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Original Research

Analysis of Forecast Scenarios of Hazardous Factors Affecting the Shift Settlement of an Oil Field Indicators

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Abstract

This article analyzes and models the impact of hazardous substances on the shift settlement of the Kumkol field. The main important items involved in the technological process at the location of these oil products are plastic oil, oil gas, distributed oil, and demulsifiers, which are used for the development of oil emulsion and removal of water from oil in the process of separation of oil, and inhibitors that are intended for the prevention of corrosion and corrosion, as well as other chemical reagents and substances. The probability of accumulating the main explosive gasses and vapors at the field arises in pipelines with oil and gas wells, in a complex oil preparation and injection plant, and in oil and gas separators. The most dangerous objects include work in wells and oil pumping tanks. The main simulated damaging factors in an oil field accident include thermal radiation from fire, explosion overpressure, and toxic effects of hydrogen sulfide (H_2S). According to the main scenarios, the initial data depends on weather conditions, including wind speed. Probability of exposure to damaging factors in the area of damage: Wind speed and direction greatly influence the level of damage to people in the event of poisoning with toxic gasses or fire. The probability of an explosion of large

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volumes of gaseous masses can only occur in windless weather conditions. The explosion will not affect the residential population as it is on the territory.

Keywords: thermal radiation, overpressure, fire, toxic effects of H_2S, environmental

Introduction

Nowadays, the oil and gas industry is one of the key sectors of the economy, providing many countries with resources for development and growth. However, oil and gas enterprises refer to hazardous productions with working conditions where employees are at significantly greater risk than workers in other industries.

One of the key problems facing the oil and gas industry in the 21st century is the increase in labor productivity. This stimulates the active search for new methods of field development [1-14].

Today, oil and gas companies are aware of their employees' importance in producing high-quality goods. Therefore, they pay special attention to ensuring occupational safety and health. Work at oil and gas facilities is associated with high injury risks; therefore, it requires increased attention from management. Safe working conditions are a key aspect of the oil and gas sector's social responsibility. Technogenic disasters and accidents can harm not only employees but also the environment [1-14].

Oil and gas companies' industrial safety consists of protecting their main assets, personnel, third parties, and the environment from the effects of harmful factors, non-standard and emergency situations, and other potential threats in production. The main components of industrial safety include occupational safety and industrial and fire safety.

One of the main aspects of occupational safety at oil and gas enterprises is ensuring employee safety and preventing accidents at production. To do this, regular inspections and audits are necessary, as well as training employees on safety rules. Any violation of safety regulations or negligence can lead to countless accidents at work.

In addition, oil and gas enterprises should have special risk control and management systems that allow timely identification and elimination of the slightest inconsistencies in their work. It is also important to take into account the specifics of the industry and develop special training and professional development programs for employees. Employees should not be allowed to perform their duties without a labor protection certificate. Another feature of occupational safety at oil and gas enterprises is the need to take environmental aspects into account. In developing and operating the deposits, it is necessary to take into account the impact of activities on the environment and take measures to minimize the negative impact on nature.

It should also be noted that oil and gas companies often operate in hard-to-reach areas where working conditions can be particularly difficult. Therefore, it is necessary to create special conditions for working in such a production environment, including qualified medical care directly at oil and gas production facilities.

Due to the shortcomings of modern technologies, working conditions in Kazakhstan's oil and gas fields are characterized by high dust, gas pollution, and increased noise levels that exceed established standards.

There are 6 shift settlements operating at the Kumkol field, working on a rotating scheme in 2 shifts. The number of workers per shift: in Kumkol - 350 people, Aryskum - 120 people, Kyzylkiya - 70 people, Southwestern Kyzylkiya - 12 people, Maibulak - 8 people, Karabulak - 32 people. They are provided with 4 warm meals: breakfast, lunch, dinner, and a night meal (at night shift), with a dry night menu. The distance of the shift settlement from the mines and from the place of work is different, from 3 km to 15 km.

To control and manage the technological processes of oil production and refining at the Kumkol field, control points (operator rooms) were organized: a central operator (dispatching) in the shift settlement and a plant operator (dispatching) in each workshop.

