Identification of damages zones of transfer line exchanger based on modeling

M I Bayazitov, A V Rubtsov, P A Kulakov and R M Bayazitov
Ufa State Petroleum Technological University, 1, Kosmonavtov street, Ufa, 450062, Russia

E-mail: mailbmi@yandex.ru

Abstract. The task was set to simulate a quenching and evaporation apparatus in a software package based on operational and technical documentation, considering the structural and operational characteristics, as well as modeling the thermo-force effect and identifying the most loaded zones of the structure. For research, the most common exploited design of the quenching-evaporation apparatus of the “pipe in pipe” type was chosen, consisting of a welded elbow, an external pipe 325x14 mm, an internal pipe 168x13 mm, conical eccentric transitions 300/100 mm and fittings. Materials of structural elements of the quenching and evaporation apparatus are steel 20 and steel 20X23H18.

Technologically, the quenching and evaporation apparatus is installed on the metalwork and at the outlet of the pyrolysis furnace and connected to the food coil. The authors conducted a thermo-power simulation of the quenching and evaporation apparatus considering operating conditions using the APM FEM system for solving engineering and research problems integrated into the COMPASS-3D computer-aided design system. It is proposed to use the calculation model and the obtained stress-strain state to identify the most loaded zones of the structural elements of the quenching and evaporation apparatus. It is proposed to use the results obtained in modeling the combined action of temperature loads and pressure to identify damage zones in structural elements. It is shown that in zones with the most dangerous stress-strain state, defects occur and localize in the form of thinning of the wall.

1. Introduction
In the petrochemical industries, one of the most important technological processes is the process of pyrolysis of oil hydrocarbons, which is the most severe form of thermal cracking in order to produce hydrocarbon gas enriched in unsaturated hydrocarbons [1-5]. The process is carried out at temperatures from 700 to 900 °C. The pyrolysis process, as a rule, is mainly carried out in tube furnaces. But no less important equipment for the process of hydrocarbon pyrolysis is the quenching-evaporation apparatus (ZIA), designed to quickly cool the pyrogas using a steam-water emulsion. During the operation of the ZIA there are problems associated with ensuring the strength due to its complex thermal power loading. In order to ensure the safe operation of the ZIA, it is periodically subject to industrial safety review of technical devices in accordance with regulatory documents. All types of visual measuring and non-destructive testing are carried out. Further operation is allowed on the basis of an expert opinion of a specialized organization. Despite the simplicity of the design, the ZIA does not apply to pressure vessels or pipelines. Therefore, the analysis of the technical condition
based on traditional approaches does not take into account the problems of complex thermo-force loading.

In this regard, the urgent task is to simulate the thermo-force effect on the elements of the ZIA and to identify the most loaded zones [6-8].

2. Methodology of research

Structurally, the apparatus is a device in the form of a U-shaped cooler, into the inner tube of which pyrogas is fed after the furnace, and a steam-water emulsion into the annular annular space. The high structural load is due to the high temperature difference (up to 600 °C) and pressure drop. A particular influence is exerted by the design of the outlet of the pyrogas pipe through a conical transition. An analysis of the documentation and the technical condition shows that the ZIA is subject to increased and uneven erosion-corrosion wear and during long-term operation defects are present in the form of thinning of the wall on all its elements. Material performance of structural elements - steel 20 and 20X23H18. It is made of pipes measuring 325x14 mm and 168x13 mm. The device is equipped with nozzles with flange connections for inlet and outlet flows, as well as drainage.

The passport technical characteristic of the ZIA is given in table 1.

| Table 1. Passport technical characteristic of ZIA. |
|-----------------------------------------------|
| Parameter                  | Value          |
| Design pressure, MPa      | Annular space | Pipe space |
| Temperature °C            | 230            | 820        |
| Working environment       | Steam emulsion | Pyrogas    |

To study the strength analysis, various software products are used. The most convenient are those that are used to build solid-state models and in the same environment, engineering analysis is performed by the finite element method. This allows, if necessary, to correct the model itself, to explore various options and optimize the design according to strength criteria.

