On the Specifics of Fire Extinguishing During Dangerous Goods Transportation in the Northern Regions

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Abstract. The article considers the variants of emergency situations that occur during railway transportation of oil and petroleum products in the Northern regions. Options for implementing measures to eliminate fires and explosions related to these events are given. It is demonstrated that the railways in Russia in the Arctic zone are long and carry a large number of different cargoes, including dangerous ones. The analysis of the most resonant large fires in railway transport was performed; the causes of these emergency events were determined. The peculiarities of fire extinguishing during transportation of dangerous goods by rail were considered, and some difficulties in extinguishing fires at low temperatures (below -10°C) were analyzed. Some national samples of fire engines (multi-purpose fire truck and GAZ-59402 "Purga") were analyzed in relation to their use in firefighting in the Arctic zone. Proposals for responsibilities distribution between railway and fire services in case of emergency response and recovery work have been developed. Possible ways for solvation of the problems arising during firefighting on railway transport at low temperatures were suggested.

1. Introduction

The mass media report on fires and accidents in cities, enterprises and transport that occur in different countries, as well as information about their consequences and victims almost daily.

The damage to nature from the fire that occurred in the Mangistau region as a result of the collision of a fuel tanker and a train with oil tanks amounted to 120 million tenge [1]. The accident occurred on November 16, 2013 at a railway crossing near the Mangistau station. The train, consisting of more than 30 oil tanks, was smashed by a fuel tanker of Emir Oil, LLP. As a result of the accident, the largest fire in Mangistau ever occurred. 17 oil tanks were burning. The train driver's assistant died during the accident. The driver himself was burned. The contamination area was more than 3 thousand square meters [1]. Figure 1 depicts a photo from the scene of the accident.
This and many other examples of fires and accidents (on April 22, 2004, two trains carrying liquefied gas and oil collided at the Yongchon station in Pyongan-Pukto province in North Korea). More than 150 people died, more than a thousand people were injured, and thousands of residential and industrial buildings were destroyed during the explosion of oil products being transported [2].

2. General provisions.
Rail transportation is an important link in the state's transport traffic, which accounts for more than half of the country's cargo turnover. Today, the Northern Railway is one of the largest in Russia. Its deployed length is more than 8,5 thousand kilometers. It passes from the center to the North through Yaroslavl and Vologda to Arkhangelsk on one branch, and on the other, it passes through Kotlas and through the whole Republic of Komi beyond the Arctic circle. 33 stations and 227 stations of the road serve passengers; 235 stations are available for cargo operations.

Many cities and towns in the Northern regions are connected by the Northern railway. The road is operated in severe climatic conditions. Figure 1 illustrates a section of the Norilsk railway in winter, and figure 2 represents an image of the railway station.
At the same time, unsafe cargo transportation by railway involves a significant transport risk, since up to 1000 wagons with various unsafe chemicals can be immediately located in an emergency situation. In fact, there may be unsafe chemicals on any freight train in force majeure situations. As a result, freight trains represent their own kind of potentially unsafe objects [5]. Several thousand tons of cargo with various explosion and fire hazards are transported every day.

Freight transportation is significantly complicated by weather conditions on the Northern railway. In these latitudes the negative temperature dominates all year round. Experience has shown that fire extinguishing at low temperatures requires a large amount of material and human resources.

Dangerous goods include substances, materials and products that have dangerous physical and chemical properties, and this is a manifestation that can lead to death and disease of people and animals, environmental damage and material damage if transport conditions are violated.

Classification of substances, materials and products that are transported as dangerous goods is based on the characteristics of the corresponding types of transport risk, sorting and criteria of special test methods [6].

The most dangerous are freight and marshalling stations characterized by [7]:
- the existence of cars simultaneously located on the railway tracks, tanks, container ships and other means of transport. They contain flammable solid and liquid fuels and liquefied gases. All these goods are extremely dangerous in the event of a fire at the station;
- lack of fire-fighting water supply.

