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Application of emergency process development modeling and risk assessment to ensure safe operation of oil and gas industrial facilities

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Introduction. One of the main tasks of the production organization is to prevent accidents. In the oil and gas industry, a significant part of accidents occur on process pipelines. Depressurization of the process pipeline leads to negative consequences up to a complete shutdown of production and can cause human casualties. Modeling the pipeline depressurization process in accordance with accident scenarios is one of the approaches to ensuring the safety of technological pipelines.

Problem Statement. The purpose of this study is to model the process of pipeline depressurization in accordance with scenarios of industrial accidents under certain environmental conditions.

Theoretical Part. In most cases, the main causes of accidents are internal hazards associated with depressurization and destruction of technical devices, as well as personnel errors due to violation of the requirements of the organization and production of hazardous work. There is no unified methodology for drawing up a scenario for the development of accidents at hazardous production facilities, and the existing guidelines for determining possible scenarios are of a recommendatory nature. Various types of fire and explosive process media located inside the pipeline are considered in the preparation of scenarios. The object of experiments was a 3D model of an industrial site with a hypothetical process pipeline under such variables as building density, meteorological conditions, and air mass stagnation zones. The latter were modeled in the FlowVision software package, which visualizes three-dimensional liquid and gas flows.

Conclusion. The developed universal algorithm made it possible to create scenarios for the development of an emergency situation on a hypothetical process pipeline. The results are applicable for further modeling of emergency situations.

Keywords: accident, modeling, risk, process pipeline, depressurization, oil and gas industry, production, safe operation.

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Introduction. Accidents in oil and gas industry are usually characterized by significant emissions of dangerous substances that negatively affect natural and social environment, cause serious economic damage, and are dangerous to human health and life.

In most cases, such incidents provoke internal hazards. The main ones are listed below:

— depressurization and destruction of technical devices,

— staff errors,

— violation of the requirements for organizing and performing dangerous types of work [1-3].

It is impossible to completely exclude accidents at hazardous production facilities. That is why the problems of preventing accidents in oil and gas industry, as well as eliminating the severe consequences of such events, remain relevant [4]. In addition, it is of interest to prevent accidents at the stage of defect formation.

Accidents on process pipelines. In oil and gas industry, most accidents occur on process pipelines. The analysis of causes and consequences of accidents on domestic technological pipelines revealed main sources of risks: unsatisfactory condition of the equipment, corrosion, thinning of the wall thickness, violation of industrial safety requirements and the human factor. Some enterprises have been operating for many decades and are equipped with outdated equipment with serious defects.

Depressurization of process pipelines leads to negative consequences up to a complete shutdown of production and can cause human casualties.

Problem Statement. One of the ways to ensure safety of technological pipelines is to model the depressurization process in accordance with accident scenarios. This approach allows us to determine the most vulnerable, critical from the point of view of safety pipeline parts [3, 5]. The purpose of this study is to model the process of pipeline depressurization in accordance with scenarios of industrial accidents under certain environmental conditions.

Theoretical Part

Emergency situations modeling. As part of risk analysis at a hazardous production facility (HPF), the scenarios for the development of an emergency situation can be determined (Fig. 1).

