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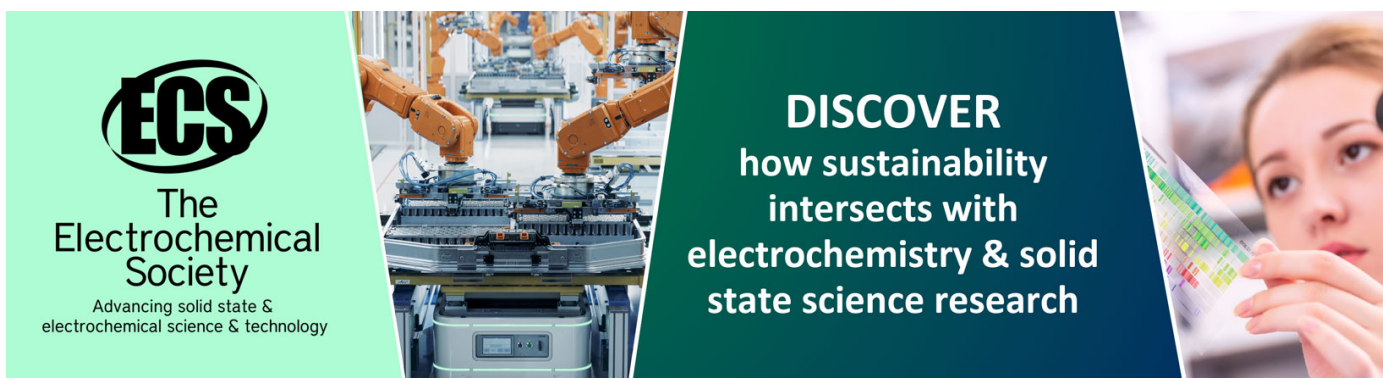
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Simulation modelling of the filling oil products process in the arctic zone using neural network forecasting

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Abstract. The intensification of the extraction of natural resources in the Arctic leads to an increase in the anthropogenic load on the environment. Due to wear and tear of equipment, corrosion of metals, mechanical damage, due to lack of proper maintenance and prolongation of the operating time in difficult climatic conditions, the operation of equipment used at enterprises leads to an increase in the risk of accidents. On the territory of the Russian Arctic, there are a number of large potentially dangerous objects, which have over 60 tanks for storing petroleum products. In 2020, there were technological accidents related to the bottling of petroleum products, which actualized the problem of taking prompt measures to prevent such emergencies. The methods for assessing the area of bottling of petroleum products currently used, especially in the Arctic zone, have a number of limitations. In the work with the use of the software product Toxy + risk, the risk of an emergency at one of the enterprises of the Russian Arctic was calculated. Neural network prediction of the area of pollution of the surface of the Kheta River was carried out using the NeuroPro neural network simulator. Comparison of the simulation results with the data obtained earlier in the analysis of the accident in the tank farm located beyond the Arctic Circle in the city of Norilsk.

1. Introduction

The Arctic territory of the Krasnoyarsk Territory is a territory of intensive extraction of natural resources, metal production and other types of industrial activities that threaten the natural ecosystem of this unique region. One of the most dangerous and widespread pollutants in the ecosystem of the North is oil products used for heating, transport and industrial equipment. Despite the measures taken in the field of technosphere and industrial safety, accidents continue to occur, and their scale is increasing every year. So in 2020, in the Arctic zone of the Krasnoyarsk Territory, there were three technogenic accidents associated with the bottling of oil products, which caused irreparable damage to the ecology of the region and affected the production processes at enterprises.

Routine operations at the oil depot with petroleum products are as follows:

- pumping from petroleum products from a barge to storage tanks;
- storing petroleum products in tanks;
- supplying petroleum products to tank trucks;
- bunkering of vessels, loading oil products into tankers and barges;



- intra-base pumping;
- accounting of received and released oil products.