For modeling and research of strength analysis, the APM FEM system was used to solve engineering and research problems, integrated into the COMPASS-3D computer-aided design system [9-12].

This system is built into the software product and allows you to perform modeling in solving strength and thermal problems. The procedure is performed in three stages:

- the adoption of a method of fixing and the application of existing loads and temperatures;
- creating a finite element mesh, its optimization according to various criteria;
- execution of the calculation.

Previously, the results of the latest thickness gauge were studied. The structural elements are shown conditionally. Up to 4 measurements were carried out in each section of the ZIA element, and the lowest value was used for further analysis.

Since the design thicknesses of the individual elements differ from each other, the relative values of the residual thickness to the design ($S_{out} / S$), as well as the ratio of the rejection thickness to the design ($S_{sample} / S$), were calculated element by element according to the results of the thickness gauge.

For visualization, the final processing results in the form of a distribution of the relative residual and reject thicknesses are shown in figure 1.

When building the model, technical documentation was used with the main dimensions of the quenching and evaporation apparatus and its material design. A separate engineering analysis of the lower part was carried out, made of truncated pipes. A preliminary calculation showed that there is no
significant difference in the nature of the stress-strain state (VAT) for smooth bending and consisting of truncated pipes. Therefore, in the future, the ZIA model was built from pipe bends.

The three-dimensional solid-state model of the ZIA was built in the Compass-Graph-3D software package. For engineering analysis, the apparatus was fixed on supports installed in the middle of the outer pipes in the amount of 4 pieces. Effective loads in the form of internal pressure and temperatures and adopted according to table 1, were applied to the internal cavity of the pipes. In accordance with the calculated parameters according to table 1, the wall temperatures of the inner and outer pipes were set. A three-dimensional sectional model is shown in figure 2.

In the study of the model, various parameters of the finite element mesh were considered, but the above ones were considered sufficient to ensure the given accuracy of calculations and computer performance. The breakdown of the model into finite elements was performed as follows:

- the maximum length of the side of the element is 100 mm;
- maximum coefficient of condensation on the surface - 3;
- coefficient of rarefaction in the volume of 1.5;
- the number of finite elements - 58887;
- the number of nodes - 116589.

The fastening was installed at the installation site of the support.

Thermal and static analyzes were carried out in an elastic setting, i.e., without plastic deformations [13-16]. Thus, this design of the ZIA under the accepted conditions is under the conditions of a complex thermo-force impact. Figure 3 shows the values of the equivalent Mises stresses in the areas

---

**Figure 1.** The distribution of relative thicknesses in the housing ZIA (outer pipe).  
**Figure 2.** Finite element ZIA model.
of greatest actual damage shown above in figure 1. The VAT of the entire apparatus is shown in Figure 4.

![Figure 3. Finite element ZIA model.](image1)

![Figure 4. VAT ZIA in working conditions.](image2)

A more detailed analysis in these zones shows that the stresses in the region of the supports do not exceed the permissible values, and further research is not of interest. The stresses arising in the inlet / outlet zone of the pyrogas can exceed the limit values for the applied steels, that is, the yield strength and strength. The voltage distribution is shown in figure 5.

![Figure 5. Stress distribution along the generatrix of the conical shell.](image3)

The main reason for thermal deformation of structures, as a rule, is the temperature difference between the walls of its individual elements. For this analysis, temperatures at characteristic locations were considered. Figure 6 shows one of these zones.

Mutual deformation of the pipes is also of interest in order to verify the possible contact interaction of U-shaped elements in the lower part.
Analytical calculations of the temperature elongation of individual elements of the ZIA does not allow us to identify zones of joint thermal deformation, since they do not allow taking into account deformations from the applied pressure. Therefore, it is also necessary to conduct modeling of ZIA behavior and study of displacements.

In accordance with the technical documentation and the developed drawing, the geometric clearance in the annular space is 64.5 mm. When modeling under operating conditions, the results of which are shown in figure 7, it was found that the vertical displacement of the internal U-shaped element at the lower point is 43.3 mm, and the external only 8.7 mm. Then the gap will decrease by $\Delta = 43.3 - 8.7 = 34.6$ mm and will be $64.5 - 34.6 = 19.9$ mm.

