UDC 62:658.382.3

ANALYSIS OF EQUIPMENT OPERATION TIME AT THE REFINERY

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The results of the analysis of the service life of equipment operating under excess pressure at the Belarusian oil refineries are presented, directions for improving industrial safety when working with this type of equipment are proposed in this study. The average service life of equipment operating under excessive pressure at the studied enterprise has been identified.

Keywords: oil refinery, industrial safety, accident rate, equipment

Introduction. The enterprises of the oil refining industry are some of the most explosive objects. The high fire and explosive level of these enterprises is explained by the presence of a large amount of hydrocarbons that circulate in the process [1-13]. Emergency depressurisation of the technological equipment at a refinery plant can cause a major accident with concomitant emissions of toxic substances, destruction and damage of expensive equipment, breakdown of the technological processes, fires and explosions [14-16]. Every year approximately 20,000 major accidents occur in the oil and gas industry in the world, and in recent years there has been an increase of the accident rate in the oil refining industry [17-21]. Several examples of such accidents are:

– An accident in March 2005 at the isomerisation unit of one of the largest US refineries owned by British Petroleum in Texas City. There was a powerful explosion, followed by a strong fire. 15 people were killed and over 70 were injured;

– On May 29, in 2008, a hydrogen-containing mixture exploded in a hydrogen compressor unit for the secondary processing of oil at the Kirishi Refinery, and then a fire occurred. One person died on the spot, four died in hospital. The damage from the accident amounted to 107 million Rubles;

– On August 7, 2011 there was a fire at the Khabarovsk refinery. Spilled fuel and pumping station burned on a total area of 50 m^2 3 people were injured and 2 died;

– On June 15, 2014 at the gas fractionation unit of the Achinsk refinery there was a leak of hydrocarbon gas, which led to a major explosion and fire. 8 people died, 7 were hospitalised, the total number of the injured was 24 people. The damage amounted to approximately $ 800 million.

In the CIS countries there is a targeted state policy in the field of industrial safety. However, the state of accidents at work place continues to be a complex socio-economic problem.

Statistics show that the major accidents at oil refineries in most cases are due to leaks of flammable liquids and vapours or hydrocarbon gas. The reasons of their occurrence are as follows:

– violation of the rules of operation, technological regulations (27% of cases);
– defects in construction and installation works, low quality of installation and repairing of equipment (21%);
– defects in the manufacture of equipment and materials (16%);
– deviation from the requirements of the design and technical documentation (12%);
– equipment deterioration, product leaks through gaskets, mechanical seals, oil seals, equipment corrosion, furnace burnout in furnaces (11%);
– constructive imperfection of equipment (5%);
– external natural and man-made impacts (5%);
– imperfection of design solutions, etc. (less than % 3).

Improving the resiliency and trouble-free operation of equipment under excessive pressure at oil refineries, are now particularly relevant directions to improve the level of industrial safety for the industry. This fact has determined the purpose of this study.

Research methods. Equipment operating under excessive pressure at a Belarusian full-cycle oil refinery has been taken as a research object; equipment such as columns, vessels and reactors has been studied; heat exchangers (including crystallisers), separators and filters. The expert-statistical and analytical methods have been applied on the basis of a comprehensive analysis of repairing documentation for the period of 2008-2018 as well as the terms of operation of equipment functioning under excessive pressure at the Belarusian oil refineries.

Results and discussion. With the purpose of determination of the current state of equipment during shutdown repairs, as well as during technical diagnostics, and determination of the suitability for further operation and extension of the life cycle of equipment that has worked out a standard period the following combination of non-destructive testing methods is usually used: visual inspection in accessible places; ultrasonic thickness measurement of housing elements and nozzles; ultrasonic defectoscopy of welds, as well as control of the continuity of the base metal; penetration test; hydrostatic test.

Columns at a research plant accounts for 6% of the total number of equipment. According to GOST 31838-2012, this type includes cylindrical vertical vessels of constant or variable cross-sections, equipped with internal heat and mass transfer devices (plates or packing), as well as assistant units (liquid inlets, devices for set-up packed elements, etc.). providing a process (for example, rectification or direct heat exchange between steam (gas) and liquid, etc.). The analysis of repair documentation for the period of 2008-2018 has shown that the highest frequency of work is achieved by replaced nozzles with conditional passage up to DN100 (37% of the scope of work), replacing internal devices (23%), replacing nozzles with conditional passage DN100 and more (21%), while less frequently repairs take place on the base metal and metal of the body welds (about 19% of the work).

