes and required minimum mechanical strengths are used in shell and tube heat exchangers. In this context Tube to Tube-sheet joint design in Shell & Tube type heat exchanger is one of the most critical considerations often checked and analyzed.

The strength of a tube-to-tube sheet expansion joint chiefly depends upon leak tightness for the intended service conditions of fluids on either side of the tube and tube-sheet. Higher temperature difference between two heat exchanging fluids leads to large thermal gradient between the wall surfaces of tube and tube-sheet and more importantly at the tube joints.

1.1 Classification of tubular heat exchangers

Tubular heat exchangers can be further classified into four types as follows.

1. Tube in tube heat exchanger.
2. Triple tube heat exchanger.
3. Spiral tube type heat exchanger.
4. Shell and tube type heat exchanger.

1.1.1 Tube in tube heat exchanger

Tube in tube heat exchanger is often called double tube heat exchanger. The process fluid passes through the inner tube, while the heating or cooling media goes through the outer tube. Because of the large size of the product tube, these heat exchangers have the ability to process very large particulates. They can handle high pulp products, create low shear, have a low initial cost, can handle high pressure.

1.1.2 Triple tube heat exchanger

Triple tube heat exchanger is designed with three concentrically mounted tubes. For heat transfer applications, the heating or cooling medium flows through the space between the inside and outside tubes while product travels in the opposite direction through the middle tube.

1.1.3 Spiral tube type heat exchanger

Spiral tube heat exchanger is one in which the tubes will be spiral in shape as the name implies.

1.1.4 Shell and tube type heat exchanger

Shell and tube type heat exchanger consists of a bundle of parallel sanitary tubes with the ends expanded in tube sheets. The bundle is contained in a cylindrical shell. Connections are such that the tubes can contain either the product or the media, depending upon the application. They can transfer lots of heat due to the surface area.

The most commonly used heat exchanger is the shell and tube type. It is the workhorse of industrial process heat transfer. Shell and tube heat exchangers are the most versatile type of heat exchangers. They are used in process industries, in conventional and nuclear power stations as condensers, in steam generators, in pressurized water reactor plants, in feed water heaters, and in some air conditioning systems. They are also proposed for many energy applications including ocean, thermal, and geothermal.

Shell and tube heat exchangers provide relatively large ratios of heat transfer area to volume and weight and they can be easily cleaned. Shell and tube exchangers offer great flexibility to meet almost any service requirement. The reliable design methods and shop facilities are available for their successful design and construction. Shell and tube heat exchangers can be designed for high pressures relative to the environment and high-pressure differences between the fluid streams.

The cross-sectional picture of a shell and tube heat exchanger which shows the assembly of various components of shell and tube heat exchanger is as shown in the figure below.

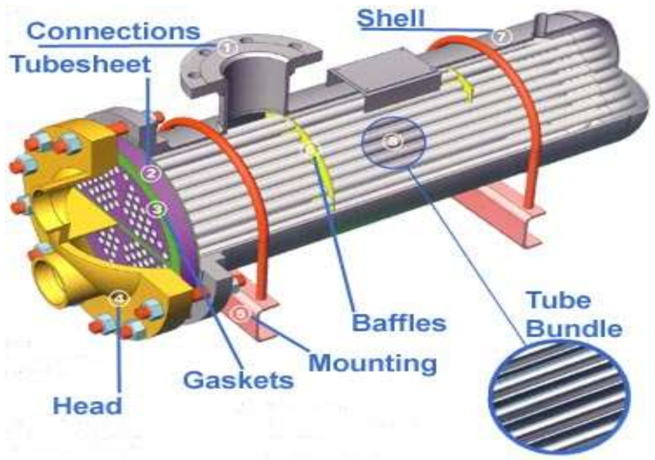

Figure.1: Cross-sectional view of shell and tube heat exchanger.