The distance from the central control point of the shift settlement to the hazardous object is from 1 to 10 km, and the distance from the control points of the Kumkol field factories to the complex oil preparation and injection factory and the gas utilization factory is 50 m to 600 m; the distance from the oil production factory is up to 10 km. Operators are equipped with a technological process control system at each stage of oil and gas movement, an emergency disconnection system in case of exceeding the process parameters, a fire detection system, turning on automatic fire extinguishing, and an emergency alarm system. The operator's premises are built from fire-resistant materials and equipped with heating, ventilation systems, fluorescent lighting, and personal protective equipment.

The magnitude of the risk to which employees are exposed at field facilities is determined by a quantitative risk assessment. The resulting level of risk is assessed according to eligibility criteria, after which the necessary measures to reduce it are developed [1,14].

Materials and Methods

The production, transportation, processing, and storage of oil and gas products at the Kumkol field are characterized as extremely hazardous.

First, there are the radiation hazards from natural radionuclides during the production of petroleum products; second, from waste released into the environment during the processing of products if there are harmful effects; and third, the production danger associated with the release of fire-hazardous and explosion-hazardous products, with the risk of technological processes occurring under high pressure [15, 16].

Potential damaging factors in the oil and gas industry (Fig. 1), appearing as a result of non-compliance with safety measures, injury to personnel in this industry, and even death:

– thermal radiation from a combustible oil and gas mixture of gas or oil;
– poisoning with toxic hydrocarbon combustion products;
– exposure to excess pressure from the explosion of vapors of petroleum products;
– poisoning with gas vapors containing hydrogen sulfide.

The main hazardous substances involved in the technological process in the field are oil production products: reservoir oil, oil gas, degassed oil, demulsifiers used to separate water from oil in the process of oil emulsion decomposition and oil separation, inhibitors used to prevent corrosion and salt scale, and other chemical reagents and substances [17].

Hazardous and harmful factors in the field include waste with flammable toxic substances, asphyxiating (causing fainting) substances, and anesthetics.

Waste (drilling solution with water), toxic fumes in a concentration hazardous to health, which can occur as a result of the release of salts from the soot that is a consequence of the seal failure of the compound systems or the use of cleaning solvents, or welding and grinding [18].

Hydrogen sulfide is present in many operations related to oil and gas. If safety measures are constantly observed, work with it can be safely carried out. Many fatal cases are caused by poisoning from it.

The following parameters determine the influence of spilled hydrogen sulfide:

– the content of hydrogen sulfide in the air (MES) in the working zone of oil, which belongs to hazardous substances, mg/m^3 – H_2S – 3,0, R-SH – 0,8 (GOST 12.1.011);
– maximum allowable concentration in the air, mg/m^3 – H_2S – 0,008, R-SH – 9x10^{-6} (RK SanNαR.3.02.036.99);