For the columns the replacement of internal devices usually means the replacement of the supporting elements of the plates welded to the vessel body, which have become unusable in the result of corrosive wear under the influence of the working medium. It is controlled visually and with the help of measuring devices. An effective way to increase safety is to widely use the technology of welding support elements through shims welded directly to the body of the vessels. If it is necessary to repair this unit, the support element is cut out and a new one is welded to the shim plate without touching the body of the vessel.

At the same time, there is no possibility of mechanical damage to the body when re-disassembling the support element. It also excludes its local overheating and changes in the metal structure as a result of overheating. It favorably affects to the period of further operation of this equipment. This method can also be applied to elements welded outside vessels, such as service platforms, booms, supporting elements of level gauge columns, etc.

Separators make up 6% of the total number of the examined equipment, belong to the settling items. Separators are similar in design to columns, but have smaller size and are equipped with fewer plates or an overflow plate for separating liquids by density. According to the maximum frequency of the types of repairs carried out by separators the work is performed on replaced nozzles with conditional passage of up to DN 100 (76% of the work); a small percentage falls on other types of repairs (repair of base metal and metal of body welds - 11% conditional passage of DN 100 or more - 9%, replacement of internal devices - 4%).

Filters make up 7% of the total number of the examined equipment, belong to the apparatus for the implementation of the filtering process. The most frequent repairs on filters are made for replacing nozzles with conditional passage of up to DN100 (71% of works), a small percentage are for other types of repairs (repairing base metal and metal of body welds - 19% and replacing fittings with conditional passage DN100 and more - 10%). The reason for this is that this type of equipment has low average life.

Reactors make up 2% of the total number of the examined equipment, belong to vessels in which chemical reactions take place including those with the use of a catalyst. As a rule, the presence of high pressure and temperature is observed. According to the maximum frequency of conducted repairs of reactors, repairs are made on the base metal and metal of the protective casing welds that were repaired (75% of the scope of work), 13% of the repairs mean replacing the internal devices of the reactors.

The small number of repairs of this type of equipment is explained by the large margin of safety used in manufacturing, due to the high operating pressures and temperatures, and the difficulty of carrying out repair on thick buildings. When defects are detected, this type of equipment is changed entirely to ensure trouble-free operation during the overhaul period.

Almost a single type of repair that is applied to the equipment of this type is repairing of the protective case, which is designed to protect the sprayed concrete lining from the corrosive effects of the working medium in the old types of reactors. From the point of view of improving reliability it is advisable to switch to modern bimetallic reactors.

Vessels make up to 41% of the total number of the examined equipment. According to TR CU 032/2013 vessels are hermetically closed containers (divided into fixed and mobile). This type of equipment is designed for conducting chemical, thermal and other technological processes, and also for the storage and transportation of gases, liquids, and other substances. The replacement of nozzles with conditional passage of up to DN100 (70% of the scope of work) has the highest frequency of repairs of vessels, 15% of the amount of work involved replacing nozzles with conditional passage of up to DN100 and more and repair of the base metal and metal of the body welds.

Heat exchangers make up 37% of the total number of examined equipment. According to GOST 31842-2012 heat exchangers are the equipment designed to transfer heat under non-isothermal operating conditions. According to the maximum frequency of the types of heat-exchange equipment repairs carried out, work on repairing the base metal and metal of the welds (31% of the work), work on replacing nozzles with conditional passage up to DN 100 (30% of the work) and replacing and repairing, are allocated partition walls of distribution chambers (24% of the scope of work).

The main defects detected in tube bundles of heat exchangers include:

– corrosive wear-out of pipe bundle pipes. It is controlled by hydraulic tests in the annular space;
– corrosive wear-out and thinning of the metal in the area of rolling tubes in tube plates.
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Reducing the number of operational defects and extending the time for maintenance-free operation of heat exchange equipment can be achieved by introducing strict control over the operation of this equipment. Often, the gaps in the places of rolling of the pipes are caused by the deformation of the pipes by the excessive pressure in the annular space during the filling of the apparatus. The filling of the apparatus must be made starting with the tube bundle for the purpose of balance the pressure and reduce the probability of deformation of the tube.

Similar in construction are rigid tube-shell heat exchangers. Detected defects are the same as in shell-and-tube heat exchangers with removable tubular system. At the same time, there is no possibility of visual control of the inner surface of the case. To increase the level of control and detect defects at earlier stages, maps of wall thickness measurements with an increased number of control points are compiled for heat exchangers of these types compared to heat exchangers with a movable pipe system. In addition, rigid tube heat exchangers are supplied with bellows expansion joints to compensate for temperature expansions. Compensators are made of thin-walled stainless steel. At the same time, based on the practical experience of operating devices with a lens compensator, there was often a situation in which the wall thickness of the case had sufficient margin to the screening thickness and the lens compensator became unusable due to corrosive erosion wear. Repair of heat exchangers of this type is impractical because of a non-dismountable design. So disassembly, replacement of worn-out sections of the shell or tube bundle pipes, replacement of a compensator, and the following assembly, are comparable in cost to new heat exchangers.

