Physical and mathematical Model of Emergency Situations When Handling Fuel Oil at the Fuel Enterprise in Murmansk

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Abstract. The article presents the physical and mathematical model of emergencies at the fuel oil handling enterprise in the city of Murmansk. The technological equipment and the results of risk calculations during transportation, pumping, and storage of fuel in case of complete and partial depressurization of tanks are described. Risks with a potential of human losses in the most difficult emergencies, the possible radius of damage are shown. Solutions for the optimization of industrial safety are presented. Technical solutions for ensuring industrial safety allow us to conclude that the impact areas of the damaging factors of hypothetical accidents will not go beyond the health protection zone and will not affect nearby settlements.

1. Introduction

The environmental protection and industrial safety action plan may vary slightly at different enterprises [1-3]. This is primarily due to the industry specificity of enterprises [4]. The protection of industrial enterprises against fires and explosions is inextricably linked with the study of the fire and explosion hazards of production processes. The main source of energy at the "Toplivnoe Khozyaistvo Thermal Power Plant (TPP)" in Murmansk is fuel oil [5]. To reduce the fire hazard, it is necessary to strictly comply with all fire safety requirements regulated in the technical regulatory legal enactments [6-7].

This study aims to simulate possible emergencies for developing fire protection measures for the production process.

2. Materials and methods

To calculate the amount of hazardous substance released from a depressurized container and capable of damaging the working personnel, it is necessary to calculate the following parameters: the mass of the substance in the apparatus with complete and partial depressurization, the density of the substance, the intensity of evaporation and heat radiation, the excess pressure of the explosion and the void volume of the room.

The calculation of the intensity of thermal radiation was carried out considering the speed of movement of a person and the distance from the location of the person to the area where the intensity of thermal radiation does not exceed 4.2 kW/m², m [8].

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The calculation of the risk for each \( i \)th scenario was carried out considering the coefficient of the vulnerability of a person placed at a certain point with coordinates \((x, y)\) from the damaging factor, considering the protective properties of the room and the emergency shelter in which a person can be at the moment of the accident [9-11].

Information about the research object. The TPP operates using the hazardous substance - fuel oil (grade 100 in accordance with ГОСТ 10585-99) with no more than 1% of mechanical impurities; water - no more than 1%; sulfur - no more than 0.5 ÷ 3.5%. The boiling point of fuel oil is 350-5000 °C, and the flashpoint is from 80 to 112 °C. The fuel oil does not possess corrosive properties and the ability to form toxic compounds with air and wastewater in the presence of other substances and factors at ambient temperature. It must not be present in water. The fuel oil irritates the mucous membrane and human skin, causing its damage and the occurrence of skin diseases. Prolonged contact with fuel oil increases the risk of respiratory diseases. In the event of a fire, it may produce thermal effects on people and the environment, as well as pollutes the atmosphere with combustion products.

The equipment at the plant is sealed and protected from static electricity. The electric components have protection form are explosion.

Considering the location of sites, technological equipment, communications, and the production characteristics, the structure of the TPP can be divided into units, which have the main technological equipment for handling hazardous substances:

- Unit No. 1 - Receiving and unloading device (length – 298 m) for servicing railway tank cars (receiving, draining fuel oil, cleaning of tanks);
- Unit No. 2 - Oil pumping station No. 1 with different loading capacity pumps, purification filters, and fuel oil heaters are installed outside;
- Unit No. 3 - Oil pumping station No. 2, where the recirculation pumps, their filters, heaters of the fuel oil circulation circuit are installed on the outdoor site;
- Unit No. 4 - Fuel oil storage No. 1 consists of 4 reinforced concrete (underground) tanks (9200 m\(^3\) each);
- Unit No. 5 - Fuel oil storage facility No. 2 consists of 4 metal tanks with a volume of 20,000 m\(^3\) each, located vertically and surrounded by an earthen embankment with dimensions of 60x87x5 m;
- Unit No. 6 - Main fuel oil pipelines rack (from fuel pump station No. 1 to the boiler room of the main building) with two pressure fuel oil pipelines and one fuel oil recirculation pipeline.

