Model for assessing technogenic risks at the enterprises of the fuel and energy complex of the Krasnoyarsk Territory

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Abstract. Every year on the planet there are many natural and man-made accidents that have a significant impact on the infrastructure and normal life of society. In 2020, on the territory of the Krasnoyarsk Territory, there were 2 major technogenic accidents associated with the bottling of oil products and causing significant damage to the environment, which indicates the high importance of the problem of monitoring and forecasting, as well as the need to supervise enterprises that store and refuel equipment with oil products. This issue also acquires great importance in connection with the development of the design resource, tank farm and technological equipment, which are still in operation. The solution to this problem lies in the mainstream of organizing continuous monitoring, increasing supervisory measures, organizing forecasting scenarios for the development of the situation in order to develop action plans for the implementation of one of the calculated scenarios, for a prompt response and reduce the consequences of an emergency. In this work, the problem of developing scenarios for the development of emergency situations at a tank farm and predicting possible consequences in order to reduce the likelihood of these events was solved. To solve this problem, 12 scenarios of the development of emergency situations were simulated and the situation with the ingress of oil products into the Yenisei River was simulated in order to assess the area of bottling of oil products. Modeling of emergency situations was carried out using the software product Toxy + risk and neural network forecasting of the bottling area until localization using the neural network simulator NeuroPro, developed at the Institute of Computational Modeling of the Federal Research Center of the KSC SB RAS. A comparison is made between the analytical method for determining the area of the oil spill in a reservoir and the neural network method.

1. Introduction

Despite the development of green technologies, oil and its derivatives, which also play a major role in the chemical industry, remain the main source of energy for technological machines and equipment. But the active use of petroleum products often leads to local and regional environmental disasters. According to the analysis of accidents that occurred in the Russian Federation, one of the main reasons for the bottling of oil products remains the use of fuel tanks whose service life has expired, but despite this, the operation of this equipment continues. On the territory of Russia, according to the results of the analysis of the literature [1-4], according to experts, about 65% of fuel tanks have exhausted their service life, and this also applies to the equipment installed for servicing these oil depots. An example of a disaster
of this kind is the accident that occurred in the city of Norilsk in 2020 at a fuel storage, as a result of which more than 30,000 tons of diesel fuel got into the soil and water bodies.

Oil spills may result in contamination of soil, atmosphere and water bodies. The consequence of this is the disruption of the habitat of plants, animals, birds, fish, etc. Possible destruction of food chains, displacement from habitual habitats, disruption of migration routes, etc. The severity of such consequences largely depends on the season of the spill (period migration, spawning, etc.), as well as hydrometeorological conditions.

In terms of the severity of environmental consequences, two types of mutual location of the accident site with natural objects can be distinguished: accidents with pollution of water bodies and accidents with pollution of the territory.

An urgent scientific task is to model possible accidents and consequences in order to take prompt measures and reduce the consequences of the negative impact of such accidents on the ecosystem.

The importance of emergency forecasting issues was raised in the works of researchers such as G.I. Korovin, A.A. Molchanov, G.A. Dorer, A.A. Volchek, I.A. Chuchuev [5-17].

2. Materials and methods
In this work, we set the goal of developing a model for assessing the risks of an emergency situation caused by the bottling of oil products. As a model object, a tank farm was chosen, located directly near the water protection zone of the Yenisei River, in the area of the Abalakovo settlement of the Krasnoyarsk Territory.

Modeling of scenarios of emergency situations at the oil depot was carried out using the TOXI + Risk software product [18] and the neuroimitator NeuroPro 0.25 developed at the Federal Research Center of the KSC SB RAS [19].

To solve the problem of modeling of oil falling into the Yenisei River, used multilayer neural network with sigmoid activation functions, neural network learning algorithm and parameters for the simulation are presented in [20].

Modeling of scenarios of oil product combustion (spill, fire-flash, explosion) in accordance with the Methodology for determining the calculated values of fire risk at production facilities [21], using the TOXI + Risk software product.

