Analysis of the stress-deformed state of a tube bundle at different values of partition thicknesses and their deviations from verticality

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Abstract. Shell and tube heat exchangers of hazardous industrial facilities are used to heat or cool working media and represent a rather complex individual design, which can consist of several structural elements, such as a body, bonnets, heat exchange tubes, tube sheets, partitions, etc. The failure of one element contributes to the failure of the entire heat exchanger. In the process of assembling or installing elements of the heat exchanger, the formation of various geometric deviations from design solutions is possible, which may be associated with violations of the technology of the assembly process, installation, etc. The presence of such deviations can negatively affect the reliable and trouble-free operation of the apparatus, serve as a scenario for the formation of places of increased stresses, leading to the initiation of defects in these zones and premature failure. One such deviation may be a change in thickness values and deviations from the vertical design of the transverse baffles of the tube bundle as supports for the heat exchange tubes. In the existing methods, the transverse partitions of the tube bundle do not pay attention and do not take into account their possible impact upon deflection on the stress-deformed state of the apparatus as a whole. In this work, the relationship of the effect of thicknesses, values and directions of deviation from the vertical location according to the design of transverse partitions of the pipe bundle on maximum equivalent stresses is investigated.

1. Introduction
Heat exchangers for oil refining, petrochemical and chemical operations are operated at elevated pressures, temperatures, with toxic and explosive and fire-hazardous environments and, therefore, must meet the highest requirements in the field of reliability and industrial safety.

The operational reliability and industrial safety can be significantly influenced by the quality of assembly or mounting of individual components. When performing the above noted works, the formation of various types of inconsistencies with the requirements of project documentation is possible. This may include deviations from straightness, ovality, offset edges, verticality, etc. All these deviations can further lead to an increase in stresses in certain zones of the heat exchanger, the formation of defects in these zones and the possible creation of an emergency situation with premature shutdown of the equipment. Therefore, for quality control and assessment, a wide arsenal of non-destructive testing methods is used, including one of the most informative methods - visual and measuring control (VMC) [1-5]. VMC allows you to effectively carry out internal and external inspection, identify various deviations, visible defects, size discrepancies with the project and is the
primary method in assessing the technical condition. When monitoring and assessing quality, they are guided by the requirements and norms established by the current regulatory and technical documents. However, the non-separable design of the heat exchanger with fixed tube sheets creates an obstacle for a qualitative examination of the inner surface of the apparatus body and the outer surface of the tube bundle. Although, as the analysis of failures of heat exchangers in oil and gas refineries shows, it is precisely the passage of heat exchange tubes that is the most frequent cause of failure of a heat exchanger and accounts for almost 99% of all failures associated with heat exchangers.

The leakage of heat-exchange tubes can occur in places where high stresses are concentrated in their various sections, both in the presence of corrosive and non-corrosive media. The occurrence of stress concentration zones in heat exchange pipes can be facilitated by scenarios such as, for example, changes in wall thicknesses of the transverse partitions of the tube bundle, as well as deviations from the vertical arrangement of the partitions in the case of insufficient fixation of the partitions in the tube bundle. Due to the fact that the baffles in the tube bundle are supports for the heat exchange tubes, such scenarios can have a negative effect on the reliability and safety of the tube bundles as a whole directly on the whole shell-and-tube heat exchanger [6-8].

In this regard, the current task is to simulate the stress-strain state (SDS) of the pipe bundle in order to identify the values of maximum equivalent stresses taking into account the change in wall thickness of the partitions and various values of deviations of the partitions from the vertical design position in different directions.

2. The research method
One-way shell-and-tube heat exchanger of oil refinery with the following technical and operational characteristics was selected for SDS analysis:

- inner diameter of the housing is 400 mm;
- pipe length of tube bundle is 2000 mm;
- total number of heat exchange tubes is 109 pieces;
- the tubes have a smooth surface;
- the size of heat-exchanging tubes is 25×2.5 mm;
- design temperature of pipe space is 85 °C;
- design temperature of annulus is 50 °C;
- design pressure of pipe space is 3.9 MPa;
- design pressure of annulus is 0.6 MPa;
- material of structural elements: steel 20;
- type of pipe grid - stationary.

Figure 1 shows a tube bundle with fixed tube sheets and numbered transverse partitions.
The SolidWorks software package was used to simulate and evaluate the SDS of a tube bundle with fixed tube sheets [9-15].