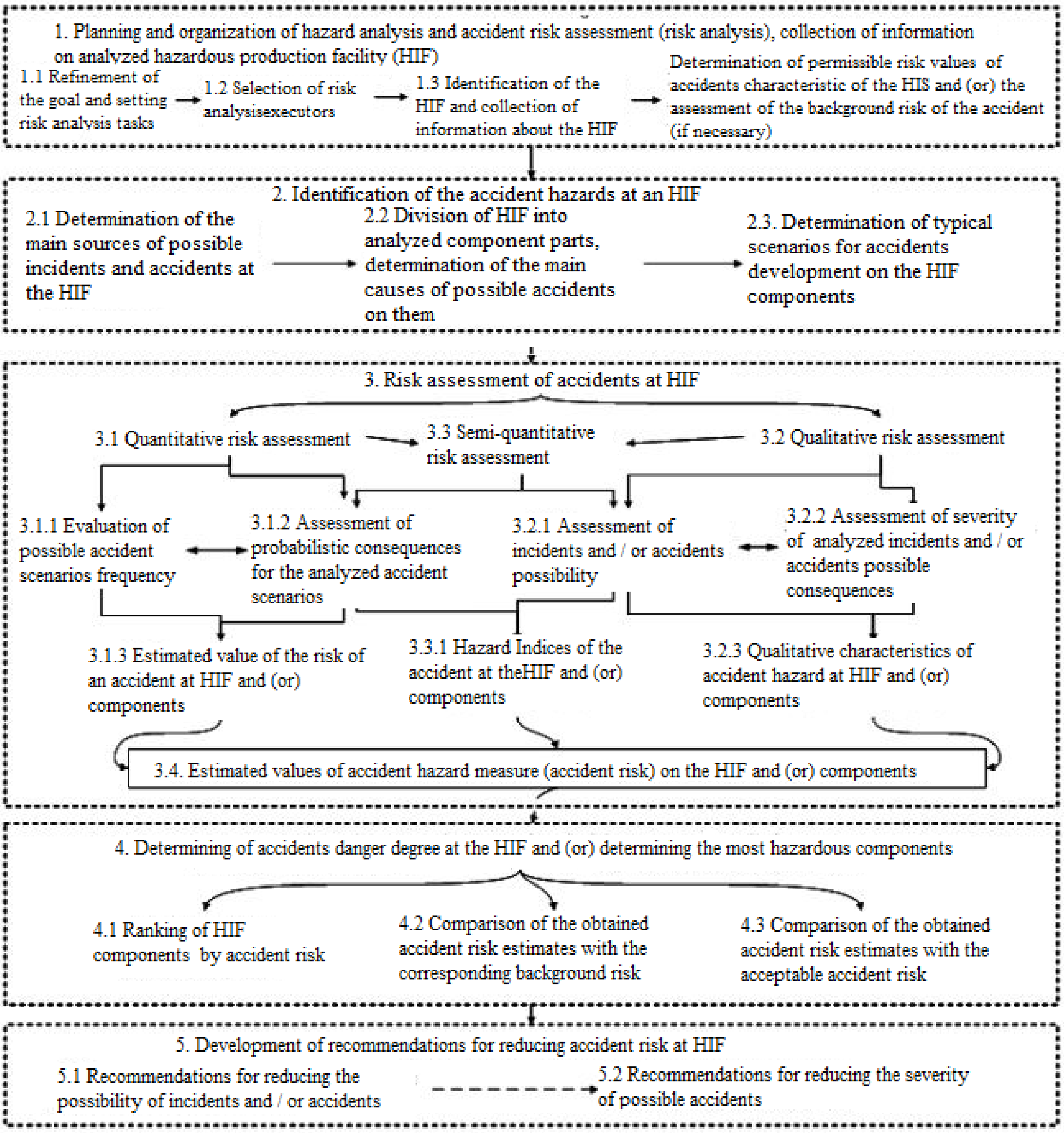


Fig. 1. General scheme of hazard analysis and risk assessment of accidents at HPF

There is no unified methodology for creating a scenario for the development of accidents at hazardous production facilities, and the existing guidelines are of a recommendatory nature. The developed algorithm for creating scenarios for the development of an emergency situation, shown in Fig. 2, can be used for risk assessment at the HPF [6, 7].