3. Results and discussion
As part of this work, we have analyzed various scenarios for the development of an emergency. Any scenario begins with an initiating event that can occur with a certain frequency. Possible causes and factors contributing to the occurrence and development of accidents at the facility.

When assessing the frequencies of initiating events, a statistical assessment of malfunctions and accidents was carried out by types of equipment, taking into account the possibility of initiating an accident from external causes (lightning strikes, sabotage, terrorism). According to statistical data, the occurrence of sources of initiation of an emergency scenario in petrochemical plants is implemented with the frequencies shown in table 1.

| Table 1. Basic frequency indicators of failures of individual items technological equipment. |
|---------------------------------------------------------------|
| The source of the accident | Alarm triggering event | Hole diameter expiration, mm | Frequency depressurization, year⁻¹ |
|-----------------------------|------------------------|-------------------------------|----------------------------------|
| Pipelines                   | Depressurization with subsequent outflow of liquid or two-phase medium | 5 | 4.3×10⁻³ |
|                             |                        | 12.5                          | 6.1×10⁻⁴ |
|                             |                        | 25                            | 5.1×10⁻⁴ |
|                             |                        | 50                            | 2.0×10⁻⁴ |
|                             |                        | Complete destruction          | 1.0×10⁻³ |
| Pumps                       | Failure of pumping equipment | -                            | 5×10⁻⁴  |
|                             | Depressurization with  | All types                     | 1.0×10⁻⁴ |

2
Reservoirs for storage at pressure close to atmospheric

| Reservoirs with stationary roof | Liquid in the dump | Quasi-instant | - | 9.0\times10^5 |
| Reservoirs without stationary roof | Fishtail | Up to 5 | The gap | 1.2\times10^3 |
| Bulk devices (tips, hoses, sleeves) | The gap | Quasi-instant destruction | 4.5\times10^5 |
| Tanks (auto and railway) | Depressurization with | - | - | 1.4\times10^5 |
| for transportation | | | | 2.0\times10^6 |
| petroleum products | | | | 4.3\times10^3 |

According to the statistics given in Table 1, the frequency of occurrence of the most dangerous event - depressurization of an oil storage tank - is $5.0 \times 10^{-6}$ 1/year.

Let us calculate all possible scenarios for the development of an emergency in accordance with the methodology described in Section 1.

3.1. Scenario 1
Emergency depressurization of the ground tank. Complete depressurization of the above ground tank with diesel fuel with a volume of 5000 m$^3$.

Tank 1 is located in tank farm 1. The height of the earth embankment is 2 m. The cover material inside the embankment is soil. The embankment area of the second group of tanks is 9430 m$^2$.

If the tank is depressurized, the spill area will be 9430 m$^2$, the oil product will not go beyond the embankment. The thickness of the spilled oil product layer will be 0.5 m.

3.2. Scenario 2
In the event of a quasi-instantaneous destruction of the above ground tank 1 with diesel fuel, with a volume of 5000 m$^3$, which is in the embankment, with an area of 9430 m$^2$, with a height of an earthen embankment of 2 m, as a result of a hydrodynamic shock, the embankment may be destroyed, a part of the spilled oil product will go beyond the embankment and spill over the adjacent territory. The projected spill area is 25,000 m$^2$. The spill, with an area of 15570 m$^2$, will go beyond the embankment of the tank. The coating material inside and behind the embankment is soil. The layer thickness will be 0.05 m.

3.3. Scenario 3
Emergency depressurization of the above-ground tank 2. Complete depressurization of the above-ground tank with diesel fuel, volume 5000 m$^3$.

Tank 2 is located in tank farm 1. The height of the concrete embankment is 1.3 m. The coating material inside the embankment is concrete. The embankment area of the third group of tanks is 7310 m$^2$.

If the tank is depressurized, the spill area will be 7310 m$^2$, the oil product will not go beyond the embankment. The thickness of the spilled diesel fuel layer will be 0.6 m.