2.0 ANALYSIS

The Finite Element Method (FEM) has become a powerful tool for the numerical solutions of a wide range of engineering problems. FEM is being extensively used all over the world for obtaining approximate numerical solutions for a large varieties of problems, and it has become an indispensable tool, in particular, in the field of stress analysis.

This work focuses on analyzing the strength of tube to tube sheet expansion joint in shell and tube heat exchanger. The problem is solved in Ansys 9.0 as a method of non destructive testing and the stress and strain concentrations for the tube and tube sheet joint are obtained. To solve the problem in Ansys, basically some assumptions are made. They are as follows.

2.1 Assumptions made in the F.E.M. analysis

1. The assumption that the assembly is concentric between effective tube sheet ligament radius and both the tube outer diameter and inner diameter.
2. The assumption that the strains are uniform at any particular radius in the effective tube sheet ligament portion and in the tube during and after expansion.
3. The loading of pressure on the inner surface of the tube is uniform.
4. Loading produces yielding of the tube material before closing the gap between tube hole and tube outer diameter.
5. Further loading of the tube causes loading of tube sheet ligament and proceeds within elastic or plastic region of tube sheet material to the required level so as to cause residual stress in the tube after unloading of pressure.

2.2 Analysis model outline

The object in consideration is cylindrical. Hence one quarter of the object is only required to be considered as the object is symmetrical along both vertical and horizontal axis.

The stresses within the tube sheet thickness at every plane parallel to the tube sheet face in same. Hence Plane stress element PLANE82 is chosen in ANSYS. Since the gap between tube outer surface and tube hole surface needs to be communication, CONTACT element pair CONTA172 & TARGE169 is chosen. Given below is the tabular column of element, element type.

Table 1: Element and element type

Sl.No	Element	Element type
1	Tube	PLANE82
2	Tube sheet	PLANE82
3	Contact	CONTA172
4	Target	TARGE169

2.3 Modeling

The model of the problem is created in Ansys. The model created is in two-dimensional form. The tube and tube sheet are both circular in shape and hence they are considered to be symmetrical along their circumference. Single quadrant is considered for ease in analysis. The required geometry is modeled by first creating the key points at each and every corner of both tube and tube sheet. As a second step, lines and curves are created to build two closed shapes of both tube and tube sheet and by selecting the create areas command available in Ansys library, areas are created in both tube and the tube sheet. A gap of 1.25mm is considered between the tube and the tube sheet. The model of the problem created in Ansys is as shown below, in Figure.2

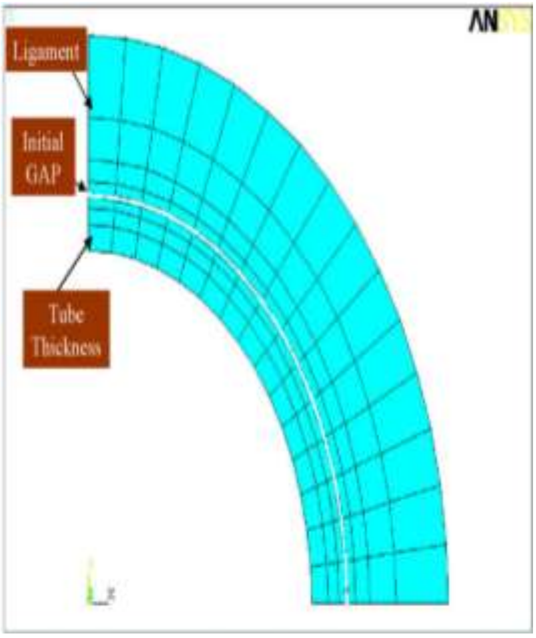

Figure.2: Ansys F.E.M model of the object.

2.4 Defining material properties

The tube and tube sheet are assumed to be made of admiralty and steel respectively and hence their material properties such as density, coefficient of friction, poisons ratio, young's modulus, yield point, tangential modulus are specified after surveying from the literature of mechanical properties of materials. Both the tube and tube sheet are considered to be isotropic in nature and isotropic material properties are specified.