Storage of oil products is carried out in vertical steel tanks, separate for each brand of oil products. The release of oil products is carried out in tank trucks, tankers and barges, as well as the tank farm carries out bunkering of ships.

The most dangerous places of accidents are the points of loading of oil products and unloading of tankers and places with navigational hazards (shallow water, ridging and compression of ice, etc.).

Figure 1 shows various scenarios leading to an accidental oil spill from a reservoir.

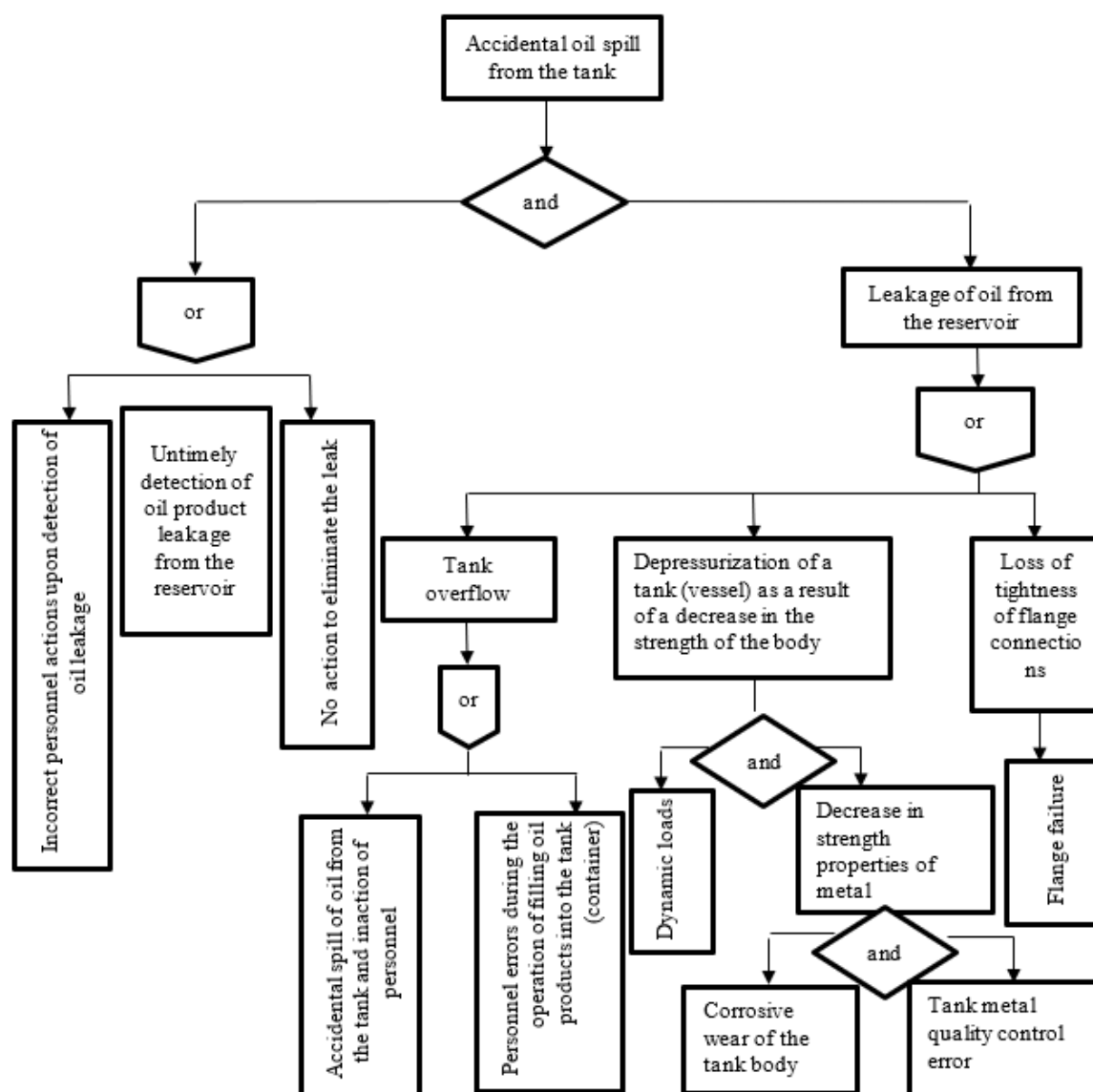


Figure 1. Fault tree.