3.4. Scenario 4
In the event of a quasi-instantaneous destruction of a ground tank 2 with diesel fuel with a volume of 5000 m$^3$, located in a concrete embankment, with an area of 7310 m$^2$, a height of 1.3 m, as a result of a hydrodynamic shock, the embankment may be destroyed, a part of the spilled oil product will go beyond the embankment and spill over the adjacent territory. The projected spill area is 25,000 m$^2$. Concrete surface area 7310 m$^2$. The spill area on the ground surface will be 17690 m$^2$. The thickness of the spilled oil product layer is 0.2 m.
3.5. **Scenario 5**
Emergency depressurization of the ground tank 3. Complete depressurization of the ground tank with gasoline, volume 2000 m$^3$.

Tank 3 is located in tank farm 2. The height of the earth embankment is 1.5 m. The cover material inside the embankment is soil. The area of the park is 9830 m$^2$.

When the tank is depressurized, the spill area will be 9830 m$^2$, the oil product will not go beyond the embankment. The thickness of the spilled gasoline layer will be 0.2 m.

3.6. **Scenario 6**
Emergency depressurization of the ground tank 4. Complete depressurization of the ground tank with fuel oil, volume 400 m$^3$. Tank 4 is located in a tank farm with an area of 4860 m$^2$, an earthen embankment height of 1.5 m.

When the tank is depressurized, the spill area will be 2000 m$^2$, the oil product will not go beyond the embankment. The thickness of the spilled fuel oil layer will be 0.2 m.

3.7. **Scenario 7**
Quasi-instant destruction of railway tank cars on a two-way railway unloading overpass No. 1 (gasoline A-95, as the most dangerous substance). Depressurization of 50% of the total volume of tanks in a railway train, which is 12 railway tanks, because the simultaneous reception of up to 24 railway tank cars with a volume of 161.6 m$^3$ each is provided.

Complete depressurization of a train can occur as a result of its derailment, overturning and fracture of the hulls when hitting the ground. This can happen due to improper actions of the locomotive driver, train builder, or a faulty track.

The total volume of 12 railway tanks is 1939.2 m$^3$.

The spill will occur on a concrete surface with an exit to the ground. Concrete surface area 1158 m$^2$. The estimated spill area is 9696 m$^2$. The layer thickness will be 0.05 m.

3.8. **Scenario 8**
Quasi-instant destruction of railway tank cars on railway unloading rack 1 with gasoline. Depressurization of 50% of the total volume of tanks in a railway train, which is 3 railway tanks, because it is provided for the simultaneous reception of up to 6 railway tanks, each with a volume of 161.6 m$^3$.

The reasons are the same as described in scenario 7.

The total volume of 3 railway tanks is 484.8 m$^3$.

The spill will occur on a concrete surface with partial exposure to the ground. Concrete surface area 355 m$^2$. The spill area will be 2424 m$^2$. The layer thickness will be 0.05 m.

3.9. **Scenario 9**
Quasi-instant destruction of railway tank cars on the railway unloading rack 2 with gasoline. Depressurization of 50% of the total volume of tanks in a train, which is 1.5 railway tanks, because provided for the simultaneous reception of up to 3 railway tanks, each with a volume of 161.6 m$^3$.

The reasons are the same as described in scenario 7.

The total volume of 1.5 rail tank cars is 242.4 m$^3$.

The spill will occur on a concrete surface with partial exposure to the ground. Concrete surface area 116.76 m$^2$. The spill area will be 1212 m$^2$. The layer thickness will be 0.05 m.

3.10. **Scenario 10**
Accidental spill of gasoline (as the most dangerous substance) when a tanker is at the site for loading light oil products. Loading area - 1200 m$^2$. The site has an asphalt surface. The volume of the tanker is 17 m$^3$.

The predicted spill area may be 85 m$^2$, the spill layer thickness is 0.05 m.
The filling is carried out under the supervision of the operator and the driver of the tanker truck. Therefore, the time it takes to detect an emergency is minimal. In the event of a leak of oil products, it is necessary to immediately shut off the supply of oil products, and then take measures to prevent fire.