Table 2: Material properties of Admiralaity brass and steel.

Sl. No	Material property	Admiralty brass	Steel
1	Density	8525 kg/m^3	7850 kg/m^3
2	Coefficient of friction	0.35	0.8
3	Poisson's ratio	0.35	0.25
4	Young's modulus	110 Gpa	207 Gpa
5	Yield point	217 Mpa	207 Mpa

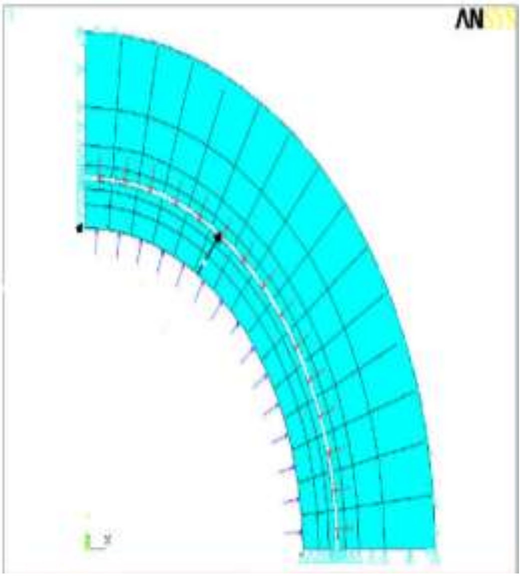

Figure.3: Boundary conditions applied to Ansys F.E.M. model.

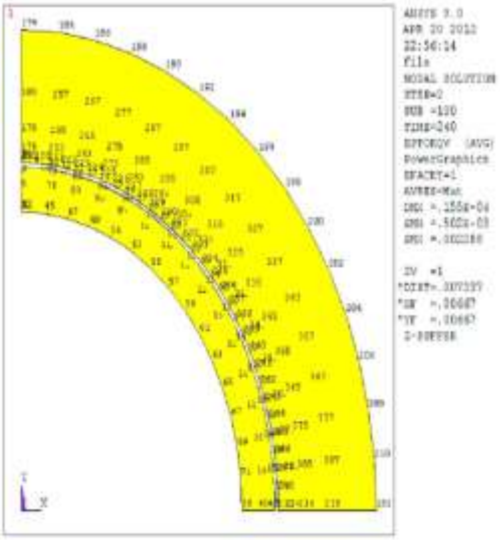

Figure.4: Contact gap before loading.

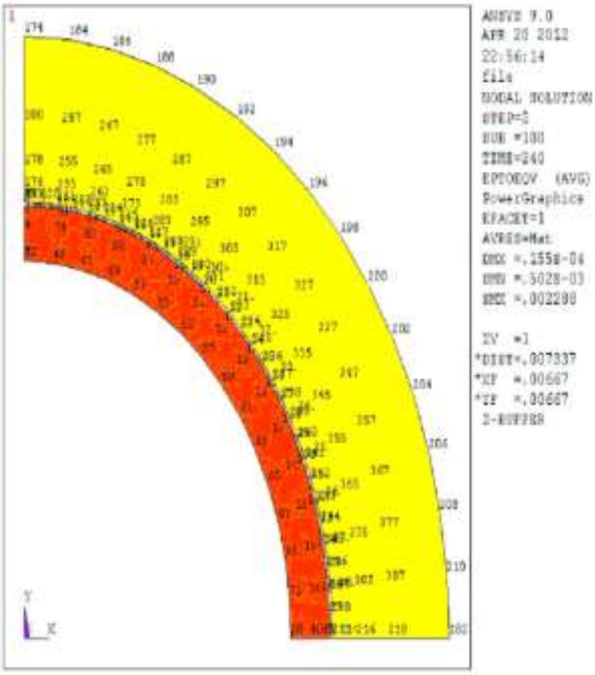

Figure.5 : Pressure loading started.