A specific type of heat exchange equipment is scraper chillers, that are additionally equipped with a scraper axle inside the internal tubes of heat exchangers. At the enterprise under study such equipment makes only 1% of the total number of equipment items, but the average lifetime of the chillers is significant - 49.2 years. The analysis of the repair documentation for repairs carried out on chillers showed that the only type of repair is the replacement of internal or less often external pipes, as the main wear parts of this type of equipment. In addition to the corrosive effects of the environment, the wear of the inner tubes is influenced by the friction of the scrapers. At axial displacement of the axle during assembly, or uneven wear of the bearings, there is increased wear-out of the composite gaskets of the shaft scrapers, and then friction of the metal scraper on the inner surface of the pipes. At the same time, there is no possibility to control the condition of the scraper gaskets and the internal pipes of the chiller because the pipes are inaccessible for full visual inspection, it is impossible to conduct ultrasonic thickness gauging. Ultrasonic thickness gauging of external pipes, visual inspection of internal pipes in accessible places using a flashlight along the pipe axis, as well as a hydraulic test for tightness and density of internal pipes, are used to assess the state of these technical devices. If a defect is suspected or traces of mechanical wear-out are detected, the inner tube is replaced. At the same time, in such devices it is advisable to use pipes made of solid steel grades to reduce mechanical wear-out of the internal surface of the pipes.

Table 1 shows the average service life of equipment operating under excessive pressure at the Belarusian refineries.

Table 1. – Lifetime of equipment operating under excessive pressure at the refinery.

Type of equipment operating under overpressure	Average life at the refinery, years
Columns	38,6
Vessels	34,8
Reactors	32,8
Heat exchangers	31,2
Separators	28,3
Filters	25,0

The table shows that the columns, vessels, and reactors are operated the longest. At the same time, the service life of the vessels working under excessive pressure declared by the developer is usually 20 years.

The comprehensive analysis of the life cycle of equipment operating under excessive pressure at the Belarusian oil refineries showed that nozzles with conditional passage of up to DN100, base metal and metal of the body welds of various equipment are subject to a high risk of increased wear-out during operation.

The reason for the frequent replacement of nozzles with a small conditional passage is associated with a small margin between the executive and rejecting thicknesses of nozzles.

For example, a pipe with a nominal thickness of 4 mm is most often used for the nozzle of DN50 by strength calculation. In accordance with the instructions for revision, repair and rejection which are applied at the enterprise under study, the rejection thickness for the DN50 connection pipe is 2.0 mm, unless otherwise greater value is indicated in the strength calculation. The executive wall thickness as a result of an error in the manufacture is often about 3.8-3.9 mm. At the same time, in practice such nozzles are rejected with a thickness of 2.5-2.7 mm, as an approaching rejection to improve the reliability and infallibility of work during the overhaul period and to prevent the process installation from stopping due to the omission of the product. In this case, even with a corrosion rate of up to 0.1 mm / year the thickness of the nozzle is not enough even for the declared service life of the vessel (usually 20 years). From practical experience, the replacement of such nozzles during the repair with heavy walled ones of about 6-8 mm leads to trouble-free operation of these units throughout the life cycle of the equipment until they are replaced.

Thus, as a way to increase the industrial safety of the equipment operating under excessive pressure, it is proposed that the new equipment is coordinated with the developers to reach an increase in the thickness of the fittings with conditional passage of up to DN100. At the same time, despite the slight increase in the cost of such equipment, it is possible to achieve maintenance-free operation of the equipment even after the end of the designated service life. The reasons for repairing the base metal and weld metal are hidden metallurgical defects and weld defects that were not detected during the manufacture of the vessel (apparatus), as well as the aggressive influence of the working medium of the vessel (apparatus), the formation of stagnant zones, the accumulation of solid particles from the working medium (scale, contamination, etc.), which are monitored visually and using ultrasonic thickness gauging. Ultrasonic and penetrant tests can be additionally performed in places suspicious of defects. In our opinion, in order to minimise the number of repairs of this type, it is necessary to strengthen the incoming control for the newly installed equipment. Also it is necessary to strengthen control over the selection of material for a specific working medium and operating parameters such as temperature and pressure and to ensure strict adherence to operation regulations. In the newly designed equipment modern technical solutions are applied to minimise the number of stagnant zones.

Conclusion. The results of the research on the comprehensive life cycle analysis of equipment operating under excessive pressure can be effectively used to increase the level of industrial safety, reduce the risk of accidents at oil refineries and petrochemical plants.

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