Cause Analysis and Stress State Study of Corrosion Case of Shell and Tube Heat Exchanger

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Abstract. Shell and tube heat exchanger is an important equipment in nuclear power, chemical industry and other industries. The working conditions of such equipment are sometimes complex, and the use temperature, fluid state and flow may affect the normal operation of the equipment. In addition, there are many connecting pipes on the shell and tube head of the shell and tube heat exchanger connected with other equipment, which has an impact on the continuity of the equipment structure. Reasons for the corrosion of the shell and tube heat exchanger tube box head in a chemical plant was analyzed in this paper. Finite element method was used to model the corroded tube box head, studies of the stress distribution after corrosion. Some suggestions was given to avoid this kind of corrosion.

Keywords: heat exchanger, corrosion under insulation, finite element analysis

1. Introduction

During an inspection and maintenance shutdown of a large chemical enterprise, it was found that there was serious corrosion at the outer tube box head of the shell and tube heat exchanger. After statistical measurement, a total of 12 corrosion pits were found. The installation form of the heat exchanger was vertical installation, and all corrosion occurred at the upper tube box head of the heat exchanger. Through observation, the heat exchanger is installed on the 3rd floor in the southwest of the whole unit building. It is found that there is no roof on the southeast top floor of the unit, that is, there is no rain shelter above the upper head. The whole equipment is insulated with rock wool, and the connecting pipe at the top of the upper head is not covered with thermal insulation material.

2. Basic parameters of heat exchanger and defects

2.1. Basic parameters of heat exchanger

The main design parameters of the heat exchanger studied in this paper are shown in Table I. The tube side medium of the heat exchanger is MCB + N2, explosive and toxic. The material of the pipe box is Q345R. The diameter of the tank is 600mm, the nominal thickness of the cylinder is 8mm, the nominal thickness of the head is 10mm, the working pressure is vacuum, the design pressure is 0.6MPa, the working temperature is 12 ℃ - 51 ℃, and the design temperature is - 10 ℃ - 200 ℃. The material performance parameters at design temperature are shown in Table 2, and this part of the data comes from GB150.[1] The parameters of vessel main material Q345R at design temperature are shown in Table II[2].

Table 1. Main design parameters of heat exchanger

Name	Shell Side	Tube Side
Material	Q345R	Q345R
Design Pressure/MPa	1.0/-0.1	0.6/-0.1
Design Temperature/℃	-10/200	
Max Working Pressure/MPa	0.9	0.54
Working Temperature /℃	10/28.73	51.01/12.7
Corrosion allowance /mm	2	2
Joint coefficient	1	1

Table 2. Parameters at material design temperature

Material	Q345R
Young's modulus/MPa	2.01×105
Poisson's ratio	0.30
Allowable stress at design temperature /MPa	189
Density g/cm3	7.85

2.2. Basic information of defects found in inspection

Basic information of defects found in the inspection. The defects found in the inspection are mainly located on the pipe box, and their location is shown in Figure 1. See Table III for the size and location of relevant defects.