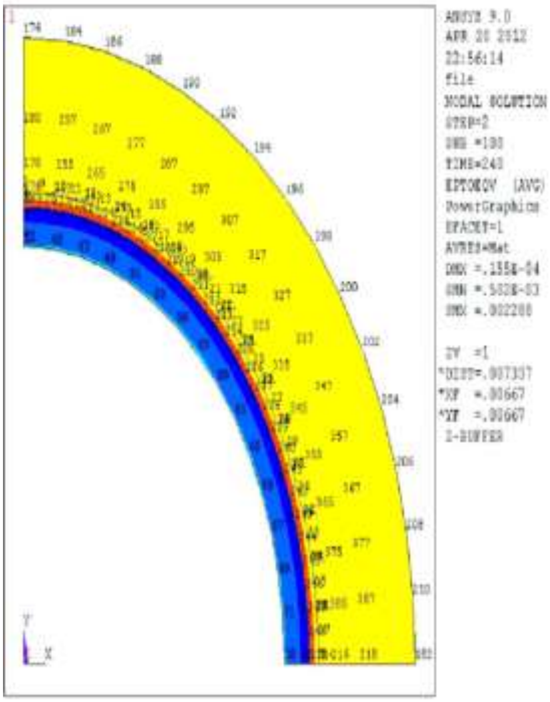

Figure.7: Further loading continues within tube sheet ligament

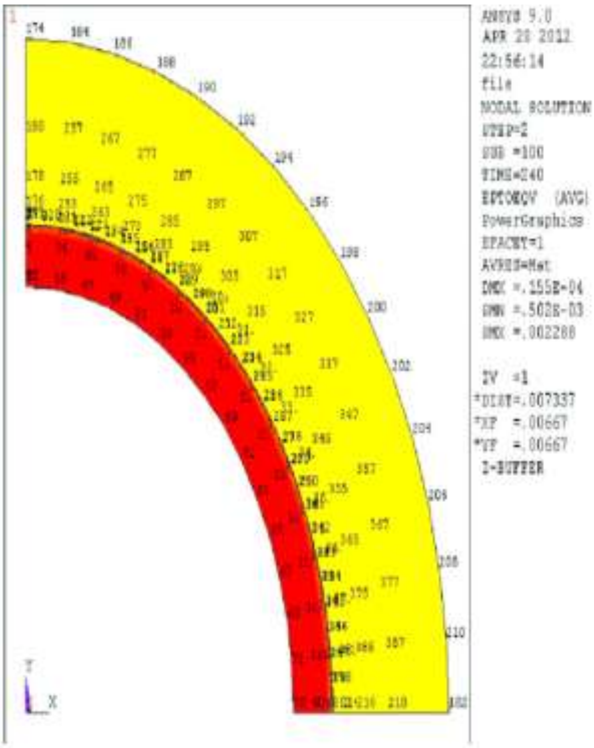

Figure.6: Tube yield point crossed- gap closed

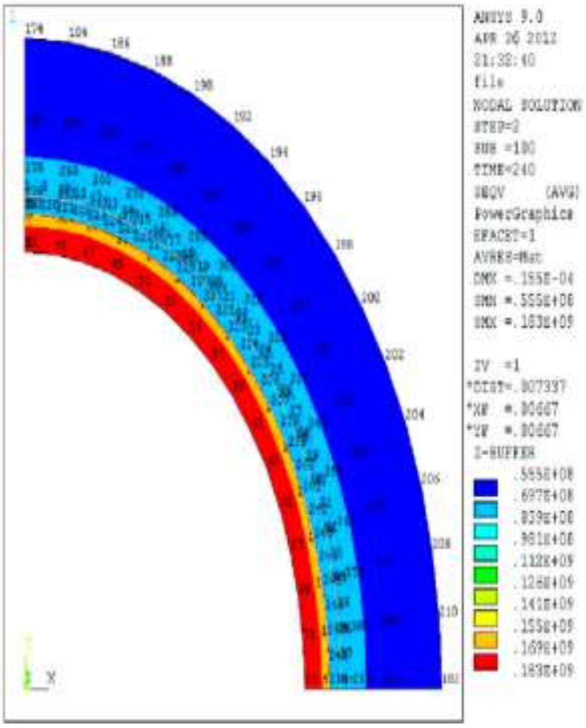