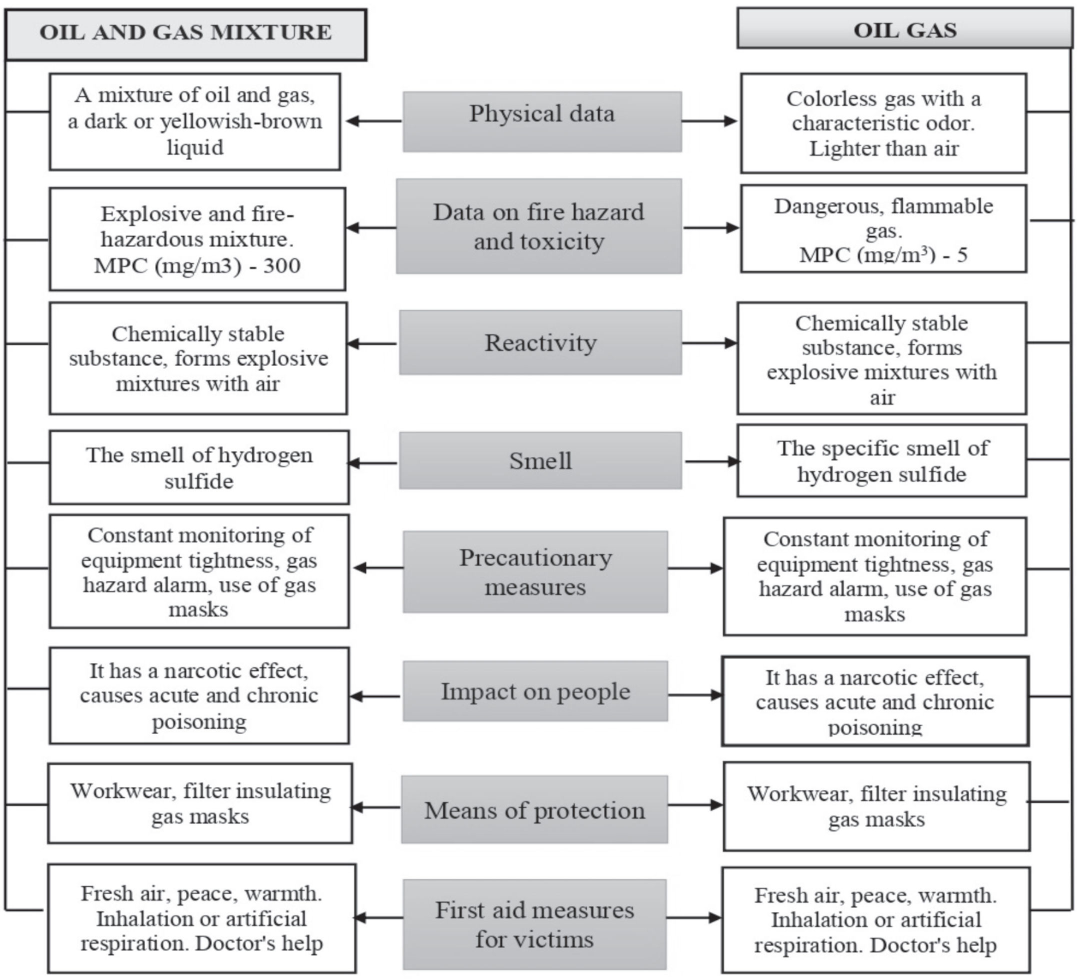

Fig. 1. Characteristics of hazardous substances in the production, preparation, and transportation of oil at the field of JSC “PKKR”.

- lethal dose LCt_{50}, dose H_2S – 750 – 100 mg/m^3;
- threshold sensing toxic dose PCt_{50}, H_2S – 200-280 mg/m^3;
- lethal concentration LC_{50}, H_2S – 227mg/l, R-SH – 20 mg/l.

Poisoning, burns, wounds, and skin charring can occur in wells, compressor stations, or oil refining plants due to improper handling of alkalis, acids, polymers, and surfactants during well processing and improper handling of containers for storing toxic substances.

In order to prevent the release of hazardous substances into the environment, liquid substances are stored in containers, solid chemicals are stored in storage pockets, and strong chemicals are stored in steel containers. When transporting and storing resources and materials, they should not interact with each other. This is because the effects, such as combustion, eruption, and explosion, occur. Hazardous waste is stored in containers and barrels of special brands that meet exceptional standards of the Republic of Kazakhstan and international standards. Measures to reduce losses in the event of a spill of chemicals and hazardous substances are carried out by using equipment and reagents in accordance with the methods of stopping with a specially developed plan.

Toxic substances enter the human body at inhalation and penetrate the skin or eyes together with dust steam, and the toxicity can lead to serious injuries, burns, or death [19].

Potentially explosive gasses and dust are the basis of our existence; they are the source of energy. There are 8 different types of potentially explosive gasses: methane, propane, pentane, heptane, ethane, butane, hexane, and octane.

A non-flammable substance does not ignite on its own but can emit toxic fumes when heated.

- vapors can accumulate in narrow spaces (basements, cisterns, bunkers/wagons, etc.);
- toxic substances release very toxic substances or toxic gasses when they react strongly with water;
- reactions to water can generate a lot of heat, increasing the concentration of solids in the air;
- contact with hot metal can release hot hydrogen;
- Heating or mixing with hot water can cause explosions;

In the field, there is a possibility of accumulation of explosive gasses and vapors:

- in the adjacent area of oil and gas wells;
- in the group facilities area;
- in the measuring facilities area;
- in the factory for complex preparation and distillation of oil;
- in the intermediate oil and gas separators;
- in the Block-Bush pumping station and surrounding area;
- in the pre-water collection plant area;
- in insulated and ventilated industrial premises;
- in technological pits and wells;
- in trays with technological pipes and industrial sewer wells [20].

The severity of the consequences of an accident is influenced by the stability of atmospheric phenomena, wind speed, and direction [21].

Employees and equipment are subject to the consequences of an accident. The consequences of an accident are likely to be different. They depend on the number and volume of discarded materials, disposal duration, speed, and whether or not non-combustion combustion is used. The stability of atmospheric phenomena, wind speed, and direction influence the severity of the consequences of an accident.