The most dangerous scenarios for an accident development at a tank farm are accidents in a tank farm for storing petroleum products. The probable causes of emergencies include:

- incidents in production processes, problems with power supply, hydraulic shocks, etc.;

- human factor, violation of labor protection rules, errors in the operation of equipment, etc.;
- failures of technological equipment, these accidents can occur as a result of wear and tear of metal products, factory defects, poor-quality construction and installation work, including defective welding;
- factors of a natural and man-made nature, earthquakes and landslides that violate the tightness of tank equipment, thunderstorms, strong winds and hurricanes, the impact of flood waters, the effect of damaging factors from accidents that occurred at objects and installations located nearby;
- deliberate illegal actions of people.

A large number of works are devoted to solving the problem of bottling oil products on soil and in water bodies [1-3]. However, a universal approach to solving this problem has not yet been developed [4-6]. As part of the implementation of the program for the sustainable development of the Arctic region and the adoption of preventive measures to prevent man-made accidents in this region, the assessment of the risk of emergencies associated with the bottling of oil products remains an urgent task. One of the effective means of solving the complex problem of risk forecasting is the widespread implementation of monitoring and data processing systems. One of the effective means of solving this problem is the use of big data technologies and neural network forecasting, which are successfully used in various branches of science and technology. In this work, we set the task: based on the data obtained in the analysis of the consequences of the accident that occurred in 2020 at one of the enterprises of the Arctic zone of the Krasnoyarsk Territory, to assess the risk of a man-made accident and, using neural network algorithms, to simulate its consequences.

2. Materials and methods

The tasks set in the work: assessment of the likelihood of emergencies in the tank farm of the enterprise and modelling the situation with the ingress of oil products into the Kheta River are solved using the TOXI + Risk software [7] and the neuroimitator NeuroPgo 0.25 developed at the Federal Research Center of the KSC SB RAS [8]. The data array for risk assessment and modelling was obtained from the Main Directorate of the Ministry of Emergency Situations of Russia for the Krasnoyarsk Territory, the agency for civil defense, emergency situations and fire safety of the Krasnoyarsk Territory on the basis of emergencies that occurred in 2020.

Initially, for the purposes of predicting an emergency spill of oil products, the scale of the calculated plan was set and the area of objects with the personnel present was calculated. Also, the areas of objects were determined, which indicated the number of people falling into the risk zone, as well as the coefficient of their presence. The number of personnel falling into the risk zone corresponds to the maximum number of people who can simultaneously be at the facility. People who can be in the industrial area of the enterprise and can get into the dangerous affected area belong to the group of personnel.

The use of the TOXI + Risk software product allows you to analyze the risk of a probable emergency and assess the consequences of potentially dangerous facilities for the economy enterprises. To use the software product, the following actions were analysed:

- organization of work on risk analysis;
- identification of hazards;
- value of possible irrecoverable human losses, determined by the number of fatalities as a result of an accident;
- value of possible sanitary human losses, defined as the number of victims requiring hospitalization;
- the expected frequency of the accident.