According to official data, no accidents have been recorded at the plant during its existence but when analyzing the conditions for the occurrence and development of emergencies, the following reasons and factors are possible that contribute to the occurrence of accidents associated with equipment failures:

- Hazards associated with typical processes (heat exchange and hydrodynamic at the declared facility);
- Physical wear, corrosion, mechanical damage, thermal deformation of equipment and pipelines;
- Termination of the supply of energy resources;
- Errors of support personnel;
- External impact from natural and man-made factors.

3. Results and discussion
Identification of accident scenarios involving hazardous substances.
A potential hazard is fuel oil, which, in case of complete or partial depressurization of equipment and the case of ignition it can lead to a fire, heat injuries, and equipment damage. Under certain
conditions (for example, when the temperature exceeds the flashpoint), an explosion of a combustible fuel-air mixture (FAM) may occur with an airwave (AW) impacting the facilities of the plant within a radius of one hundred meters.

The most probable scenarios of possible accidents associated with the circulation of fuel oil at the target facility may be as follows.

Model of scenarios \( C_1 \): partial or complete destruction of equipment → release of a flammable liquid → formation of a spill → fire of a spill → exposure of personnel and adjacent equipment to thermal radiation (probability \( 9.6 \times 10^{-5} \) per year);

Model of scenarios \( C_2 \): partial or complete destruction of equipment → release of a flammable liquid → formation of spill → evaporation of a flammable liquid → formation of a fuel-air mixture during evaporation from a spill → explosion of a fuel-air mixture → propagation of airwave → plant personnel is captured in hazardous areas → impact of airwave on people and adjacent equipment (probability \( 2.7 \times 10^{-8} \) per year).

Partial destruction of equipment was taken in the size of a hole with a diameter of 25 mm. The time needed to eliminate the accident was assumed to be 60 minutes.

In each technological unit the equipment with the maximum fuel oil content was selected, which could cause the most drastic consequences in case of emergency:

- In unit No. 1 the pipeline for filling storage tanks was chosen, in the event of depressurization of which a significant spill of fuel oil on the earth's surface will not occur, therefore, in this case, a strait fire and an explosion of AFM are not forecasted;
- Units No.2, No.3, No.5, and No.6 have the maximum amount of fuel oil causing the accident;
- Unit No. 4 consists of full-height reinforced concrete tanks, if they are depressurized, a significant fuel oil spill will not occur, therefore, a strait fire and an explosion AFM in unit No. 4 are not forecasted.

Calculation of the damaging effects of fire and explosion on personnel.

To determine the affected areas in case of strait fire for all values of the radiation intensity, it is necessary to know the spill area \( S \), the density of the ambient air \( \rho_0 \), and the average surface density of the thermal radiation of the flame \( E_f \) (tables 1-2). Similar calculations were performed for all blocks.

### Table 1. Calculation results for partial and complete depressurization of fuel oil storage No. 2 under scenarios \( C_{1-2} \) and \( C_{1n-2} \).

| Unit 5, Fuel oil storage tank | Partial | Complete |
|------------------------------|---------|----------|
| Weight of spilled fluid, kg  | 18600   | 19000000 |
| Spill area, m²               | 3970    | 3970     |
| Efficient spill area diameter, m | 71     | 71       |
| Flame height, m              | 49      | 49       |

When determining the number of victims, the location of people (in open areas or inside buildings) was considered; location of personnel, buildings, and structures (distance from the epicenter of the accident); the presence of personal and collective protection equipment.