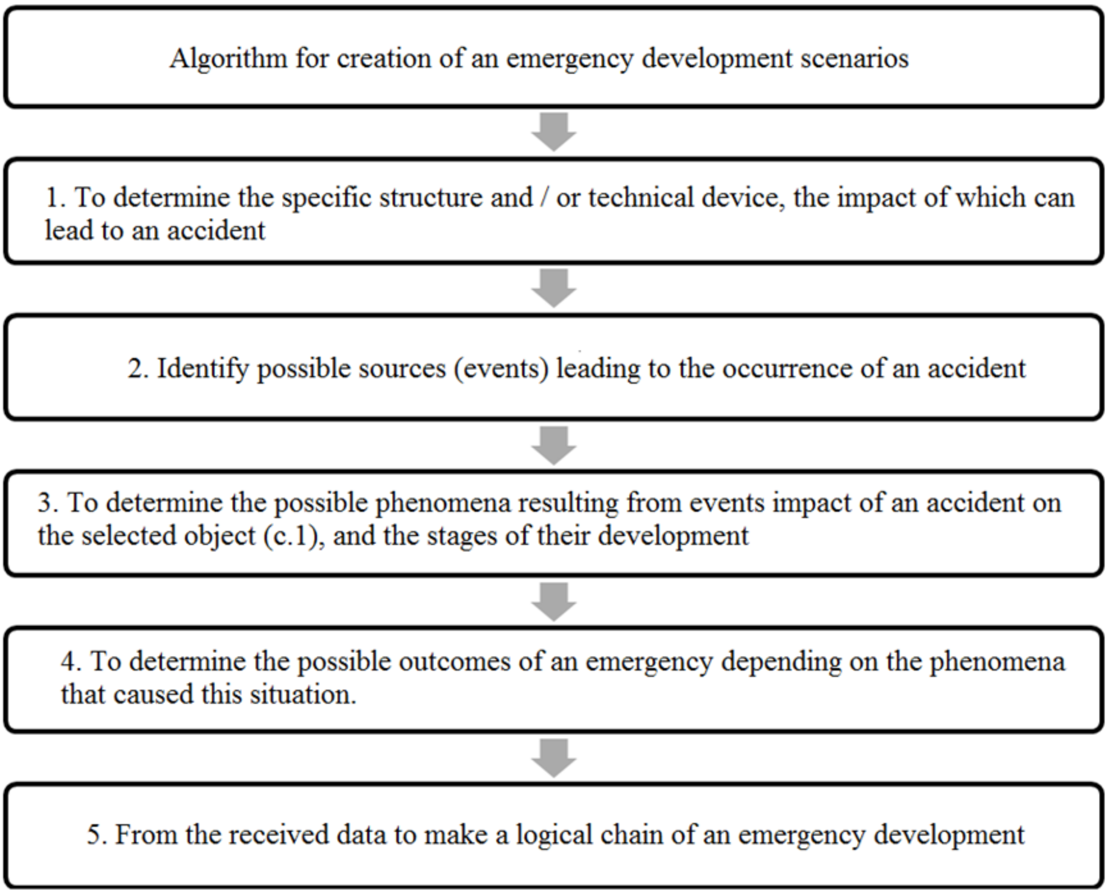


Fig. 2. Algorithm for creating emergency scenarios

The developed algorithm was used in the preparation of scenarios for the development of an emergency situation on a hypothetical process pipeline (it is considered as an object, the impact on which can lead to an accident). When preparing scenarios (Fig. 3, 4), various types of technological fire and explosive environments located inside the pipeline are considered. It was determined that the presence of any group of technological environment in the pipeline generally does not affect the change in the chain of events occurring during an accident [8, 9].

Fig. 3. Scenarios for the development of an emergency situation with the complete destruction of the process pipeline

Fig. 4. Scenarios for the development of an emergency situation in case of partial destruction of the process pipeline

According to Fig. 3-4, depressurization of the process pipeline is the cause of product spillage. Vapor-gas-air mixture, in turn, is formed because of the spillage. Modeling the stress state based on the actual state of the pipeline can provide more detailed information about a possible spill.

The resulting cloud will drift along the earth surface until the source of ignition is found. This will create areas of gas accumulation and stagnation zones, the size of which mainly depends on the environmental conditions, terrain and building density. In order to prevent accidents, it is necessary to develop and implement emergency situations development models in production practice, taking into account building density and meteorological conditions at a particular object [10, 11].