Therefore, in models of accident performance, to identify the main damaging factor:

- the distance to the beam acquisition level is 37,5 kW/m^2 in the case of fire;
- the distance of the gas-air mixture cloud to the shock wave when it explodes is 35 кПа;
- the distance to the maximum impact level determines the toxic effects of spills.

Results and Discussion

The development of emergency situations for equipment and pipelines of oil and gas mixtures and gas and oil, and their localization during equipment depressurization, corresponds to the following general sequence: depressurization of equipment or pipeline→release of oil and gas mixture, gas, and oil under pressure→distribution of gaseous and liquid fractions of emission products→environmental pollution→possible ignition and explosion→sealing of the damaged area, equipment, or pipeline by means of valves and pressure relief valves→turning off compressors and pumps→localization and elimination of bottling (fires).

The main scenarios of predicted accidents are well fires, pipe explosions, pressure drops at the joints, shut-off equipment failure, and excess pressure formation in the tanks [22].

1) Ignition of the oil and gas mixture in the well. In Fig. 2a) and 2b), the horizontal flow of fire from the well in the diagram of the ellipses of thermal radiation was 4 kW/m^2, 12 kW/m^2, and 37,5 kW/m^2, the ignition of the oil and gas mixture in the well was considered. The simulation predicted the formation of a horizontal flare (jet) fire. The fire department is located in the shift town of the Kumkol field, 2.2 km from the factory for complex oil preparation and injection and 1.8 km from the production zone. At a wind speed of 105,2 m at 1/A and a distance of 5/D – 85,0 m, all technological equipment of the fire center will be damaged, a nd under the influence of thermal radiation, there will be 100% mortality. At a distance of 345.0 m at 1/A and a distance of 192.2 m at 5/D, metal structures are destroyed under the influence of explosion wave overpressure.

In Fig. 2a) and 2b), the thermal radiation flows from the well fire at 4 kW/m^2, 12 kW/m^2, and 37,5 kW/m^2 move only slightly at a wind speed of 1 meter per second, and the effect of the heat flow from the fire increases in Fig. 2b); although the flows of thermal radiation flare up due to the wind at a wind speed of 5 m/s, the effect of thermal radiation weakens.

The effect of hydrogen sulfide on the human body is small when the wind speed is 5 m/s. When the wind speed is 1 m/s, the concentration dissipates, and the effect is felt from a distance of 9 m [17, 18].

The level of thermal radiation emanating from the flame in the well:

- at 4 kW/m^2, in case of emergency actions, people without protective equipment can walk for up to 1 min due to second-degree burns. Fatal outcome: 0%;
- at 12,5 kW/m^2 with prolonged exposure to thermal radiation, the number of cases of ignition of surrounding objects and fatal outcomes in 1 min is likely to be 1%;
- at 37,5 kW/m^2, in the absence of protection of technological equipment from thermal radiation, its damage and “exacerbation” of the situation can occur in a matter of minutes. Fatal outcome in 1 min: 100%.

Accidents at production wells can lead to flare fires. Due to the absence of closed volumes, significant overpressure should not form. At low overpressure and in calm weather, the ignition of a cloud of a gas-air mixture is more likely than deflagration (explosion).

The toxic hazards of oil depend on its composition and amount of impurities; oil with a high hydrogen sulfide content is the most dangerous. However, compared to marine oil, Kumkol oil contains a much smaller percentage of hydrogen sulfide and carbon dioxide than marine oil.

In a pipe gas accident, if the effect of hydrogen sulfide on the human body is felt at a distance of 14-16 m, then at a distance of 9 m, there is no smell, and fainting begins in 15 min.

In a gas separator accident, the effect of hydrogen sulfide on the human body is observed at a distance of 3-5 m, and fainting begins in 15 min.

When collecting the oil and gas mixture, the effect of hydrogen sulfide on the human body occurs at a distance of 28-30 m. The smell of hydrogen sulfide can be felt at a distance of 1100-1230 m [23].

2) Ruptures of oil and gas separators and gas separators are unlikely to produce consequences such as the consequences of flare fires; instead, a “fireball” may form. In an oil and gas separator accident, the effects of hydrogen sulfide on the human body can occur at a distance of 30-35 m. The possibility of a catastrophic explosion of an oil and gas separator, followed by ignition and explosion, was considered.