The SDS of the bundle was estimated for the following cases:

- thickness of transverse partitions is 10 mm, 8 mm, 6 mm and 4 mm without their deviation from the vertical position according to the design;
- transverse partitions No. 1 and No. 6 are deviated from the vertical position according to the project by values from 0 to 15° with a pitch of 3°, in the direction of clockwise direction and similarly counterclockwise direction at thickness of partitions equal to 8 mm;
- transverse partitions No. 1 and 2 with a thickness of 8 mm are mutually deviated from the vertical position along the project in a clockwise direction by values from 3 to 15° with a pitch of 6°;
- transverse partitions No. 1 and 2 with a thickness of 8 mm are mutually deviated from the vertical position according to the project, at that partition No. 1 is deviated in the direction of clockwise direction, and partition No. 2 against the direction of clockwise values from 3 to 15° with a pitch of 6°;
- partitions No. 1 and 3 with a thickness of 8 mm are mutually deviated from the vertical position along the project in a clockwise direction by values from 3 to 15° with a pitch of 6°;
- partitions No. 1 and No. 3 with a thickness of 8 mm are mutually deviated from the vertical position according to the project, at that partition No. 1 is deviated in the direction of clockwise direction, and partition No. 3 is deviated in the direction of clockwise direction from 3 to 15° with a pitch of 6°.

3. Results of the research and the discussion

According to the results of the SDS assessment of the pipe bundle, in the above cases, dependency graphs were obtained, which are shown in figures 2-8.

![Graph of dependence of maximum equivalent stresses on thickness of transverse partitions.](image-url)
Figure 3. Graph of the dependence of maximum equivalent stresses on the values of the partition No. 1 deviation from the vertical location according to the project: "-" – in the clockwise direction; "+" – counterclockwise.

Figure 4. Graph of the dependence of maximum equivalent stresses on the values of the partition No. 6 deviation from the vertical location according to the project: "-" – clockwise direction; "+" – counterclockwise.

Figure 5. Graph of dependence of maximum equivalent stresses on values of deviations of partitions No.1 and 2 from vertical position in the project in the direction of clockwise direction.
4. Conclusion
Based on the results of the SDS simulation of the tube bundle of the shell-and-tube heat exchanger with different thickness values and values of deviation of the partitions from their vertical location according to the project, it is possible to formulate certain conclusions:
it was found that with an increase in the thickness of the transverse partitions of the tube bundle, an increase in the maximum equivalent stresses in the heat exchange tubes occurs, and the maximum stresses increase by about 2 MPa for every 2 mm of increase in thickness;

- it is shown that the values of the maximum equivalent stresses of the tube bundle depend on the values of the deflection of the partitions. When the values of deviations from the vertical location according to the design of transverse partitions increase, the values of maximum equivalent stresses are observed. This must be taken into account when diagnosing the heat exchanger in order to timely detect the most loaded zones.

References

[1] Valentina D P, Valentina D S, Salvatore M and Stefano R 2021 Procedia Computer Science 180 958-967
[2] Kuusk A and Gao J 2021 Lecture Notes in Mechanical Engineering 201-213
[3] The Y-L and Kuusk A G 2021 Lecture Notes in Mechanical Engineering 153-163
[4] Freund L and Al-Majeed S 2020 2020 International Conference on Innovation and Intelligence for Informatics, Computing and Technologies, 9312015
[5] Kriegel M and Berdermann J 2020 2020 European Navigation Conference 9317443
[6] Rubtsov A V, Kulakov P A, Mukhametzyanov Z R, Arkhipova K S and Gimaltdinov I K 2020 Journal of Physics: Conference Series 1661(1) 012079
[7] Galiev I, Ibragimov R, Ashrapov A and Radaykin O 2020 IOP Conference Series: Materials Science and Engineering 890(1) 012140
[8] Mukhametzyanov Z R, Kulakov P A, Rubtsov A V and Churakov Y A 2020 Journal of Physics: Conference Series 1582(1) 012055
[9] Rubtsov A V, Kulakov P A, Mukhametzyanov Z R, Bayazitov M I and Farshatov A R 2020 Journal of Physics: Conference Series 1515(5) 052053
[10] Begalinov A, Almenov T, Zhanakova R and Bektur B 2020 Mining of Mineral Deposits 14(3) 28-36
[11] Nasibullina O A and Tyusenkov A S 2019 IOP Conference Series: Materials Science and Engineering 537(2) 022018
[12] Zheng L Q, Chen X M, Zhang B, Zheng Y Z and Lin Z L 2019 Chinese Journal of Tissue Engineering Research 23(36) 2095-4344
[13] De Miranda D A and Nogueira A L 2019 Materials Research 22(2) e20180564
[14] Erick Fiestas S and Sixto Prado G 2017 2017 LARS 14th Latin American Robotics Symposium and 2017 5th SBR Brazilian Symposium on Robotics December 1-6
[15] Qi J, Meng H, Kan Z, Li C and Li Y 2017 Transactions of the Chinese Society of Agricultural Engineering 33(24) 65-71