Meteorological characteristics as one of the main factors of hydrocarbons combustion determine the extent of the damage. The number of options for spreading explosive substances in the atmosphere significantly increases if we take into account meteorological conditions, possible wind directions and speeds.

The World Meteorological Organization has adopted the Beaufort scale (Fig. 5) to approximate wind speed based on its impact on ground objects.

Beaufort number	Wind speed kt	Wind speed km/h	Wind speed mph	m/s	Mean wind speed (kt / km/h / mph)	Description	Land conditions
0	0	0	0	0-0.2	0 / 0 / 0	Calm	Calm. Smoke rises vertically.
1	1-3	1-6	1-3	0.3-1.5	02 / 04 / 2	Light air	Wind motion visible in smoke.
2	4-6	7-11	4-7	1.6-3.3	05 / 09 / 6	Light breeze	Wind felt on exposed skin. Leaves rustle.
3	7-10	12-19	8-12	3.4-5.4	9 / 17 / 11	Gentle breeze	Leaves and smaller twigs in constant motion.
4	11-16	20-29	13-18	5.5-7.9	13 / 24 / 15	Moderate breeze	Dust and loose paper raised. Small branches begin to move.
5	17-21	30-39	19-24	8.0-10.7	19 / 35 / 22	Fresh breeze	Smaller trees sway.
6	22-27	40-50	25-31	10.8-13.8	24 / 44 / 27	Strong breeze	Large branches in motion. Whistling heard in overhead wires. Umbrella use becomes difficult.
7	28-33	51-62	32-38	13.9-17.1	30 / 56 / 35	Near gale	Whole trees in motion. Effort to walk against the wind.
8	34-40	63-75	39-46	17.2-20.7	37 / 68 / 42	Gale	Twigs broken from trees. Cars veer on road.
9	41-47	76-87	47-54	20.8-24.4	44 / 81 / 50	Strong gale	Light structure damage.
10	48-55	88-102	55-63	24.5-28.4	52 / 96 / 60	Storm	Trees uprooted. Considerable structural damage.
11	56-63	103-117	64-72	28.5-32.6	60 / 111 / 69	Violent storm	Widespread structural damage.
12	>63	>117	>72	>32.7	N/A	Hurricane	Massive and widespread damage to structures.

Fig. 5. Beaufort Scale

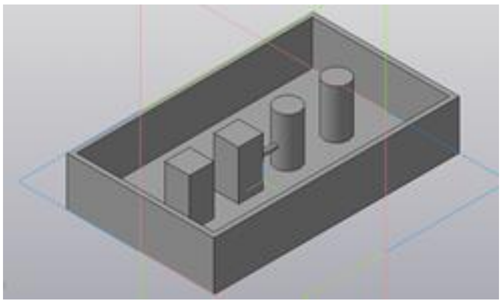
Building density is one of the most important factors for assessing risk and predicting emergencies at hazardous production facilities.

Building density is the ratio of the building area to the area of the enterprise within the fence. In other words, building density refers to the intensity of use of the territory. As a rule, the minimum building density for oil and gas facilities is about 45 %.

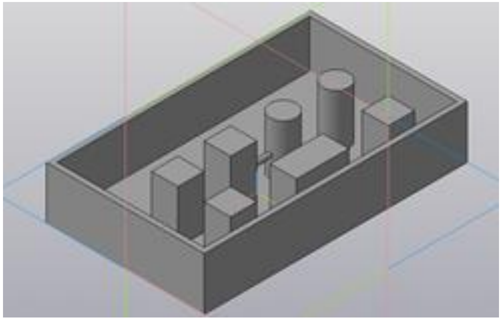
It is obvious that building density significantly affects the development of an emergency. That is why it is recommended to take into account both meteorological conditions and building density when forecasting and assessing risks. This work also identifies the worst-case wind direction. A 3D model of an industrial site was created, and then the air flow directions were modeled on it [12, 13].

The model of the site of the industrial facility was built in the three-dimensional design system "Compass-3D". To do this, the following items are created sequentially: a detail; a parallelepiped; sketches of buildings, structures, and equipment.