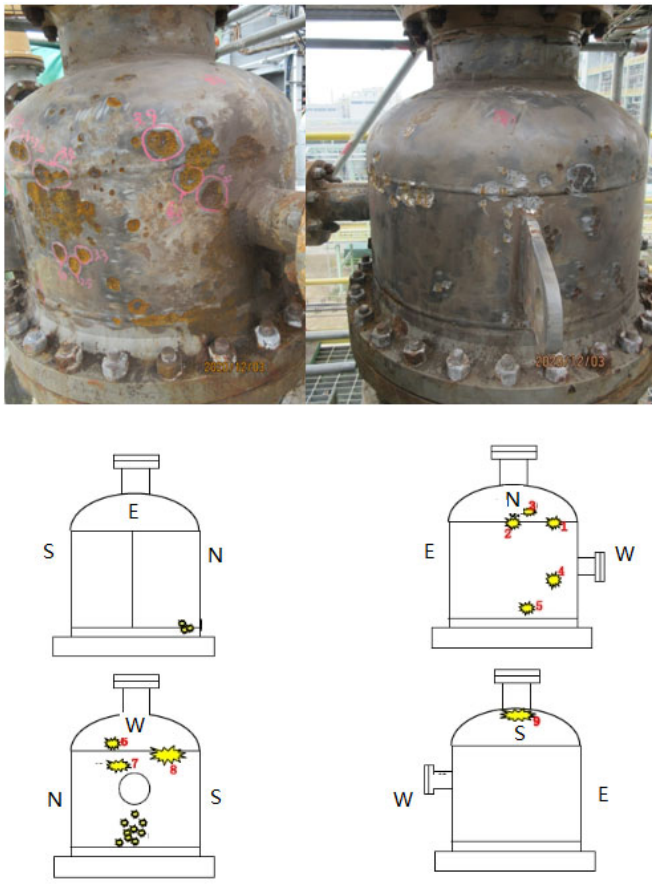


Fig.1 Schematic diagram of head defect distribution

Table 3. Defect size of pipe box head

Defect number	Defect depth/mm	Defect length/mm	Defect width/mm
1	3.4	70	35
2	3.0	48	40
3	3.0	41	29
4	3.3	49	31
5	3.3	35	28
6	3.9	42	39
7	4.4	61	52
8	3.5	82	30
9	3.5	48	25

2.3. Cause analysis

According to the actual corrosion and equipment insulation, the heat exchanger was corroded under the insulation layer. Corrosion under insulation (CUI) refers to a corrosion phenomenon that occurs on the outer surface of pipes or equipment wrapped with thermal insulation materials.[2] Generally, the local corrosion of the external surface of the pipeline or equipment is caused by the condensed water or rainwater entering the insulation system. When moisture exists under the insulation system, pipelines made of carbon manganese, low alloy and austenitic stainless steel are prone to electrification, pitting corrosion, stress cracking and crevice corrosion.

3. Finite element stress analysis of vessels with defects

Due to the large number and depth of corrosion pits, it is impossible to use the relevant provisions in the safety technical code for fixed pressure vessels tsg21-2016 for safety assessment.[3] In order to further understand the stress distribution on the corroded pipe box and the safety of the equipment, this paper carries out finite element modeling and linear elastic stress analysis for the defective pipe box head.

3.1. Modeling and meshing

All the models are meshed by hexahedral elements, and the girth weld and head are meshed. The grid model is shown in Figure 2

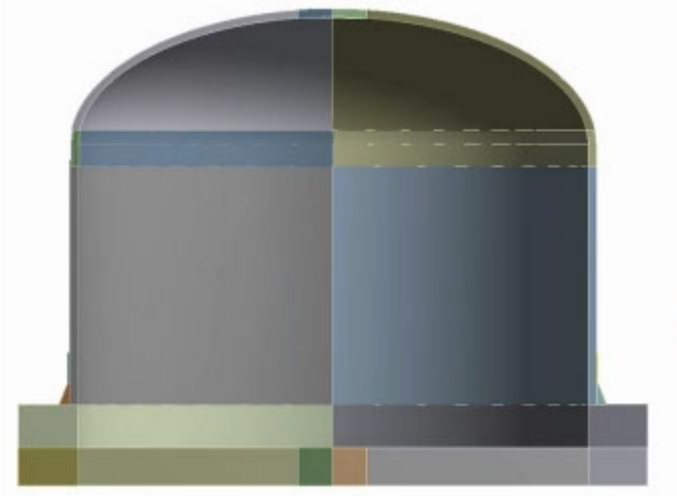


Fig.2 Geometric model of head with defects

According to Fig.1, defects are mainly distributed in four parts: head, cylinder, cylinder flange girth weld and head cylinder girth weld. Based on Saint Venant's principle, the static stress analysis is mainly

carried out for the parts with defects. In the analysis, the detailed stress analysis is focused on the defects with the largest defect depth, that is, four defects with No. 1, 5, 6 and 7 are selected for analysis. In order to simulate the defects, the tile mounted defects are used to simulate the uniform thinning of wall thickness, The elements meshing of the upper tube box head with defects is shown in Figure 3. Meshing detail of defects with No. 1, 5, 6 and 7 are shown in Figure 4(a)~(d).