The results of calculating the possible number of fatal cases (mortality ratio) and injuries (casualties) in the case of the most probable accident scenarios at the target facility are presented in table 3.
Table 2. Dimensions of the areas affected by thermal radiation in case of a strait fire for partial and complete depressurization of fuel oil storage No. 2 under scenarios С\textsubscript{1-2} and С\textsubscript{1n-2}.

| The intensity of heat radiation, kW/m\textsuperscript{2} | Partial depressurization | Complete depressurization |
|--------------------------------------------------------|--------------------------|---------------------------|
| 1.4                                                    | 72                       | 96.96                     |
| 4.2                                                    | 69                       | 55.39                     |
| 7                                                      | 56                       | 40.74                     |
| 10.5                                                   | 48                       | 30.6                      |
| 12.9                                                   | 43                       | 26.16                     |
| 17                                                     | 36                       | 22                        |

Table 3. Possible number of injured people in case of an accident in Unit 5.

| Facility               | Distance from the epicenter of the accident, m | Most probable scenario С\textsubscript{1} (fuel oil storage 2) | Total |
|------------------------|-----------------------------------------------|---------------------------------------------------------------|-------|
| Fuel oil storage 2     | 0                                             | The main damaging factor is thermal radiation                 | -     |
|                        |                                               | The radius of hazardous area = 69 m                           | -     |
|                        |                                               | The radius of fatal injuries area (within fall area) = 36 m   | 3     |
|                        |                                               | Casualties, ppl.                                              | 3     |
|                        |                                               | Fatal cases, ppl.                                             |       |
| Total taking into account the probability of impact: | -                                             | -                                                             | 3     |

Table 4. Possible number of injured people in case of an accident in Unit 5 (continuation).

| Facility               | Distance from the epicenter of the accident, m | Most hazardous scenario – С\textsubscript{1n} (fuel oil storage 2) | Total |
|------------------------|-----------------------------------------------|---------------------------------------------------------------|-------|
| Fuel oil storage 2     | 0                                             | The main damaging factor is thermal radiation                 | -     |
|                        |                                               | The radius of hazardous area = 69 m                           | -     |
|                        |                                               | The radius of fatal injuries area (within fall area) = 36 m   | 3     |
|                        |                                               | Casualties, ppl.                                              | 3     |
|                        |                                               | Fatal cases, ppl.                                             |       |
| Total taking into account the probability of impact: | -                                             | -                                                             | 3     |

In general, at the target enterprise, the most hazardous scenario is a complete depressurization of the reservoirs in units 1 and 6. The level of the potential risk of the entire territory of the target plant is equal to \(R_{pot} (x, y) = 1.8 \times 10^{-5} \text{year}^{-1}\). The individual risk is recommended to be assessed by the frequency of injury to a certain person (a group of people) because of an accident during the year: \(R_{ind} = 3.9 \times 10^{-6} \text{year}^{-1}\), for the \(i\)th person. The maximum individual risk does not exceed the acceptable level (10\(^{-6}\)). The collective risk is \(R_{coll} = 3.4 \times 10^{-5}\text{person per year. The analysis of social risk at the enterprise under a probable accident scenario is presented in Table 4. Similar calculations were performed for all blocks.\)
Table 5. Social risk analysis.

| Unit                        | Scenario | Frequency of accident occurrence, 1/year | Number of injured people, N<sub>ppl</sub> | Frequency of cases with injuries, 1/year |
|-----------------------------|----------|------------------------------------------|------------------------------------------|------------------------------------------|
| CSR                         | C<sub>in-2</sub> | 3.7·10<sup>-7</sup> | 5 | 3.7·10<sup>-7</sup> |
| Pumping line 1              | C<sub>in-2</sub> | 2.4·10<sup>-7</sup> | 4 | 6.1·10<sup>-7</sup> |
| Pumping line 2              | C<sub>in-2</sub> | 1.4·10<sup>-7</sup> | 3 | 7.5·10<sup>-7</sup> |
| Fuel oil storage 2          | C<sub>in-2</sub> | 2.7·10<sup>-6</sup> | 3 | 7.77·10<sup>-7</sup> |
| Main fuel pipelines rack    | C<sub>in-2</sub> | 3.2·10<sup>-6</sup> | 1 | 3.9·10<sup>-6</sup> |

The analysis of accident risk indicators shows that the most hazardous Unit is No.5 with "Fuel oil storage 2", where the number of victims in a possible accident can reach up to three people. It should be noted that the impact areas of the damaging factors of hypothetical accidents do not go beyond the health protection zone and do not affect nearby settlements. In general, all technical and organizational solutions at the target facility are carried out taking into account the requirements of the current regulatory documents and comply with the modern level of industrial safety.