Figure.8: Required loading reached in tube sheet ligament

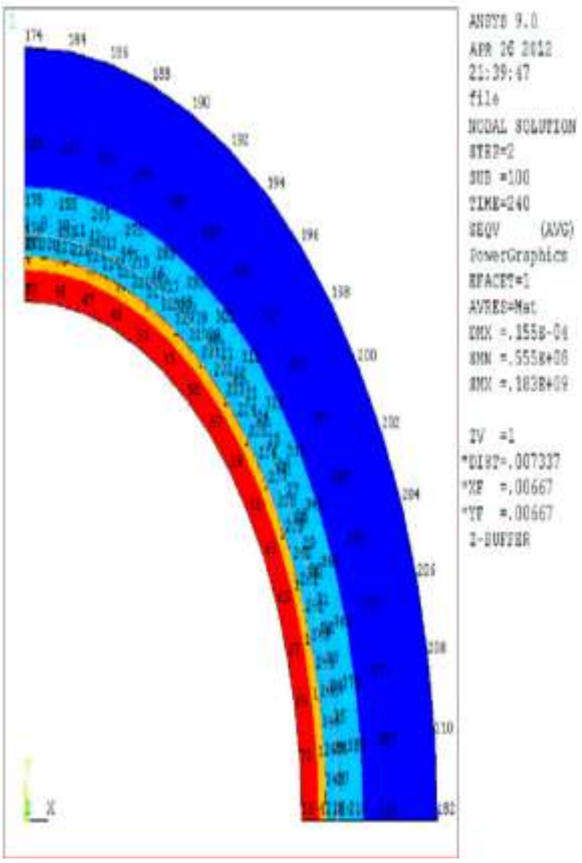

Figure.9: Before unloading started

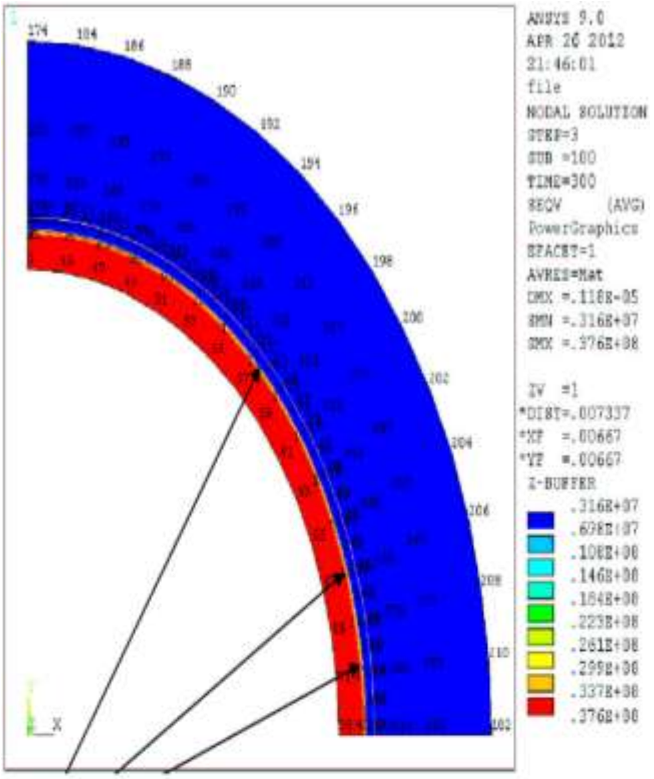

Figure.10: After unloading ended.

