Stress Analysis and Evaluation of Double-Tube Double-Tube Sheet Heat Exchanger Based on ANSYS

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***Abstract*—Using finite element analysis method, ANSYS software was used to analyze the stress of double tubes double tube sheets heat exchanger with expansion joints in 7 dangerous conditions. Taking the most dangerous condition as an example, the related calculation results are given. Based on the calculation results, the stress intensity of the heat exchangers is checked and evaluated. The research of the paper provides a train of thought for the design and calculation of this type heat exchangers, and gives a specific implementation method, which is of guiding significance to researchers in relevant fields.**

***Index Terms*—Volume Separator, Double Tubes Double Tube sheets Heat Exchanger, ANSYS, Stress Analysis, Stress Intensity Check**

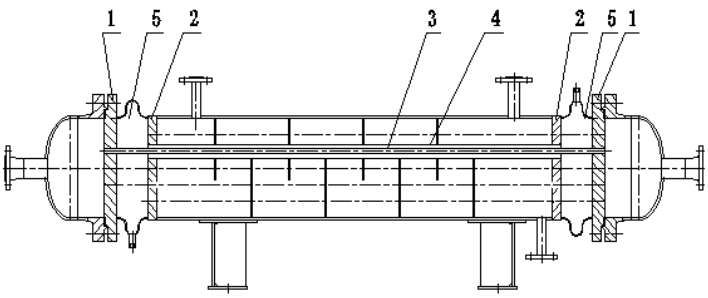
I. INTRODUCTION

Shell and tube heat exchangers are widely used in the process of industrial for heat exchange between hot and cold process. Leakage is one of the common failures of heat exchange equipments. For ordinary heat exchangers, once leakage occurs, the two media involved in heat exchange will make contact with each other [1]. In general chemical processes, it is usually permissible for little leaks to occur in the heat exchanger, but in many special occasions such as polysilicon, silicone and fluorochemicals, the two media must not be exposed to mixed contact, otherwise the device will be destroyed and even trigger a catastrophic accident. With regards to this, in recent years, technicians in relevant fields have developed a new type of double tubes double tube sheets heat exchanger which are respectively arranged with two tube sheets in its two ends and each of heat exchange tube is composed of two tubes sleeved together. This special structure can effectively prevent the two media contact due to leakage to ensure the safety of equipment [2-5].

At present, the researches in this field mainly focused on the aspects of structure selection, double tubes type, heat transfer analysis and leakage monitoring. However, the research on the strength design of tube plate is still scarce. No relevant standards were formed, and no relevant Research institutes put forward reliable design methods, and many designs relied mainly on engineering experience or experimental verification. This paper studies the structure of the new heat exchanger, the finite element method is used to analyze and evaluate the stress of double tube heat exchanger with expansion joint by ANSYS [6]. It explores a reliable analytical design method for the strength calculation of this type of heat exchanger. The two ends of the heat exchanger are respectively arranged with two tube sheets, an outer tube sheet and an inner tube sheet, a gap is arranged between the two tube plates and an expansion joint is arranged.

II. STRUCTURE INTRODUCTION OF DOUBLE TUBES DOUBLE TUBE SHEETS HEAT EXCHANGER

“Fig. 1,” shows structure of a double tubes double tube sheets heat exchanger with expansion joint using in engineering. Each tube of the heat exchanger is composed of two tubes sleeved together, which are respectively an external heat exchange tube and an internal heat exchange tube. The two ends of the inner tube are respectively connected with two outer tube sheets, the outer tube is respectively connected with the two inner tube sheets, a gap composed of the inner tube and the outer tube, the gap and the gap between the inner and the outer tube plates is mutually penetrated to form a sealed Cavity, called the isolation chamber.



1-outer tubesheet;2-inner tubesheet;3-inner tube;4-outer tube;5- expansion joint

Figure 1. structure of a double tubes double tube sheets heat exchanger with expansion joint

In operation, the tube media flows in the inner tube of heat exchanger, and shell-side medium flows in the outer tube, the two media are completely isolated by isolation chamber. When the heat exchanger leaks, whether it is the tube fluid or shell-side fluid will enter the isolation chamber, which will cause fluctuations in the pressure isolation chamber. Through the detection of pressure can determine whether the heat exchanger leaks and we can take measures in time to ensure the safety of equipment maximize in some special occasions.