Within the framework of the study, three conditional models of a section with a hypothetical process pipeline that connects two objects were created (Fig. 6).



a)



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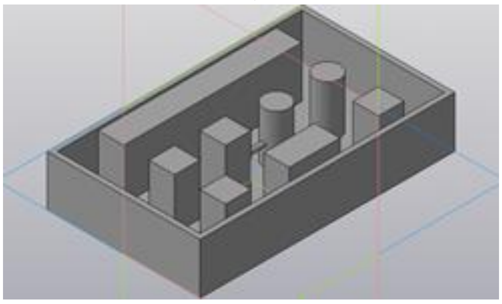


c)

Fig. 6. Models of an industrial site with a hypothetical process pipeline: minimum building density (a), medium building density (b), high building density (c)

On a site with a minimum building density, the external environment has the maximum impact on the pipeline in adverse weather conditions. Under the same conditions and medium building density, the pipeline is partially exposed to the external environment. Accordingly, high building density provides minimal impact on the object.

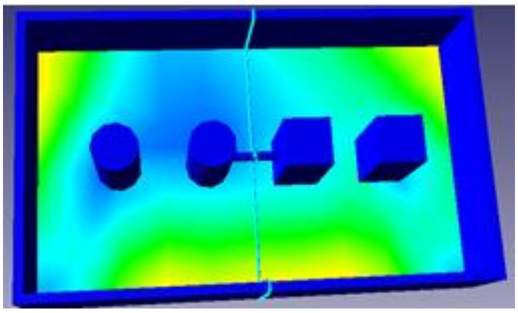
At the final stage of the simulation, we work on the zones of air mass stagnation. For this purpose, the FlowVision software package is used, which visualizes three-dimensional flows of liquid and gas in technical and natural objects [14].

An incompressible liquid is set as a mathematical model. The selected substance is air.

To create air flow models, we used 3D models of industrial sites with different building densities — minimum, medium and high.

The specified wind speed corresponds to 3 points on the Beaufort scale (5 m/s). According to the set parameters "input", "output" and "wall", air masses will enter and exit the model with a certain building density. The paper considers models of the direction of air flows from all directions of the world, so the boundary conditions change depending on the wind direction.

In all FlowVision models, air stagnation zones differ in a spectrum of cold colors: from dark blue to light blue (Fig. 7-9) [15].



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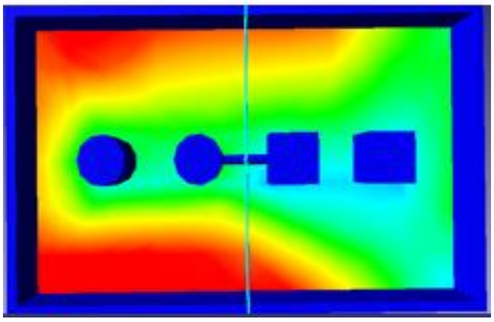
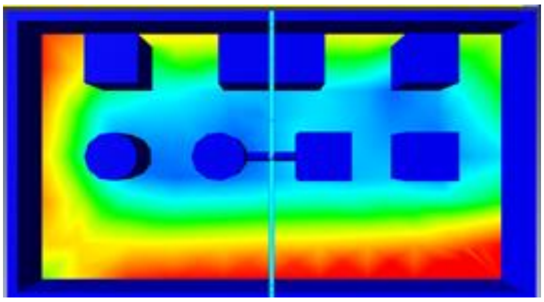
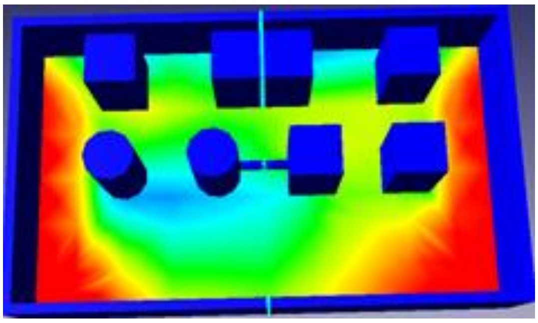


b)