A fireball was formed as a result of the catastrophic explosion. At wind speeds of 1/A and 5/D, the fireball radius was 138.31 m, and the action time was 17.99 s. All technological equipment at a distance of 312.97 m from the fire center will be damaged, and under the influence of thermal radiation, there will be 100% mortality.

In Fig. 2c) and 2d), the radius of action is 921.1 m at wind speeds of 1/A and 5/D with thermal radiation of 4 kW/m^2; at 12 kW/m^2 - 543.3 m; at 37,5 kW/m^2, the radius of action is 312.97 m. As thermal radiation increases, the exposure distance becomes closer.

If oil and gas separators and gas separators are connected to large-diameter pipes, a “fireball” will form due to all the material inside the isolated area. The size of the “fireball” is determined by the size of the entire stock of material located in an isolated area, not just the material inside the tank.

In the calculations of emergency situations during depressurization of pipelines and equipment, the following dangerous events are possible, affecting maintenance personnel and equipment:

- possible formation of a toxic cloud;
- flare fire with expansion (escalation);
- pool fire;
- explosion of expanding vapors of boiling liquid and possible formation of a “fireball”;
- explosion of a mixture of hydrocarbons with air.

In the calculations of individual risks, it is assumed that up to 50% of the personnel who fall into the zone of damaging factors will die (mainly in catastrophic accidents, i.e., when pipelines or equipment rupture over the entire diameter of pipes). In the case of medium and small accidents (sizes of defective holes 50 and 10 mm), the possible death of personnel does not exceed, respectively, nine and one percent of catastrophic ones [24, 25].

The following levels of impact on equipment and people are accepted for these dangerous events (Table 1).

3) Due to the influence of an external flame, ruptures of tanks (Fig. 2e), 2h), and Fig. 3) are less likely to rupture than pipelines since the thickness of the walls of the tanks is greater, and this will require more time for their overheating. However, in the case of emergency depressurization of equipment, increased temperature and pressure contribute to the active release of hazardous substances and the formation of vapor-gas clouds of fuel-air mixtures.

The main scenarios for hypothetical accidents are a fire at a well, a pipeline rupture, depressurization of connections, failure of shut-off equipment, and the creation of excess pressure in tanks [26].

The option of a catastrophic rupture of an oil reservoir at a pre-water discharge plant with subsequent ignition and explosion was considered. The time in question is 18.75.

Consequences: An oil spill fire with a diameter of 40.62 m is formed. With prolonged exposure to thermal radiation, 12.5 KW/m^2 wood fire is possible at 1/A at a distance of 22.15 m and 5/D at a distance of 26.06 m.

The option of a catastrophic rupture of an oil reservoir to a pre-discharge water installation with subsequent ignition and explosion was considered.