The design parameters of the double tubes double tube sheets heat exchanger with expansion joint are as follows. Tube design pressure is 0.6MPa, tube design temperature is 0/165 ℃,Shell design pressure is 1.2MPa, shell design temperature is 0/220 ℃. The overall design can refer to GB/T151-2014[7], but its heat transfer tubes and tube sheets parts use finite element method for strength calculation, and are part of the finite element analysis. Assessment method reference JB4732-1995[8]. Allowable stress is selected according to GB150-2011[9], the relevant technical parameters shown in Table I.

TABLE I.
PHYSICAL PARAMETER OF MAIN MATERIAL OF BUNDLE PARTS

	cylinder	inner tube	outer tube	tubesheet
material	20	S31603	10	S31603II
Thermal Conductivity W/m.k	49.73	16.3	49.78	17.0
Elastic Modulus GPa	197.9	191	193.2	187
Linear expansion coefficient mm/mm℃	11.9875×10^{-6}	17.11×10^{-6}	11.9783×10^{-6}	16.84×10^{-6}
Allowable stress MPa	125.4	104.8	104	104.8

(Note: The elastic modulus of materials, linear expansion coefficient according to the average wall temperature to choose, allowable stress by design temperature to select.)

III. FINITE ELEMENT ANALYSIS

A. Model Establishment

According to the structural characteristics of the double tubes double tube sheets heat exchanger, one eighth of the whole heat exchanger is selected as the research object. Shell theory research shows that: When the distance from the discontinuity (the length of the cylinder) exceeds 2.5Rδ (R is the radius of the cylinder and δ is the cylinder wall thickness), the effect of edge stress is negligible. In the actual calculation, the general length of the cylinder is taken not less than 2.5Rδ. Therefore, in the longitudinal direction of the structure, the length of the shell-side shell is taken as 5Rδ.

B. Meshing

Considering the influence of the temperature field, the calculation uses the entity unit and the structured grid. Although adopting such a model, the number of nodes to be calculated increases greatly, the requirements for computer resources are increased and the calculation time is longer, but this can truly reflect the heat exchanger Stress characteristics under pressure and temperature loads. Structural analysis uses solid185 units for the 8-node hexahedron and heat analysis uses solid 70 units. Figure 2 shows the finite element solid model seen from the side of the tube.

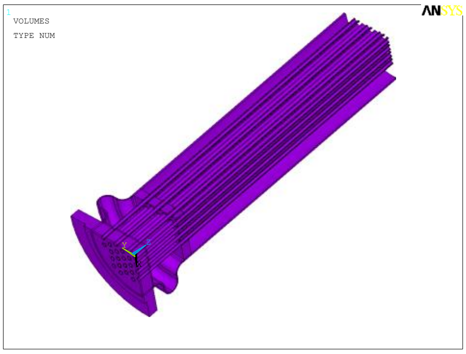


Figure 2. Finite element model

C. Loads and Constraints

Symmetrical constraints are applied to each symmetry plane, the other load by the design pressure or working pressure applied. In addition, we need to consider the bolt preload, gasket seal than pressure and to exert temperature load according to the combination of conditions.

D. Condition Selection

Finite element calculation conditions include the pipe pressure load, the shell side pressure load, temperature load and their combinations, However, considering the case of poor load, the pipe and the shell pressure load should be taken when the work load, besides, we need to consider the shutdown of the T condition. There are 7 kinds of calculation conditions, as shown in Table II.

TABLE II.
CALCULATING LOADS CONDITIONS

		Operating condition description	Load case combination	Load description
Steady state		Normal operation	Pt+Ps+T	Working pressure, working temperature
Transient state	start	First open the tube moments	Pt	The design pressure (the work pressure is less than the design, calculate the pressure)
		First open the shell moments	Ps	
		Open the tube and the shell at the same time	Pt+Ps	
	stop	First stop the shell moments	Pt+T	Working pressure, working temperature
		First stop the tube moments	Ps+T	
		Stop the tube and the shell at the same time	T	

IV. ANALYSIS OF RESULTS

In all the above conditions, there is only the design pressure, the stress is relatively small by the finite element analysis. Stress caused by the temperature load is very large and dominant. After calculation, the first stop the shell operation is the most dangerous conditions (Ps + T). The following are the results of a combination of dangerous conditions with temperature load.