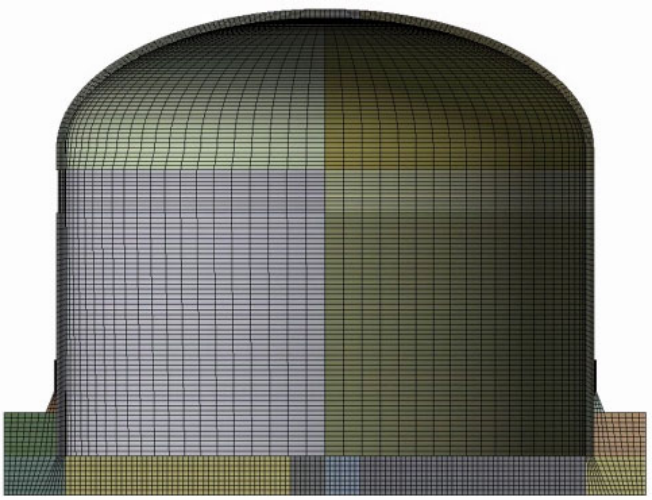


Fig.3 Meshing of head with defects

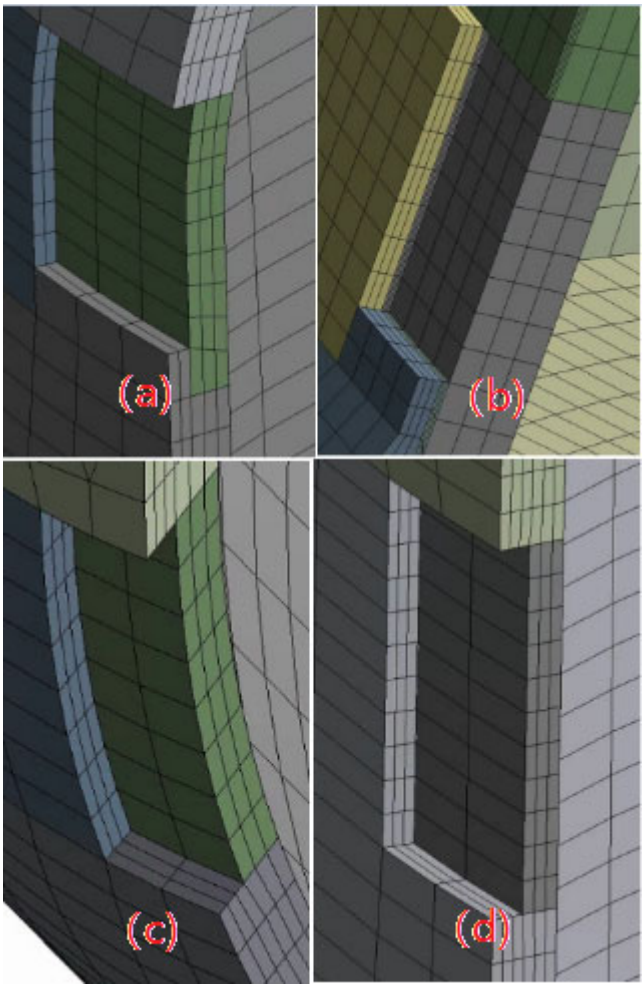


Fig.4 Meshing of defects No. 1, 5, 6 and 7

3.2. Boundary condition

The boundary conditions of the upper pipe box head are shown in Figure 5, mainly including:

(1) Fixed constraints: apply fixed constraints on the lower surface of the official tube plate;
(2) Frictionless support: apply symmetrical constraints on the section of 1 / 2 model;
(3) Internal pressure: uniformly distributed pressure load of 0.6MPa is applied in the pipe box;
(4) Weight of upper head: the upper head applies 1 time of gravity, and the gravity acceleration is 9.8 m / S^2.