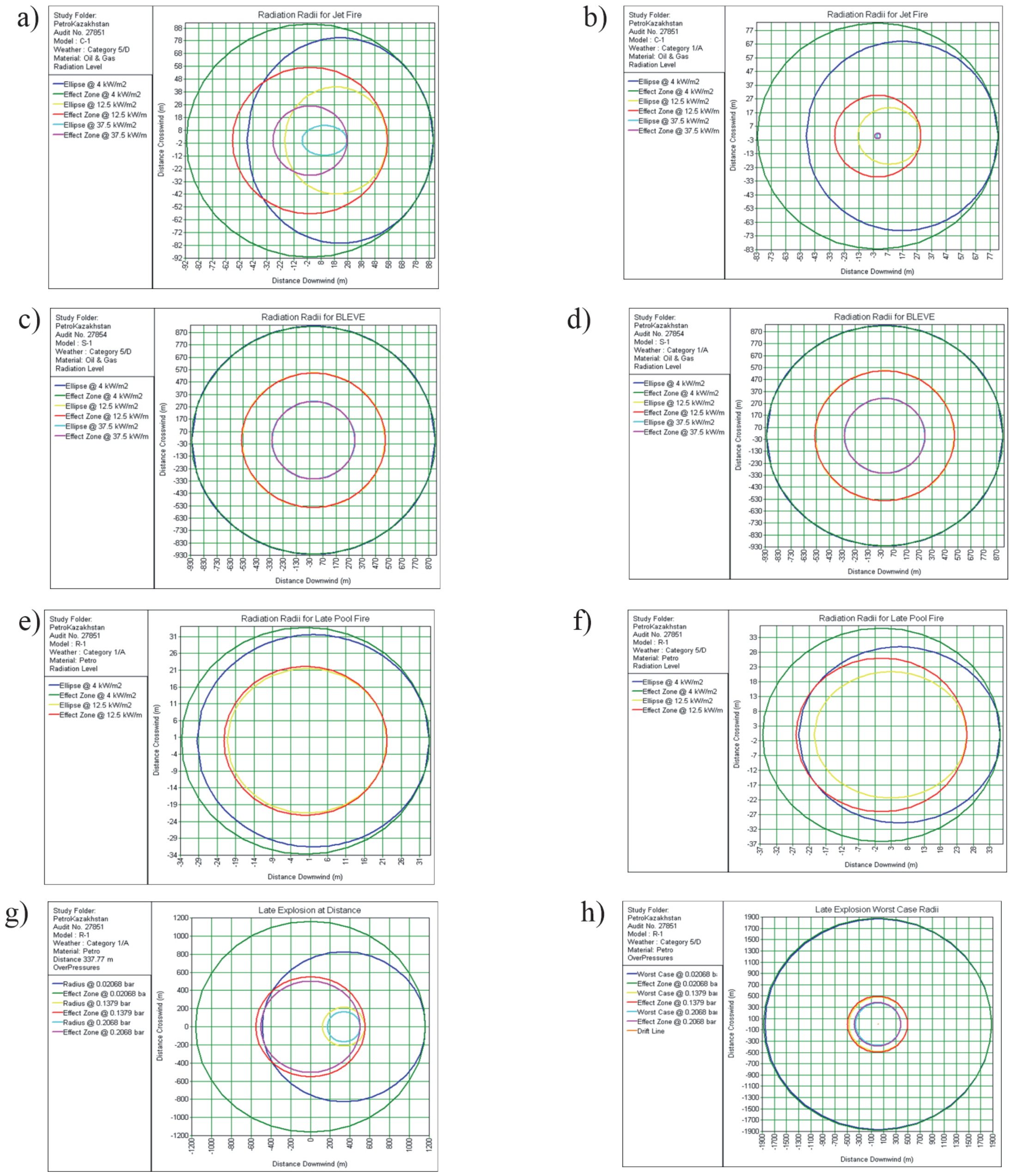

Fig. 2. Graph of ellipses of thermal radiation of 4 kW/m^2, 12 kW/m^2, 37,5 kW/m^2 of jet fire with horizontal discharge from a well: a) weather category 1/A, b) weather category 5/D, of a fireball during a catastrophic rupture of an oil and gas separator, c) weather category 1/A, d) weather category 5/D and of ellipses of thermal radiation of 4 kW/m^2, 12 kW/m^2, late oil spill fire in case of catastrophic rupture of the reservoir at the central oil treatment center, e) weather category 1/A, f) weather category 5/D and of the radii of the worst overpressure events 0.02068 bar, 0.1379 bar, and 0.2068 bar during a cloud explosion (FA) fuel-air mixture in case of catastrophic rupture of the reservoir at (central oil treatment plant), g) weather category 1/A, h) weather category 5/D.

The time in question is 18.75. Consequences: An oil spill fire with a diameter of 40.62 m is formed. With prolonged exposure to thermal radiation of 12.5 kW/m^2, wood fire is possible at 1/A at a distance of 22.15 m and 5/D at a distance of 26.06 m.

Metal structures will collapse as a result of the excessive pressure of the blast wave at a distance of 580,826 m at 1/A and a distance of 384,493 m at 5/D. Toxic substances of combustion products with a concentration of 4000 ppm are distributed at 1/A by 497.475 m and 5/D by 263.753 m.

An effective tool for reducing the risks of exposure to personnel is reducing personnel to the minimum required number, especially at particularly dangerous facilities and primarily due to complex mechanization and automation of production processes. The work area requires only a small number of employees who enter to check technologies that work without people to provide technological services.

Poisoning, burns, wounds, and skin charring can occur in wells, compressor stations, or oil refining plants due to improper handling of alkalis, acids, polymers,

Table 1. Thermal radiation from the flame of a late oil spill fire during a catastrophic reservoir rupture at the central oil treatment point and overpressure during cloud explosion fuel-air mixture in case of catastrophic reservoir rupture at the central oil treatment point.

