Technical condition examination of heat exchanger tubes with an acoustic pulse reflectometry method

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Abstract. Diagnostics of the technical condition of heat exchanger tube bundles is considered in the paper. The main problem is associated with the large total length of tubes in bundles and a limited time for examination. For examination of the internal clearance of pipes the method of acoustic pulse reflectometry, known in a science and technology, was used. This method was implemented in PAKT-04 device for express-inspection of heat exchangers. It is proposed for characterizing the wear of the tubes to introduce a generalized quantitative parameter called “defectiveness degree”. The parameter is determined by change of acoustic signal propagating in the tube. The value of defectiveness degree indicates the applicability the tube for operation in the heat exchanger. The results of measuring the parameter on different heat exchangers are discussed.

1. Introduction
This paper considers nondestructive testing of the equipment tubes at hazardous production facilities of various industry branches: chemical, petrochemical, oil-and-gas, power and others. Heat exchangers have a lot of tubes (up to several thousands) for heating or cooling of the product. The set of temperature and pressure, product chemical aggression causes tube wear and reduces tube durability. Diagnostics of the technical condition of heat exchanger tube bundles is proposed to decrease the failure risk. The main problem is that heat exchangers have a lot of tubes of small inner diameter and the large total length.

Relatively recently the acoustic pulse reflectometry (APR) [1, 2] method is used for examination of the inner surface of the small diameter tubes. It allows inspecting a lot of heat exchanger tubes for over a short period of time. However, the distortion of the acoustic signal makes it difficult to draw objective conclusions about the tube condition.

There is a technology for quick examination of the tubes technical condition at JSC IrkutskNIIhimmash. This technology also covers the heat exchangers tube bundles. It is based on the APR method. The technology is proposed to use the device for nondestructive testing, a technique of its implementation and the approved approach in practice. The PACT–04 is a computer appliance. The experience in its application and selection of evaluation criterion allows improving the technology for quick examination of the tubes. One of the evaluation criterions is a generalized quantitative parameter called “defectiveness degree”. It characterizes the wear of the tube wall.
2. The computer appliance PACT-04

The application of PACT-04 according to the principals of the technology for quick examination and its functioning is based on the APR method. The method has been performed for the scientific purposes in biological and musical acoustics for a long time. The company “AcousticEye” from Israel made the first commercial devices to test the tubes.

The idea of the technology for quick examination is as follows. The acoustic pulse is transmitted to inner volume of the tube with acoustic detector. The deposits, blockages, holes and other defects reflect, absorb or scatter the acoustic pulse propagating along the tube inner surface. The receiver of the acoustic detector registers the reflected acoustic pulse for the subsequent analysis.

PACT-04 allows recording the digital echo-signal from each tube to the computer memory. The information of tubes technical condition is presented with a two-zoned automatic defect detector (ADD) on the computer monitor. The ADD allows marking in color each tube on the tube bundle scheme which is shown on the monitor. The tubes to be remarked with color form the information about tube defectiveness. The defectiveness can include holes, blockages, deposits and other defects. The tube bundle of the heat exchanger examined with PACT–04 is shown in figure 1. There is also a tube bundle scheme with control results performed with PACT–04 in figure 1. The light marks mean that the tubes are applicable to operate, and the dark ones mean that the tubes are failed.

![Figure 1. The tube bundle scheme (at the left) of heat exchanger (at the right) with marked tubes.](image)

The PACT-04 computer software determines the defectiveness degree of each tube, forms the datasheet, and shows the distribution of the tubes depending on this parameter.

3. The defectiveness control and its classification

The heat exchanger tubes having the contact with aggressive product during operation accumulate the defects. Some of the defects can refer to wear of the tube walls, other ones – to product deposits.

These defects can be classified according to the following features:

- the wall metal deterioration due to chemical solution of the aggressive product. The solution rate depends on the discontinuity of chemical composition or steel structure, product temperature, product rate passing along the wall. As a rule it turns to leakages or tube rupture;
- the corrosion wear covering the wall surface. It turns to wall deterioration, pittings, cracks and wall holes;
- the emerging volume of corrosion such as scale which is mechanically captive with the wall;
- the insoluble deposits which can jam the tube.
The first and second types of classified defects are the ones which deteriorate the wall strength, reduce the lifetime and increase the tube failure risk. The third and the forth types of classified defects increase the hydraulic resistance and reduce the efficiency of heat exchange.

The tubes with smooth inner surface and referring to the first type of classified defects have no echo-signals from the local defects. According to the technology for quick examination of the tubes, special test-objects are applied. They allow measuring the inner diameter of the tube in any section and measuring wall thickness losses.

The other types of classified defects have a sufficient effect to acoustic waves propagating in the tube. They reflect, disperse and absorb the acoustic signal. Such aspect allows obtaining the parameters of the diminishing acoustic wave which characterizes the defectiveness degree of the tube wall.

The tubes with holes and breaches are referred to the second type of classified defects.

The defectiveness degree of the tube is a generalized quantitative parameter. It determines the erosion wall degree, the presence of deposits, blockages, and holes. Such defects stipulate the losses in functional quality of the tube, a decrease in the heat exchanger operational ability.