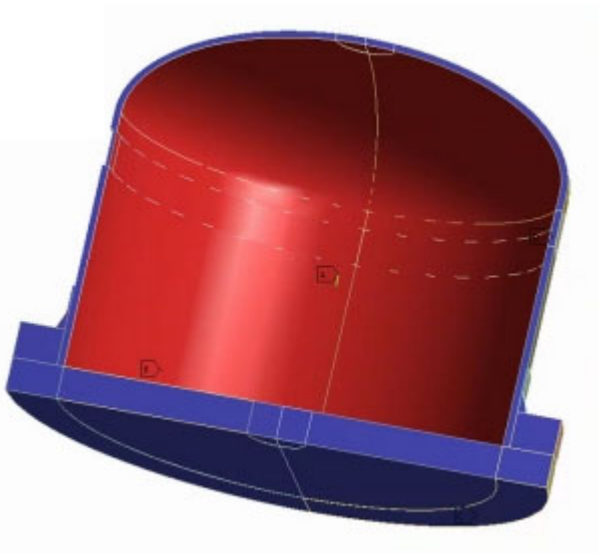


Fig.5 Schematic diagram of boundary conditions of upper head model

3.3. Calculation results

The linear elastic stress analysis of the defective upper head is carried out, and the stress intensity distribution is shown in Figure 6

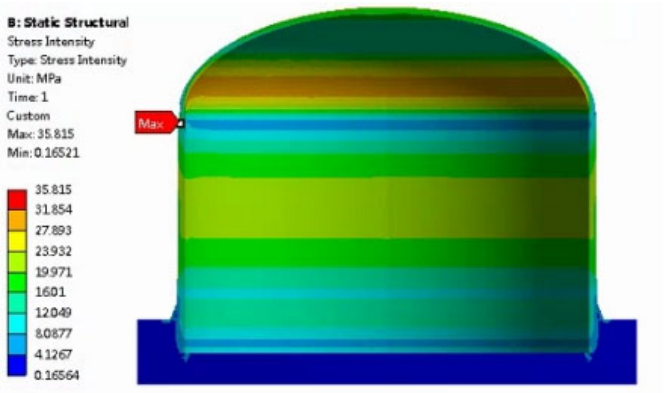


Fig.6 Cloud diagram of static stress distribution of head with defects

See Table 4 for the maximum equivalent stress information of defects No.1, 5, 6 and 7.

Table 4. Maximum equivalent stress information of defects

Defect number	Defect depth/mm	Defect length/mm	Defect width/mm	Load/MPa	Stress/MPa
1	3.4	70	35	0.6	35.8
5	3.3	35	28	0.6	29.3
6	3.9	42	39	0.6	27.2
7	4.4	61	52	0.6	41.4

The finite element analysis of the upper tube box head structure under the design load is carried out, and the stress intensity of the analysis results is evaluated. The evaluation refers to JB4732.[4] It can be seen that for the structural parts with defects, the maximum stress basically occurs at the defect

position, of which the value of defect 7 is the maximum, and its maximum stress is 41.36mpa, which is far less than twice the allowable stress of Q345R material. This shows that although the local defects of the upper pipe box head weaken the strength of the overall structure, it still meets the strength requirements, mainly because the actual wall thickness of the container is much greater than the design thickness.

4. conclusions and suggestions

4.1. Conclusions

The linear elastic stress analysis of the heat exchanger with defects is carried out by using the finite element stress analysis method. The analysis shows that the structures with defects can pass the safety evaluation..

4.2. Suggestions

It is suggested to monitor the use of the container, track the defects regularly, judge the change of defect size, pay more attention to whether the material performance is degraded, and carry out safety assessment in the next inspection to ensure safety before use.

4.3. CUI protection policy

The anti Cui corrosion coating can be painted on the surface of the container. The coating must have three functions: waterproof, temperature resistance, thermal insulation and thermal insulation.For equipment and pipelines below 600 ℃, inorganic waterproof, anti-corrosion, heat insulation and thermal insulation coatings can be directly used.

The waterproof and anti-corrosion coating is a high temperature resistant resin prepared by special functional grafting and chelation technology, which is filled with a large number of micro glass hollow beads with good fineness and high hollow rate. The cured coating has very low thermal conductivity and good waterproof and anti-corrosion effect. It can be used under the condition of lower than 600 ℃ for a long time.[5]

References

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