<table>
<tr><td colspan="2">Radiation level, kw/m²</td><td>Impact on equipment and people</td></tr>
<tr><td colspan="2">4</td><td>In case of emergency action, acting up to 1 min, carried out by persons without protective equipment but in appropriate special clothing, second-degree burns are possible. Mortality - 0%</td></tr>
<tr><td colspan="2">12,5</td><td>Ignition of wood during prolonged exposure. Number of fatal cases in 1 min: 1%.</td></tr>
<tr><td colspan="2">37,5</td><td>In the absence of protection of technological equipment, it is possible to damage it and “escalate” the situation in a few minutes. Mortality in 1 min: 100%</td></tr>
<tr><td colspan="3">Overpressure during cloud explosion of fuel-air mixture in case of catastrophic rupture of the reservoir at the central oil treatment point</td></tr>
<tr><td colspan="2">Pressure</td><td rowspan="2">Impact on equipment and people</td></tr>
<tr><td>bar</td><td>kPa</td></tr>
<tr><td>0,02</td><td>2</td><td>“Safe distance”. 10% of the windows are broken. The probability of damage to employees is 95%.</td></tr>
<tr><td>0,14</td><td>14</td><td>Destruction of the joints of the panel cladding of the building. Mortality among personnel is 10%.</td></tr>
<tr><td>0,2</td><td>20</td><td>Destruction of metal structures. Mortality among personnel is 50%.</td></tr>
<tr><td>0,35</td><td>35</td><td>Almost complete destruction of buildings. The mortality rate among the staff is more than 50%. The mortality rate among the staff is more than 50%.</td></tr>
</table>

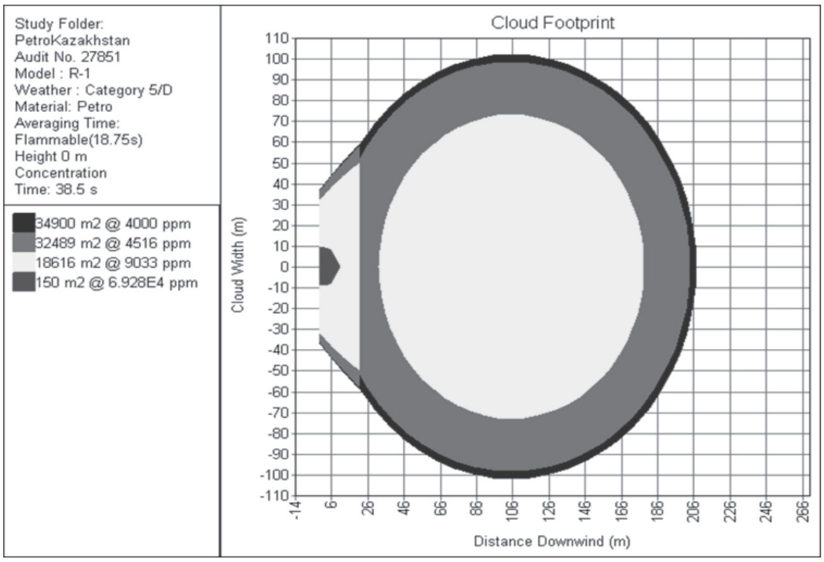

Fig. 3. Graph of the spread of the fuel-air mixture cloud (imprint) at a distance (m) after a catastrophic reservoir rupture to the central oil treatment point, time 38.5 s.

and surfactants during well processing and improper handling of containers for storing toxic substances [27-32].

In order to prevent the release of hazardous substances into the environment, liquid substances are stored in containers, solid chemicals are stored in storage pockets, and strong chemicals are stored in steel containers. When transporting and storing items and materials, they should not interact with each other. This is because effects such as combustion, eruption, and explosion occur. Hazardous waste is stored in containers and barrels of special brands that meet exceptional standards of the Republic of Kazakhstan and international standards. Measures to reduce losses in the event of a spill of chemical and hazardous substances are carried out using equipment and reagents in accordance with the methods of stopping with a specially developed plan [33-54].

Conclusions

Thus, based on the conducted research, the following measures are necessary to significantly reduce the risk of accidents and impact on personnel and equipment:

– conducting systematic emergency response exercises and exercises to eliminate the consequences of accidents in field workshops;
– organization, equipping, and training of volunteer firefighters, fountain and gas rescue teams at facilities;
– preparation of funds for the rescue of people and the elimination of accidents; the implementation of constant monitoring of their condition;
– creation of reserves of material reserves, a reserve fund of financial resources.

Implementing these measures will reduce the risk of accidents at the Kumkol field and, in case of their occurrence, the severity of the consequences.

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Conflict of Interest

The authors declare no conflict of interest.

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