A. The Overall Stress Intensity Distribution of Stress Intensity Computational Domain

"Fig.3," shows the overall stress intensity distribution of stress intensity computational domain. From the perspective of the finite element model, the maximum stress intensity appears in the expansion trough region of the isolation chamber near the inner tube plate. The region has a discontinuous structure, increased temperature gradient causes the primary stress, secondary stress and peak stress, the maximum value is 292.983MPa, expansion joint allowable stress is 126.8MPa, apparently the value less than 3 times the stress intensity. The deformation of expansion joint is 1.32mm, the maximum displacement of single wave is 3.7mm. Therefore, the deformations meet the requirement.

The 4 stress distribution diagrams of temperature difference load show that the stress distribution in the 4 conditions is basically the same, and the value and distribution of stress also changed little. Larger parts of the stress are mainly distributed in the expansion chamber at the isolation chamber and the joint of the expansion joint and the inner tube sheets. It shows that the stress of this part is mainly controlled by the temperature difference and also shows that the setting of the expansion joint effectively carries most of the temperature stress.

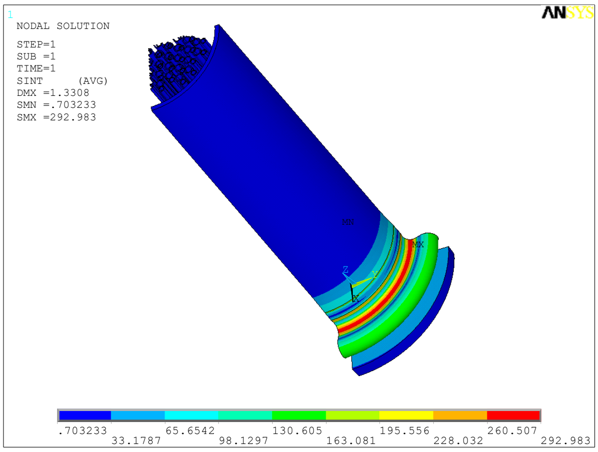


Figure 3. General stress distributing graphics of computational domain under Ps+T condition

B. Stress Distribution of Inner Tube Sheet

"Fig. 4," shows the stress intensity distribution of the inner tube sheet. The maximum value of the stress appears in the connection area between the tubes and the tube sheets near the periphery of the tube area (indicated by MX in the figure), with a maximum value of 257.646 MPa. It has characteristics at the following: (1) geometry mutation, (2) temperature stress. The stress contains peak stress, according to the stress analysis theory, the allowable stress value can be magnified 3 times. Therefore, the maximum stress in these areas is safe. The distribution of stress distribution on both sides of the tube plate shown in the figure is different, this is mainly due to considering the temperature and heat transfer, the stress changes along the thickness of the tube plate. From the figure, it can be seen that there is increased stress at the short section of the tube plate periphery and the connecting section of the isolation chamber, which belongs to the peak stress component with temperature difference stress, and the stress in these regions can be limited to 3 times the stress intensity range, It is clear that the inner tube sheet is safe under design conditions.

It can also be seen from Fig. 4 that the peak stress at the junction of the heat exchange tube and the tube sheet is larger in addition to the connection between the periphery of the tube sheet and the isolated cylinder tube section, the stress distribution in the tube sheets region is relatively uniform, the stress is about 60.8527 MPa To 117.082MPa. The design of the heat exchanger is reasonable. The cuff area is much smaller than the cuff area. This is due to the fact that temperature loading mainly and that there is no problem of weakened openings in the perimeter of the tube sheet.