To ensure explosion and fire safety, the following solutions and recommendations are provided:

- 9 critical sensors are installed on the roof of each fuel oil tank;
- The automatic foam extinguishing system was installed to eliminate fires inside the fuel oil pumping and fuel oil storage facilities (it is recommended to check the extinguishing system at least once a year);
- The resistance of grounding devices does not exceed 1000 Ohm to protect against static electricity;
- The protection against direct lightning strikes (it is recommended to inspect lightning protection devices at least once a year);
- To prevent static electricity, fuel oil is supplied through the pipeline at a speed of no more than 1 m/s (maximum speed - no more than 5 m/s);
- The recommended maximum temperature of fuel oil in the receiving tank and storage tanks is not more than 150 С;
- 25 fire hydrants (ring water system recommended);
- Hatches for measuring the fuel oil level and taking samples have protective covers made of a material that does not cause sparking;
- The inlet and outlet device is equipped with hydraulic locks that serve to prevent the propagation of a blast wave or flame into the receiving tank when fuel oil ignites in trays or at the main pipeline rack;
- The supply and exhaust ventilation was installed to control the content of hazardous gases in the premises;
- The floors in the oil pumping stations are made of non-combustible materials (with a recommended slope of 0.3% towards the drainage pit).

4. Conclusion

In conclusion, the following conclusions can be drawn:

- The analysis of the calculated indicators of the risk of accidents at the target facility shows that the most potentially hazardous unit is No. 5 with "Fuel oil storage 2", where the number of victims in a probable accident can reach 3 people;
- All technical and organizational solutions at the target facility are developed and implemented taking into account the requirements of current regulatory documents and comply with the modern level of industrial safety;
The technical solutions for ensuring industrial safety allow concluding that the impact areas of damaging factors of hypothetical accidents will not go beyond the health protection zone and will not affect nearby settlements.

References
[1] Mustafin A G 2008 Jekologija i promyshlennost Rossii 11 32
[2] Mohamed B, Rym B D, Amor E A and Hamadi B 2003 Bull Environ Contam Toxicol 70 854
[3] Regiony Rossii. Osnovnye karakteristiki subektov Rossiskoj Federacii Rosstat 2017 Retrieved from: http://www.gks.ru/doc_2017/region/subject.zip
[4] Trotsenko A A, Belevsky T V, Kievaskaya O G, Alexandrova E Y and Gurevskaya L A 2018 Definition of the effective strategic enterprise management model in context of economic security. Revista Espacios 39(36) 18
[5] Yagafarova G G, Mazitova A K, Leontyeva S V, Safarov A Kh and Vakhitova D R 2016 Bioremediation of soils contaminated with heavy oil. Proceedings of NIPI Neftegas GNKAR 3 75-90
[6] Creation of the Government of the Russian Federation No. 340 dated May 23, 2002 (as amended on October 3, 2002) "On approval of the Regulation on licensing activities for handling hazardous waste" Retrieved from: http://www.consultant.ru/document/cons_doc_LAW_36816/e57a0f3564225a4abc1d427fec31b70fc05582e2/
[7] Faulkner B C and Lochmiller R L 2000 Arch Environ Contam Toxicol 39 86
[8] Trotsenko A A 2016 Some aspects of the chemistry of spontaneous combustion and self-ignition. MDPI 1-1(7) 284-8
[9] Methodological foundations for conducting a hazard analysis and risk assessment of accidents at hazardous production facilities Retrieved from: http://docs.cntd.ru/document/1200133801
[10] Methodological recommendations for assessing damage from accidents at hazardous production facilities 2002 (Moscow: Gosgortekhnadzor of Russia) 26
[11] General rules of explosion safety of explosive and fire hazardous chemical, petrochemical and oil refineries 2015 (Moscow: Gosgortekhnadzor of Russia) 76