3.11. Scenario 11
Complete emergency depressurization of the blocking pipeline with gasoline (as the most dangerous substance), with a diameter of 200 mm, the maximum distance between the valves - 1323 m. Transportation of oil products through the pipeline occurs by gravity. The difference in heights is 31.5 m. The possible time for the expiration of oil products from the pipeline is taken as 300 seconds (the time to turn off the emergency unit). Thus, if the blocking pipeline ruptures, the spill volume may reach 111.8 m³, the spill will occur on the ground surface, the spill area will be up to 1342 m², the layer thickness is 0.05 m. The amount of gasoline is 82.7 tons.

3.12. Scenario 12
Complete emergency depressurization of the hose filling device at the berthing facilities, DN = 100 mm, the maximum distance between the valves - 10 m. Oil product - AI-92 gasoline.

Oil products are transported through the pipeline by gravity. The difference in heights is 31.5 m. The possible time for the expiration of oil products from the pipeline is taken as 300 seconds (the time to turn off the emergency unit). If the hose device is destroyed, the volume of the spilled oil product will be 17.64 m³. The oil product will freely spill over the water surface and move downstream of the Yenisei River. This scenario is the most dangerous from the point of view of damaging the ecosystem of the Yenisei River. We will carry out further modeling in order to predict the possible consequences.

In accordance with the methodology described in Section 2 of this work, using the means of using the TOXI + Risk software product, the following results of modeling the risk of an accident at a tank farm were obtained (table 2).

Table 2. Forecasting the volumes and areas of oil spills in the water area.

| Accident | Volume gasoline spill, m³ | Spill area of SGK at water area, m² | Time after the start of diesel fuel (DF) discharge into the Yenisei River, s. | The distance to which the DF slick will spread downstream of the Yenisei River from the place where the stream flows into, calculated by the analytical method, m. | Distance to which the DF slick will spread downstream of the Yenisei River from the confluence of the brook stream, calculated by the neural network method, m. |
|----------|--------------------------|----------------------------------|---------------------------------|------------------------------------------------|------------------------------------------------|
| Destruction of the onshore process pipeline in the area of possible impact on the Yenisei River | 17.64 | 5880 m² – area of pollution of the Yenisei River | 600 | 1223 | 1352 |
| | | | 1800 | 2730 | 2590 |
| | | | 3600 | 5880 | 5720 |

Figure 1 shows the zone of maximum possible contamination by spilled oil products (with full containment in 1 hour).
The most dangerous scenarios associated with environmental risk are accidents with the ingress of oil products into the water area of the Yenisei River with further spread along its course. As a result of the ingress of oil products into the reservoir, toxic pollution of the environment will occur (pollution of the soil (coastal strip) and the water area of the Yenisei River, atmospheric air with products of evaporation of oil products). The estimated area of the spill spot will be $5880 \text{ m}^2$. Coastal contamination area - $250 \text{ m}^2$. The average thickness of the spilled oil product layer is $0.003 \text{ m}$. The depth of the coastal strip contamination is 5 cm.

One hour after the accident occurred and oil products got into the water area of the Yenisei River, full containment of oil products will be carried out, and therefore no further increase in scale is forecasted.

4. Conclusion
This paper presents an approach to modeling the scenarios of emergencies at a tank farm using neural network forecasting of the bottling of oil products when they enter the Yenisei River water area. The paper compares the analytical and neural network approaches to predicting the bottling of oil products in the event of an emergency. The neural network was trained on the basis of real data obtained during the bottling of petroleum products at the oil depot in the settlements Tukhard and Norilsk in 2020. The considered scenarios of the development of emergency situations indicate that the most dangerous event for the ecology of the region is the scenario of accident No. 12, which implies a complete emergency depressurization of the hose filling device at the berthing facilities. The simulation results indicate the applicability of this approach to predicting emergency situations at oil depots.

The neural network approach, in comparison with the analytical forecasting method, allows you to quickly perform the necessary calculations by adapting and automating the model for the needs of calculating the risk at a potentially dangerous facility and developing action plans to respond to these emergencies. In the event of an emergency, perform operational modeling and forecasting in order to assess the situation and make a decision on attracting additional forces and means necessary to eliminate the accident.

The results of the work can be applied in the development of plans for the prevention and elimination of emergency spills of oil and oil products.

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