The quantitative parameter, “defectiveness degree”, which is denoted as “w” (wear) is determined automatically. It can be possible due to semi-empirical dependence of every tube testing results taking into account the inner diameter and the tube length.

The “w” value can be conferred with a condition of the tube inner section. This condition is estimated with instrumental methods or visually. The concrete value or some value range of “w” will conform to the tube applicability to operate or the necessity to plan the maintenance or to do some repair. It is obvious that the “w” value may have to undergo correction if it is necessity to take the measures. The corrosion rate, operating conditions, operating time are to be taken into account.

For example, there are tubes with inner diameters equaling 20 mm of different defectiveness degree or “w” presented in figure 2. The tube capably for operation has the “w” with value 0. It has a plain inner surface. The tube with the value 0.5 has an admissible condition. If the range of “w” is 1-2 it will be necessary to clarify the defect features and to take the measures. If the “w” is 3 and more, the tubes are not applicable for following operation (figure 2).

![Figure 2. Examples of the tubes with different defectiveness degree.](image)

The parameter “defectiveness degree” characterizes the condition of the tube wall inner surface. The determination of this parameter is an important step of the tube bundle examination. The individual examination of every tube in the bundle comes to be unprofitable or even impossible. Another thing is a quantitative characteristic. It defines the technical condition, the degree of metal...
deterioration and the heat exchanger ability to operate. The statistics of tubes distribution in the bundle depending on defectiveness degree may come of the mentioned characteristic.

The defectiveness degree is calculated for every tube when the acoustic signals are measured during heat exchanger examination. The results are inserted to table with the dates of tube location in bundle. The “w” parameter values make it possible to evaluate the tubes condition.

The tubes distribution depending on defectiveness degree is formed from the table data. It looks like a histogram or a continuous dependence for big tubes quantity. To compare the condition of different apparatuses the graphs are rated, for example, like a square. Such a graph is a relation between the tubes quantity in classification interval (relative frequency) and the defectiveness degree value.

The examination results of heat exchanger with PAKT-04 are shown in figure 3. Before the examination the apparatus had been cleaned with water under pressure. The photo of apparatus and the bundle scheme with the results are presented in figure 1. The apparatus is a multipass heat exchanger.

In figure 3 the curve demonstrates the product deposits that are intensively raised on the cooling stage with changing of the product structure. The apparatus operates like a reactor or filter degrading gradually. According to this second maximum, it is advisable to add deposit separator (special apparatus) in the technological process.

The following measures can be recommended after the instrumental and visual tube bundle examinations have been done. The tubes with “w” parameter higher than 3 (its quantity is 6% from total one) should be plugged or replaced. Such tubes have an emergency condition and do not take part in heat exchange. The tubes with “w” parameter lower than 1 should have a preventive maintenance because some of them can turn into category “maintenance required”. The tubes with

![Figure 3. The distribution graph of the heat exchanger tubes depending on defectiveness degree.](image)
“w” parameter in the range of 1-2 (the second maximum of distribution) are demanded to be cleaned from deposits. The tubes with “w” parameter in the range of 2-3 (their amount is 7% of the total) should be examined for decision-making. The hydraulic test is made after repair or preventive maintenance has been done.

The distribution characteristics make it possible to estimate the total heat exchanger condition and the tubes residual life. Also it allows identifying the tubes subjected to repair or replacement, and its location on the tube bundle. The distribution curves of the tubes depending on the defectiveness degree for heat exchangers with different tube wear level are shown in figure 4.

![Figure 4](image_url)

**Figure 4.** The tubes distribution depending on defectiveness degree for some heat exchangers.

The data presented in figure 4 allows characterizing the apparatuses in the following way. The apparatus HE-001 has an operative condition at the beginning of its exploitation. The HE-003 is also an operable apparatus and it does not require maintenance. The other two apparatuses have a significant corrosion of tube inner surface. There are few operable tubes at these heat exchangers. The long “tails” of distribution curve confirm that the tubes with defects take place.

The monotonous “w” parameter escalation is specific for tubes subjected to corrosion in the period of exploitation. Simultaneously, the probability of wall critical corrosion deterioration rises and may result in the rupture of the tube. Thus the “w” parameter and the probability of depressurizing as the results of corrosion show the symbasis. The tubes from the “tails” of distribution curve have "the perspective" for rupture. The plentiful ruptures at the tubes of HE-vk and HE-22 are the confirmation of it after hydraulic tests.

### 4. Conclusion

The application of the generalized quantitative parameter which characterizes the tubes defectiveness broadens the potential of the technology for quick examination of the tubes technical condition.

The specialist gets the information about apparatus wear degree in the whole after examination due to such factors like the maximum location and distribution width. Besides that there is the structure of tube bundle with defective tubes to be color marked. Finally, every tube echogram is kept in digital and graph forms in the computer memory. Each echogram has an individual number and may be analyzed at any time when it is necessary.
The important thing is when the next examination takes place. In this case it’s capable to compare the distribution curves and see the differences. Also it’s possible to conclude about corrosion rate, the deterioration degree of equipment and its residual life.

At present time, the collection and analysis of experimental results are carried to determine the “w” parameter ranges and its applicability for typical defects at the tubes.

References
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