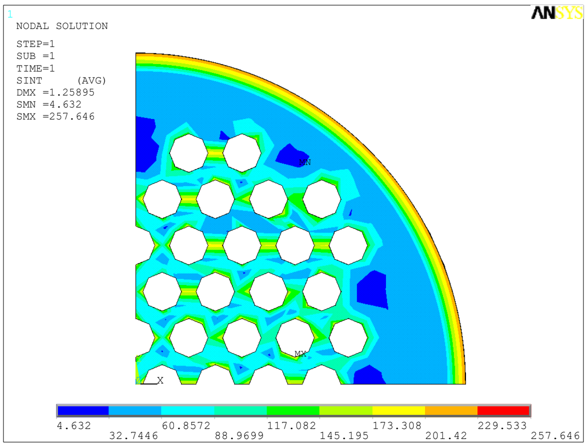


Figure 4. Stress distributing graphics of inner tube-sheet under Ps+T condition

C. *Stress Distribution of Outer Tube Sheet*

"Fig. 5," shows the stress intensity distribution of the outer tube sheet. Larger stress area are around the pipe near the center, while having a high level of stress in the region of the insulation chamber connected to the tube sheet, which is caused by a mutation in the portion of the structure. The maximum stress in the outer tube sheet is 86.438MPa and less than 3 times the stress intensity. The stress here eases with local plastic deformation. The stress level on the outer tube sheet side is obviously smaller than the stress on the side of the isolation chamber. This is also due to the fact that the stress changes along the thickness of the tube plate after considering the influence of temperature and heat transfer.

The maximum stress of the outer tube sheet is obviously less than the maximum stress of the inner tube sheet. The change of stress distribution in various working conditions considering the effect of temperature difference is larger than that of the inner tube sheet, it indicates that the influence of temperature difference stress on the outer tube plate is no longer the most important factor. The installation of expansion joints in the isolation chamber has a key role in the stress distribution of the outer tube sheet but has less effect on the stress of the inner tube sheet.

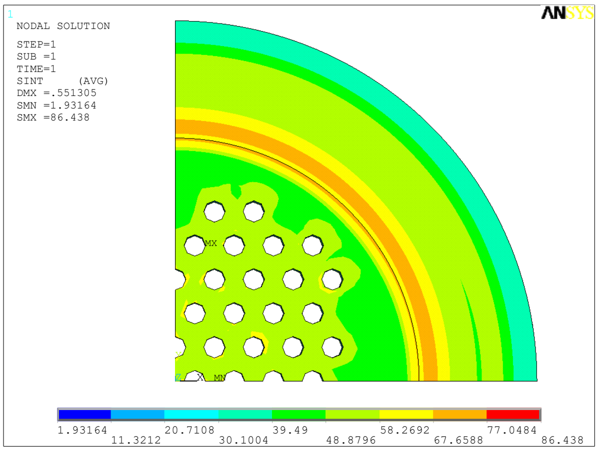


Figure 5. Stress distributing graphics of outer tube sheet under Ps+T condition

D. *Stress Distribution of Inner Tubes*

The stress intensity distribution of inner heat transfer tube shown in "Fig. 6." From the point of view of stress distribution in the heat transfer tubes, the tube bundle near the peripheral area is subject to a higher stress level than the tube bundle at the center. The maximum stress shown in the figure is due to the geometrical discontinuity of the connection between the heat transfer tube and the tube sheet. The stress level of the tube near the tube sheet is higher than the middle section due to the deformation of the tube sheet.