The following scenarios of the occurrence and development of an emergency are possible in the company's tank farm:

1. Tank destruction
 - 1.1 Instant ignition causing spill fire
 - 1.2 No multi-link ignition
 - 1.2.1 Delayed ignition and spill fire
 - 1.2.2 Non-ignited dispersion of oil products

The initial data for the calculations were the following indicators:

- density of the oil product $\rho_{oil}=850 \text{ kg/m}^3$;
- coefficient of distribution of oil products on the concrete pavement $f_p=30 \text{ m}^{-1}$;
- temperature of the oil product obtained by calculation $t_p=39^\circ\text{C}$;
- limit of concentration of flame propagation $\varphi_f = 0,9\%$;
- molecular weight of oil $M= 50 \text{ kg/mol}$;
- molar volume of steam $V_0=22,41 \text{ m}^3/\text{kmol}$;
- gravitational acceleration $g=9.8 \text{ m/s}^2$;
- atmospheric pressure $p_0=101,325 \text{ kPa}$;
- RVS height, $H_p=18 \text{ meters}$;
- RVS diameter, $D_p=40 \text{ meters}$;
- RVS filling degree $\varepsilon =0,9$;
- number of RVS in embankment $n=1$;
- size of RVS depressurization hole $d_{hole}=0,05 \text{ meters}$;
- coefficient of consumption of oil products during depressurization of the RVS $\mu = 0,62$;
- time of blocking the flow of liquid from the hole at local depressurization of the RVS $\tau_{blocking} = 3600 \text{ seconds}$.

Data obtained at the protected object:

1. saturated oil vapor pressure $p_s=60 \text{ kPa}$
2. saturated oil vapor concentration:

$$\varphi_s = \frac{p_s}{p_0} \cdot 100\% = 59,215\% \quad (1)$$

3. evaporation rate:

$$W = 10^{-6} \sqrt{M p_s} = 4,24 \cdot 10^{-4} \text{ kg}/(\text{m}^2 \cdot \text{s}) \quad (2)$$

4. oil vapor density at operating temperature and atmospheric pressure:

$$p_{steam} = \frac{M}{V_0(1+0.00367t_p)} = 2,15 \text{ kg/m}^3 \quad (3)$$

To solve the problem of modelling the ingress of oil products into the Yenisei River, multilayer neural networks with a sigmoid activation function of the following form were used:

$$f(x) = \frac{x}{c+|x|} \quad (4)$$

where c is the characteristic of the neuron; x is the set of input parameters.

The learning algorithm of the neural network was reduced to training and testing the network with predetermined characteristics. The size of the area of bottling of oil products in a reservoir depends on many factors that should be taken into account when modelling and compiling feature vectors:

1. the volume of oil product entering the reservoir;
2. protective structures and their type on the path of distribution of oil products;
3. terrain;
4. the level of watering of the area;
5. the presence of vegetation: woody, shrub, herbaceous;
6. ambient temperature;
7. spill containment time;
8. rainfall;
9. mass of oil dispersed in water, tons;
10. wind speed, m /s;
11. water flow rate, m /s;
12. type of oil product;
13. direction of the wind.

The input parameters were selected empirically. The dimension of the vectors of the features noted above was established empirically, was thirteen. In the calculation, a multilayer neural network with 12 layers and the number of neurons in hidden layers equal to 204 was used, which shows good results in practice. The percentage of reliability of the results obtained was in the range of 70-78%.

3. Results and discussion

Based on the methodology described in section 2 of this work with the use of the TOXI + Risk software product, the following results were obtained for the risk of an accident at the Taimyr Fuel Company, table 1.

Table 1. The results of calculating the probability of an emergency at the Taimyr Fuel Company.

The source of the accident	Alarm triggering event	Outflow hole diameter, mm	Depressurization probability, year ⁻¹
Pipelines	Depressurization with subsequent outflow of liquid or two-phase medium	5	$2.8 \cdot 10^{-3}$
		12.5	$3.6 \cdot 10^{-4}$
		25	$5.2 \cdot 10^{-4}$
		50	$3.0 \cdot 10^{-4}$
		Complete destruction	$2.0 \cdot 10^{-4}$
Pumps	Failure of pumping equipment	-	$4 \cdot 10^{-4}$
Storage tanks at near atmospheric pressure	Depressurization with subsequent outflow of liquid into the embankment	All types	$2.0 \cdot 10^{-4}$
	Quasi-instant destruction	-	$6.0 \cdot 10^{-6}$
Fixed roof tanks	Pressure vent valves fire	-	$10.0 \cdot 10^{-5}$
	Fire across the entire surface of the tank	-	$10.0 \cdot 10^{-5}$
Filling devices (tips, hoses, sleeves)	Flute crack	Up to 5	$1.8 \cdot 10^{-3}$
	Blowout	-	$4.3 \cdot 10^{-5}$

