Analysis of causes of failures of process equipment of oil refining and petrochemistry

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Abstract. The development of modern industry is associated with an increase in the total scale of production and processing of fire and explosion hazardous and toxic materials, a significant increase in the single capacity of plants and apparatus, and a complication of technologies and regimes for managing the production process. As a result, there is a steady trend in industry to increase the number of accidents with increasingly severe social, environmental and economic consequences. Despite significant efforts in the development of technical safety systems, accident rates (number of accidents or injuries per unit of production) in our country have increased significantly in recent years. The most dangerous situation has developed in the oil refineries of Bashkiria, Samara, Irkutsk and Perm regions where the depreciation depreciation of some technological equipment is 70%. Thus, safety is one of the main characteristics of industrial facilities.

1. Introduction
The following factors explain the relevance of improving fire and explosion safety of hydrocarbon processing plants:

- concentration of hydrocarbon systems with higher combustion heat. High pressure of saturated vapors and, as a result, explosion hazard of hydrocarbon systems and increased ability to contaminate the atmosphere with hazardous emissions;
- the presence of potential hazards (volumetric fires and explosions) causing material and human losses, which follows from the properties listed above;
- faster development of production volumes and lagging pace of development of environmental events, which is typical for modern production;
- the emergence of hard-to-dispose production wastes and new types of wastes, the application and processing of which has not yet been found;
- extremely high energy saturation of oil refining facilities. Thus, a typical oil refinery (refinery) with a capacity of 10-15 million tons/year focuses on territory from 200 to 500 thousand tons of hydrocarbon fuel, the energy content of which is equivalent to 2-5 megatons of TNT;
- intensification of technology, increase of unit capacity of devices, as a result of which parameters such as temperature, pressure, content of fire and explosion hazardous substances rise and approach critical ones;
- imperfect technology for collection and disposal of fire and explosion hazardous components of petroleum products caught in the environment;
2. Experimental procedures

A systematic analysis of the main causes of emergency situations occurring at refining and petrochemistry plants makes it possible to distinguish the following:

- organizational and technical (lack of raw materials and auxiliary materials, lack of energy resources, late shipment of finished products, error or inadequate competence of decision-making persons);
- technological (change of temperature, pressure and flow from regulated values, frequent change of quality of raw materials supplied for processing, sometimes of very low quality);
- mechanical (failure of process equipment, equipment of pipeline systems).

The structure of the causes of equipment failures in percent is shown in Figure 1. Any of these causes or their totality determines the degree of risk, danger of emergency situations and their consequences, as well as the influence on the associated process units or production as a whole. On the other hand, accidents caused by one of the reasons may cause failures for other reasons or other reasons.

From the above data it can be seen that 67.5% of failures occur due to organizational and technical reasons. The shortage of own working capital, which outpaces the growth rate of prices for machine-building products of basic petrochemical equipment (column vessels, reactors, heating furnaces, compressor equipment, automation and parameter control equipment) in comparison with the growth rate of prices for products of the energy complex does not allow technically re-equipping or updating existing obsolete fixed assets. The physical and moral wear and tear of most production equipment and in general process units that have been in operation for more than 35 years (depreciation is 70%) requires radical reconstruction and technical re-equipment. Mainly due to the lack of progressive equipment and poor equipment with automation and microprocessor equipment, many oil refining and petrochemical synthesis enterprises are forced to extensively expand most of the production on an old basis.

The most dangerous plants are: rectification units, catalytic cracking, raw material treatment.

Table 1 shows the power potential of the plants reduced to the TNT equivalent of a modern refinery.

Complex situations arise during the operation of the main equipment of process plants and industries - heating furnaces, reactors, separation (rectification) columns, settling tanks, tank farm.
The distribution of the number of accidents by types of process equipment, % at the plant EDP-AVT6 is given in table 2.

**Table 1.** Power potential of plants reduced to TNT equivalent of modern refineries.

| Process Unit Name                              | TNT equivalent $W_t$, t |
|------------------------------------------------|-------------------------|
| EDPAVT 6 (column K-2)                          | 95.6                    |
| AVT-3 (column K-2)                             | 55.9                    |
| Absorption cleaning (capacity E-3)             | 14.8                    |
| Reflux Cleaning (Column K-3)                   | 3.9                     |
| Catalytic cracking (reactor R-1)               | 120.2                   |
| EDP 1.2 (electric dehydrator E-3)              | 6                       |
| Hydrotreating LCh-24-2000 (absorber K-202)     | 1.1                     |
| Reforming L-35-11/300 (column K-1)             | 21.1                    |
| Stabilization 22-4 (ColumnK-1)                 | 8.5                     |
| Feedstock Treatment (Column)                   | 107.7                   |

Pumping equipment contains only about 0.6% of the total amounts. This type of equipment is "dangerous" in terms of the frequency of malfunctions and failures associated with the release of explosive substances into the environment.