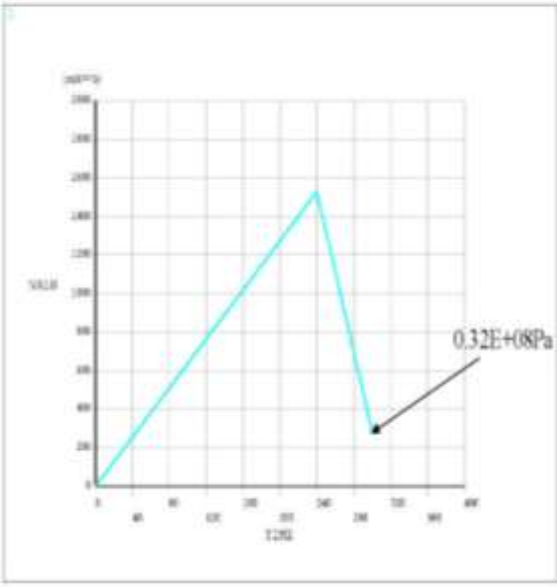

Figure.11: Time history of equivalent stress at interface.

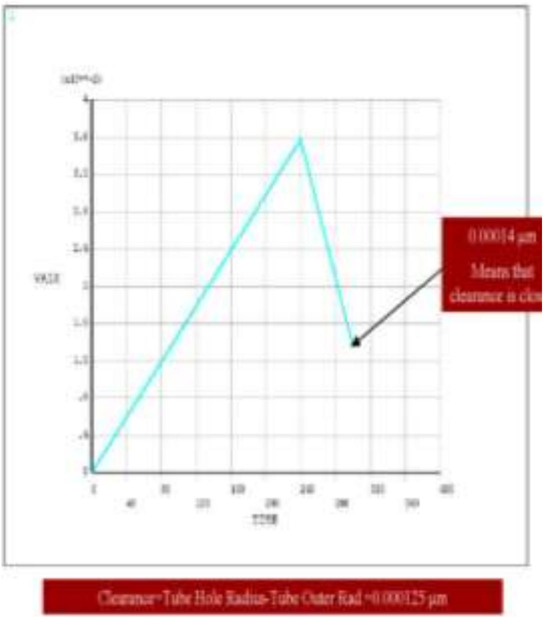

Figure.12: Strain monitoring at interface.

3.0 RESULTS & DISCUSSION

Tube to tube sheet joint in shell and tube heat exchangers were analyzed using a Finite Element method Ansys 9.0 and the stress, and strain concentrations, at the interface were observed. The gap between tube and tube sheet joint was also analyzed, using contact analysis. Mathematical calculations for bonding expansions, of tube into tube sheet were also done. Also tube pull out load, in shell and tube heat exchanger was calculated mathematically.

The experimental results of Pull out load of shell and tube heat exchanger are tabulated, and they were compared with the mathematical calculations, and are discussed in detail in this chapter. The stress value obtained in Ansys 9.0 at interface point between tube and tube sheet is compared with that of value obtained by executing computer code. and they are discussed in detail in this chapter.

3.1 Mathematical calculation for bonding expansion

Mathematical calculation for bonding expansions, gave the following results.

1. Average tube sheet hole diameter (a1) = 19.30 mm.
2. Average tube outside diameter (a2) = 19.05 mm.
3. Average tube inside diameter (a3) = 16.56 mm.
4. Average tube thickness (a4) = 1.245 mm.
5. Average inside diameter before rolling in (a5) = 16.81 mm.
6. Thinning at 5% (a6) = 0.1245mm.
7. Final inside diameter of tube after expansion (a7) = 16.6345 mm.
8. Bonding expansion = 0.3745 mm.

3.2 Mathematical calculation of pullout load

Mathematical calculations of pullout loads gave the following results.