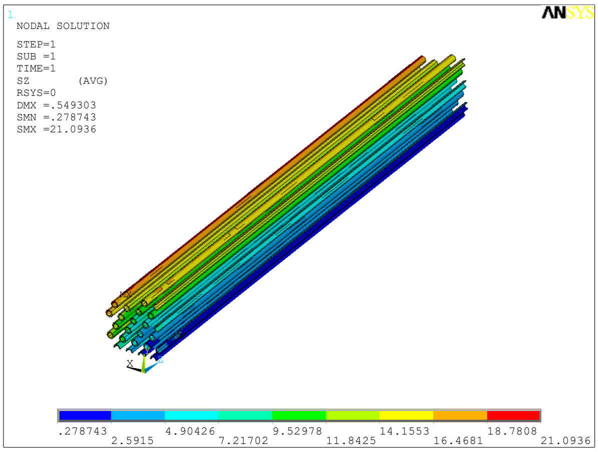


Figure 6. Stress distributing graphics of inner tube under Ps+T condition

E. *Stress Distribution of Outer Tubes*

The stress intensity distribution of outer heat transfer tube shown in "Fig. 7." As can be seen from the figure, the maximum axial stress of the outer heat exchange tube is -41.8496 MPa, which appears at the end connected with the tube sheet, and the stress levels of the remaining areas are lower than the allowable stress. The stress level of the outer heat exchange tube is higher than that of the inner sleeve as a whole, and shows little change under the 4 dangerous conditions. It indicates that the temperature stress plays a dominant role, the expansion joint set on the heat exchanger can't afford too much effect. This is due to the fact that the expansion joint is located at the header of the heat exchanger and the internal heat exchanger is actually a fixed tube sheet heat exchanger without an expansion joint.

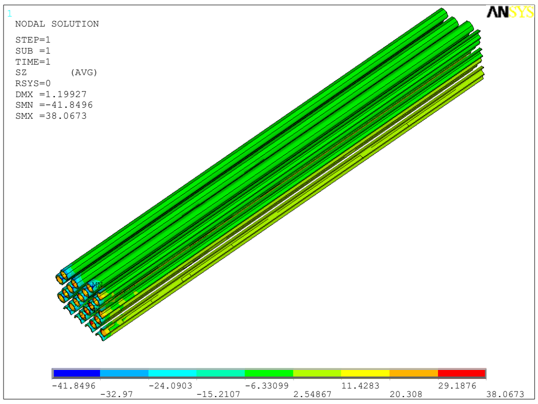


Figure 7. Stress distributing graphics of outer tube under Ps+T condition

F. *The Stress Check of Each Component*

Table III lists the maximum stresses in a finite element model for each condition where its members, and check them.

TABLE III.
STRENGTH CHECK OF BUNDLE PARTS

the parts for checking	Dangerous location	Calculated value (MPa)	Allowable value (MPa)	the results for checking
Inner tube sheet	Tube sheet and tube connections	257.646	314.4	qualified
Outer tube sheet	Tube sheet and tube connections	86.438	314.4	qualified
axial stress of Inner tube	Lattice calculation	21.0936	194.19	qualified
axial stress of outer tube	Lattice calculation	42.0413	292.95	qualified
Isolation chamber expansion joint	Valley Department	292.983	380.4	qualified
	The maximum displacement	1.31879mm	3.7mm	qualified

It can be obtained by finite element analysis of the double tubes double tube sheets heat exchanger: The maximum stress value of the spacer structure appears in the expansion joint portion connecting the inner and outer chamber tube sheet, the stress in this area is caused by the larger temperature difference between the inner tube and the outer tube and between the inner tube and the shell-side barrel, And expansion joints effectively carry most of the temperature stress. The stress at the maximum point of expansion joint stress once, twice the stress and peak stress, its strength in line with the relevant standards. There is a change in the stress in the inner and outer tube sheets and in the inner and outer tubes. However, there is a large temperature difference peak stress at the sudden change of the structure, and the stress distribution and the change of the other parts of the tube plate and the heat exchange tube are relatively uniform. And all meet the strength checking condition. This shows that the structural design is safe and reasonable. It is necessary to set expansion joints in the isolation chamber.

V. CONCLUSION

In this paper, the stress of a double tubes double tube sheets heat exchanger with expansion joint under the dangerous condition of 7 is analyzed by ANSYS analysis software. Taking the most dangerous condition as an example, the related calculation results are given. According to the calculation results, the stress intensity of each component of the heat exchanger was checked and evaluated. The related results provide a reliable theoretical basis for the industrial application of this type of heat exchanger. Due to the special structure of the double tube and double tube sheet heat exchanger, there is no unified standards for design and calculation. The research of the paper provides a train of thought for the design and calculation of this type heat exchangers, and gives a specific implementation method, which is of guiding significance to researchers in relevant fields.

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