Possible scenarios for the accident of electric dehydrators, heat exchangers may be: depressurization due to corrosion or personnel error with oil spill; mechanical destruction.

The main reasons for exit of the furnaces are the possibility of oil ignition in small leaks in the heat exchange surfaces due to close fire.

The characteristic "hazards" of the columns may be corrosion damage, mechanical destruction, depressurization of the flange joints. The risk is due to the concentration of a large number of explosive and fire hazardous substances in high temperatures and pressures, any malfunction or defect associated with the depressurization of column vessels can lead to catastrophic consequences [14-16].

**Table 2.** Distribution of the number of accidents by types of process equipment, % at the unit EDP-AVT6.

| Equipment                                        | Number of accidents, % |
|--------------------------------------------------|-------------------------|
| Process piping                                   | 31.5                    |
| Pump stations                                    | 18.9                    |
| Capacitive devices (heat exchangers, dehydrators)| 15.0                    |
| Furnaces                                         | 11.4                    |
| Fractionation, vacuum and other columns          | 11.2                    |
| Promkanalization                                 | 8.5                     |
| Tankfarms                                        | 3.8                     |
Fires and explosions at open process oil refineries are usually the result of emergency situations, developing according to approximately the following scheme:

- flammable superheated liquids and gasoline vapors are leaked as a result of tightness violation or destruction of pipelines, valves and process devices;
- spill products are either ignited or create a vast zone of gas-gas-air mixture of explosive concentration;
- the factors of the resulting fire strongly affect the device or pipeline from which the leakage occurs, as well as neighboring equipment, as a result of which the pressure in it increases above the design one, it loses strength and breaks down or its depressurization occurs due to destruction from the fire of sealing devices.

3. The results of studies and their discussion
Various methods can be used for hazard assessment, such as preliminary hazard analysis, error tree analysis, accident impact analysis, and risk assessment. The purpose of the hazard assessment, regardless of the method chosen, is to determine potential causes of failure or accidents at an industrial facility.

The risk analysis methodology includes the calculation of the probability of an accident and the assessment of its consequences (economic, environmental and social). When assessing the risk of product outflows from the plant, it is important to keep in mind the ambiguity and inconsistency of the initial information on the repeatability of the initial events. This is reflected primarily in the fact that from all available risk assessments, its upper limit is chosen - integrated risk - a complex safety indicator expressed in a single value equivalent.

To calculate the integrated risk, a possible accident scenario is drawn up, which is a sequence of physical phenomena occurring one after another as a result of an emergency.

The scenario should be divided into structural elements based on the following principles:

1) each element should contain a specific physical phenomenon, which can be represented in the form of a mathematical or empirical model;
2) the element should be isolated, ready for use in other scenarios of accident development. For example, an element (thermal damage) is a consequence of both a gas explosion and the combustion of the basin. Therefore, it does not make sense to include estimates of thermal damage in the elements for each of these phenomena, but to separate it into a separate element. The same requirement ensures interchangeability of elements. For example, depending on the type of liquid, both a neutral buoyancy gas cloud and a heavy gas cloud may be formed. In both cases, different physical and mathematical models are used to estimate cloud scattering. At the same time, the main input and output parameters of these models are the same. Therefore, the consequences can be estimated according to the same scenario, using the same elements (techniques), with the exception of methods describing scattering, which for each case will be their own;
3) the possibility of having several techniques describing the same process. For example, the process of scattering heavy gases can be calculated both from complex three-dimensional codes requiring several hours of work, and from simplified empirical models. At the same time, the input parameters for these models are the same. Depending on the evaluation objectives, timeliness and accuracy in the system, you can use a particular type of element. Here, there is also the possibility of replacing the outdated method with a new one, which does not require the processing of the entire system of methods.

In case of emergency depressurization of any of the units of EDP-AVT unit (EDP (electric desalination and electrical dehydration), AD (atmospheric distillation of oil to fuel oil), VD (vacuum distillation of fuel oil to tar with production of oil distillates), gasoline stabilization and secondary distillation unit, flue gas heat recovery unit) and emission to adjacent surface. In case of ignition source - spill fire or explosion of fuel-air mixture followed by fire on spill mirror.
4. Conclusions
As a result of the work done, it is shown that fires and explosions at the EDP-AVT plant occur only in a situation that is characterized by three factors at the same time: leakage (spilling) of combustible liquids; evaporation and formation of fire-and-explosion mixtures of hydrocarbon vapors with air; presence of ignition source.
It should be noted that in order to develop any accident scenario, it is necessary to know how the hazardous substance is distributed to the equipment, the amount of equipment in the units, the number of unit units. Further, fire or explosion frequency tables are compiled. After that, an assessment of the integrated risk of causing social, material and environmental damage to the accident at the plant is carried out.

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