Length of tube to tube sheet expansion = 0.041 m.
Coefficient of friction at interface -for admiralty brass and common steel = 0.12.
(With surface finish 1.6µm on tube and 3.2µm in hole)
Tube hole diameter = 0.0193 m.
Residual pressure at interface = 0.32E+08 pa.
Or (3263092Kg/M^2).
Pull out load = 0.12*Π*0.0193*3263095*0.041.
= 973 Kg.

The above calculated value of pull out load is compared with the values obtained in laboratory and it is found that the mathematically calculated values are in excellent agreement with that of the values obtained in the laboratory.

The pull out load obtained through manual calculations resulted in the value of 973kg, where as those of experimental results are found to be 978.6 kg and not much difference is found between them. The results of the mechanical tests that are conducted in the mechanical laboratory are shown in the tabular column as shown below.

Tube and tube sheet joint were designed using Ansys 9.0, considering tube and tube sheet as cylindrical objects, which are symmetrical along both vertical and horizontal axis. Initially there was gap between tube and tube sheet before loading was stared as shown if Fig 4.3, and gradually the gap got decreased as the loading progressed, and finally the gap got closed as the tube reached its yield point, as shown in Fig 4.5. After this, loading continues in tube sheet ligament as shown in Fig 4.6. In Fig 4.7, it is seen that the required loading is reached in tube sheet ligament. After this unloading is done, this resulted in 0.32+08 Pa, residual interface pressure, as indicted in Fig 4.9.

There was a steep continuous increase in stress along with increase in pressure at the joint which reached a value of 0.24E + 08 Pa at the interface of tube and tube sheet joint, and as unloading started, the value got reached to 0.320+08 Pa. This can be seen in Fig 4.10. This is called interface pressure. This value is in good agreement with the value 0.307+08 Pa, obtained by executing computer code. The flow chart of the process followed in the computer code is provided in appendix.

The value of strain was also monitored at the interface of tube and tube sheet joint, as shown in the graph of Fig 4.11. This graph shows a maximum value of 0.00036 µm, and reached a value of 0.00014 µm after loading and unloading was done.

Pullout load and bonding expansion of tube to tube sheet joint were calculated using mathematical calculations. Pull out load of 973 kg was obtained using mathematical calculations, and bonding expansion of 0.3745 mm was obtained for the joint. These were compared with the experimental valued obtained in the laboratory. The experimental value of tube pull out load was obtained as 978.9 Kg which is in good agreement with the value obtained from mathematical calculations.

4.0 CONCLUSION

The present study involved analysis of tube to tube sheet joint using Ansys 9.0, a Finite Element Method (FEM), mathematical calculation of pull out load, comparison with the experimental value of pull out load, determining the bonding expansion of the joint, comparison of the interface stress between tube and tube sheet joint with that of values obtained by executing readily available computer code.

The inference from the experimental work and calculations is that the controlling parameters in tube to tube sheet expansion joint are loading pressure,

Clearance for tube thickness, Stress-Strain data of materials used in assembly to get required residual pressure.

The strength analysis of tube to tube sheet joint is conducted and it is found that some parameters that affect the tube to tube sheet joint strength are to be monitored and it should be seen that those values which affect the joint strength of a tube to tube sheet joint should be kept within permissible limits to get a good and leak proof joint and resulting in better working conditions of a plant without causing any hazard of any toxic or noxious liquid with the cooling liquid, getting mixed which leads to a catastrophic disaster of the plant, and personnel working inside a plant along with financial loss.

It is also found that along with the residual stress which got developed in the joint of shell and tube heat exchanger, there was a considerable increment in hardness value after strain hardening.

As the tube diameters and thicknesses can be varying for various applications of Shell & Tube Design, the mock up test requirement is mandatory for establishing Pull out Load for Tube to Tube sheet Joint Strength for each tube size and clearance, this approach of FEM modeling and analysis is easier to assess the Strength to a reasonable accuracy of 90-95%.

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