Fig. 7. Model of air flow direction at the site of the industrial facility with the minimum building density with the largest (a) and smallest (b) number of air masses stagnation zones

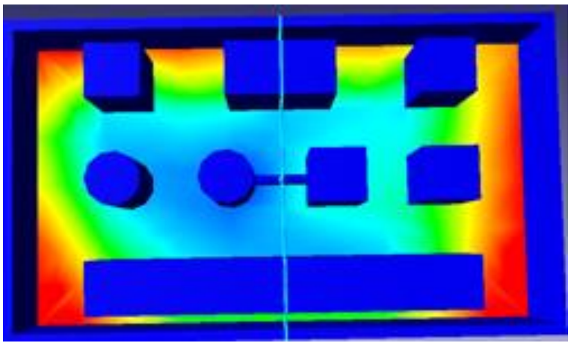


a)

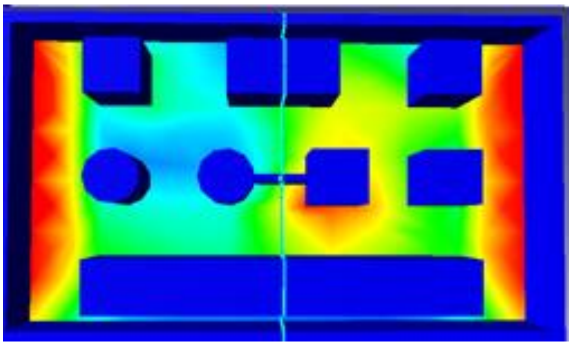


b)

Fig. 8. Model of air flow direction at the site of the industrial facility with the medium building density with the largest (a) and smallest (b) number of air masses stagnation zones



a)



b)

Fig. 9. Model of air flow direction at the site of the industrial facility with the maximum building density with the largest (a) and smallest (b) number of air masses stagnation zones

In this paper, 24 models of the industrial site with different wind directions depending on the cardinal directions are obtained. From them:

— 8 with a minimum building density,

— 8 with a medium building density,

— 8 with the maximum building density.

There were more than 50 experiments.

When evaluating the results, it was assumed that the object was exposed to the greatest damage with the maximum number of air masses stagnation zones (models with the same building density are compared). With a minimum number of stagnation zones the scale of an accident will increase, affecting a large territory.

Comparing the models designed in FlowVision, you can make the following statements.

The process pipeline and its surrounding area are least affected if the spill fire occurred on a site with minimal building density with air flows from South to North. If the air flows from North to West, the scale of the accident will increase, affecting a large area.

If the average building density is considered, then the largest number of air mass stagnation zones will be in the model with the wind direction from West to East. The model with the North-South direction of air flows has the smallest number of stagnation zones, which corresponds to a larger area of destruction as a result of the spill fire.

At the maximum building density, the model with the wind direction from East to West has the largest number of air mass stagnation zones, and the model with the wind direction from South to North has the smallest number.

Conclusion. The results of the experiments allow us to draw the following conclusions. The number of air mass stagnation zones in all models depends primarily on the wind direction. At the same time, the existence of a clear dependence of the number of air masses stagnation zones on a specific wind direction is not established. This means that when placing equipment, including process pipelines, buildings, etc. at industrial enterprises, you should take into account the most likely wind directions during certain periods of the year (summer, winter). In addition, it confirms the need to draw up a wind diagram for a specific region, the area where the industrial facility will be located.

When modeling the development of an accident during the depressurization of a process pipeline, it is important to take into account not only the meteorological conditions that correspond to this region, but also the building density of the enterprise.

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Contribution of the authors:

K. N. Abdrakhmanova and V. V. Shabanova — experimental research and patent analysis. A. V. Fedosov — literary, patent analysis and participation in theoretical research. N. Kh. Abdrakhmanov — formulation of the main idea of research and article structure, editing.