**Figure 6.** Temperature distribution in the inlet / outlet area of the pyrogas.

**Figure 7.** Mutual deformation of the inner and outer pipes ZIA.
Thus, on the basis of thermal power modeling of the quenching-evaporation apparatus, it is possible to identify the zones that represent the greatest potential danger due to the occurrence of stresses and strains in them, leading to a decrease in their structural strength, the occurrence and development of defects. The results of studies of the ZIA model correlate with the level of defectiveness in residual thicknesses in its individual zones.

3. Conclusion
The obtained simulation results of thermo-force loading of ZIA design elements must be taken into account both in the design of this type of equipment and in the periodic assessment of the technical condition, as well as supervision during operation.

Since the operating conditions of the ZIA are characterized by a high level of thermal loading and a high temperature difference between the flows of pyrogas and steam-water emulsion and reaches 600 °C, the assessment of the stress-strain state of the structure makes it possible to identify the most loaded temperature zones and, therefore, to carry out more thorough control by non-destructive testing methods in these zones.

The temperature deformations of the ZIA elements from the side of the pyrogas and the steam-water emulsion have a mutual influence and are possible causes of the appearance and development of defects in the ZIA elements. This aspect must be considered when periodically monitoring the technical condition.

Structures and devices consisting of elements rigidly interconnected and located in a differently loaded state, in order to identify “promising” defective areas and ensure operational safety, should be calculated as an integral structure. The element-by-element calculation for the maximum possible loads does not allow to reveal the nature of the interaction of elements after applying the existing complex loads.

It should be noted that the simulation of thermal force loading and assessment of the stress-strain state of equipment that is so complex in terms of operating conditions as ZIA allows to identify potentially dangerous zones and regularly monitor them using non-destructive testing methods to prevent premature failure and ensure industrial safety during operation.

Reference
[1] Sun L, Tuo J, Zhang M, Wu C and Chai S 2019 Energy and Fuels 33(7) 6283-93
[2] Ryu H W, Lee H W, Jae J and Park Y K 2019 Energy 179 669-75
[3] Yu R, Liu D, Lou B, Ye J and Zhu C 2019 Fuel 247 97-107
[4] Zhao S, Sun Y H, Yang Q C and Li Q 2019 Dongbei Daxue Xuebao/Journal of Northeastern University 40(6) 896-902
[5] Ganvir K D and Pachkawade N D 2019 AIP Conference Proceedings 2104 030044
[6] Tukhvatullin R R, Sultanov I M, Zaynullina S R, Gabzalilov R F, Tlyasheva R R and Bayazitov M I 2015 Bashkir chemical journal 22(4) 71-9
[7] Tropkin S N, Tlyasheva R R, Bayazitov M I, Rafikova Z R and Kuzeev I R 2013 Electronic scientific journal Oil and Gas Business 1 476-86
[8] Tropkin S N, Tlyasheva R R, Kuzeev I R and Bayazitov M I 2018 IOP Conference Series: Materials Science and Engineering 327 042012.
[9] Panchenko V, Kharchenko V and Vasant P 2019 Advances in Intelligent Systems and Computing 866 108-16
[10] Belousov S V, Pomelyayko S A and Novikov V V 2018 MATEC Web of Conferences 224 05006
[11] Nurgaliev R Z, Bakhtizin R N, Urazakov K R and Gubaidullin A G 2017 Neftyanoe Khozyaystvo - Oil Industry 10 113-5
[12] Kuftyrev R Y, Polushin N I, Kotel’Nikova O S, Laptev A I and Sorokin M N 2017 Izvestiya Ferrous Metallurgy 60(9) 745-51
[13] Shi T F, Wang C J, Liu C, Dong Y H and Li XY 2016 Smart Materials and Structures 25(3) 035029
[14] Kamerkar P 2012 American Laboratory 44(1) p. 19-20
[15] Viafara C C and Sinatoria A 2011 Wear 271(9-10) 1689-700
[16] Shung C B and Peng Z Y 1985 Proceedings of the ASME Turbo Expo 4