As follows from the above data, the greatest probability is an emergency situation associated with depressurization of process pipelines, and the greatest danger is the destruction of a reservoir with an oil product.

The main causes of emergencies are risks of production processes, such as metal corrosion, mechanical damage, shutdown electricity, natural and man-made hazards; dangers of the human factor

(wrong actions or inaction of the personnel and management of the facility, malicious intent, terrorist acts).

Technological processes of storage, reception, bunkering of ships, filling oil products into tankers and barges, pumping oil products, violation of operating rules and during repair work, creates the risk of emergencies associated with depressurization of equipment and pipelines and bottling of oil products into the soil and water bodies.

The solution to the second task, namely neural network forecasting of the oil slick area, was carried out using the technique described earlier in the materials and methods section. Using the monitoring data on the accident on 12.07.2020 at the oil depot of the Taimyr Fuel Company, we performed a simulation. The obtained computational results were compared with the accident prevention action plan in the event of an emergency and real data on the accident.

Comparison of the results obtained using the neural network and real values of the oil slick area are presented in table 2.

Table 2. Data on the real and estimated area of the oil slick.

Date	Actual area with a cumulative total, m ²	Calculated area with a cumulative total, m ²	Deviation
12.07.2020	15200	14800	400
13.07.2020	22600	21200	1400
14.07.2020	29300	33350	-4050
15.07.2020	32200	35100	-2900
16.07.2020	35500	36100	-600
17.07.2020	36800	36500	300
18.07.2020	38300	38500	-200

Discrepancies in the first days of real data and simulated ones associated with the adoption of operational measures to contain and eliminate the oil spill were carried out in 3 stages. At the first stage, measures were taken to localize oil spills by installing booms and using the “Unisorb” sorbent. The use of booms was reflected in the results obtained during modelling by means of neural network forecasting (in table 1 starting from 07.14.2020), since in fact, predicting the time of application and the number of booms and sorbent substances is a separate difficult task, which is rather difficult to estimate numerically. In fact, with the accumulation of oil at the booms, the spill area was reduced, and there was also a partial pollution of the coastal strip.

At the second stage of work, measures were taken to collect the bulk of the fuel-water mixture and contaminated surface soil. At the third stage, measures were taken to pump the fuel-water mixture from the area of the reservoir mouth to the temporary storage warehouse in the area of the tailing dump. There are 84 tanks installed at the temporary storage warehouse, with a total volume of 21,000 cubic meters.

As a result of taking prompt measures, it was possible to avoid spilling of oil products over a large area, which resulted in a significant discrepancy between the model data; the data differed by the amount of error.

As a result of taking prompt measures, it was possible to avoid the spill of oil products over a large area, which resulted in a significant discrepancy between the model data; later, after the bottling was localized, the model data and the real data differed by the amount of error.

4. Conclusion

An important and urgent problem of man-made accidents associated with the bottling of oil products in the Arctic zone of the Krasnoyarsk Territory, which has become aggravated due to the increase in the number of accidents at enterprises, is considered in the work. One of the effective ways to minimize the losses of enterprises and prevent man-made accidents is the use of modern means of monitoring and forecasting emergency situations, drawing up models of the development of the situation and calculating

the risks of probable emergency situations. The development of modern technologies for neural network forecasting and modelling makes it possible to automate the processes of predicting the risks of emergencies, which was directly demonstrated in this work. The results obtained 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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