The greatest threat to marshalling yards and freight stations is determined by the following factors [7]:
- a lot of rolling stock with different flammable liquids and other materials;
- availability of warehouses, their construction density and significant length;
- existence of too narrow extended gaps between the railway trains, which contribute to the rapid spread of fire over a large area;
- insufficient water supply for firefighting purposes.

The explosion of railway tanks carrying oil products is the result of exposure to an open flame for about 20 minutes. The height of the flame torch increases to 50 m during the explosion of flammable liquids. The height of the flame increases to 50 m when the explosion of combustible and flammable liquids. The explosion of the tank increases the fire area to 1500 m2, depending on the ballast state of the railway tracks and terrain. Most often, a fire occurs when liquid flows out of railway tanks as a result of an accident, collision, or railway disaster. If the tanks were damaged and overturned, the fire

![Figure 3. Norilsk railway station in winter](image)

**Figure 3.** Norilsk railway station in winter
area may be 10-35 thousand m². In case of oil refining products leakage, the fire covers not only railway trains that are located nearby, but also warehouses, industrial and administrative buildings, and in some cases even buildings of the urban area that are located in the close vicinity of the accident place. If the spilled product gets into the drainage or sewer system, the fire can go to various objects located in the zone up to one kilometer from the fire focus.

In other words, fire extinguishing and rescue operations on railway transport are complicated by the following problems:
- delayed start of fire extinguishing due to detection of physical and chemical properties of the cargo;
- contact networks must be de-energized;
- risk assessment of accident consequences in case of tank depressurization;
- possibility of leakage of flammable liquids, dangerous chemicals and contamination of the area around the place of emergency;
- necessity of evacuation of the population from the areas adjacent to the place of emergency.

In order to prevent boiling or discharge of the flaming liquid, it is necessary to take measures to supply the extinguishing agent for cooling the tank with compact water jets, and then feed the foam barrels inside the tank through the neck of the loading hatch to extinguish the burning liquid.

When depressurization (perforation) of a railway tank intended for the transportation of liquids (oil, fuel oil, gasoline, oil products), liquid products leak out. In a large number of cases, liquids are ignited by accidental sources of ignition (metal or electric spark; open sources of fire-welding, matches, burning cigarettes; heated metal surfaces of tanks). The fire-fighting tasks in this type of combustion consist primarily in cutting off the leaking liquid product from the tank. Foam or water jets are used for this purpose [9].

Fire control is carried out by fire protection services or specially organized groups. The time of control is determined by the mode of total fire cessation. Traffic on railway tracks is not allowed until the end of the fire.

When extinguishing fires at low temperatures (-10°C and below) in accordance with the fire extinguishing regulations [10], it is necessary:
1) use high-flow fire barrels for open fires and with sufficient water, limit the use of overlapping barrels and spray barrels;
2) take measures to prevent the formation of ice on the routes of people's evacuation and movement of personnel;
3) lay lines of rubberized and latex sleeves of large diameters, install sleeve branches inside buildings if possible, and insulate them during outdoor installation;
4) protect the connecting fittings of sleeve lines with available means, including snow;
5) when feeding water from ponds or fire hydrants first, it is necessary to feed water from the pump to the free branch pipe and only when the pump is running steadily, it is necessary to feed water to the hose line;
6) create a reserve of dry pressure hoses;
7) in case of reduced water consumption, it is necessary to heat it in the pump, increasing the engine speed;
8) avoid overlapping of fire trunks and hose branches, avoid switching off the pumps;
9) when replacing and stacking fire hoses, building up lines, it is necessary not to stop the water supply, and the specified work should be carried out from the trunk side, reducing the pressure;
10) determine the place of refueling with heated water and, if necessary, fill the tanks with it;
11) heat the frozen connecting fittings of fire hoses, as well as the hoses in places of kinks and connections with hot water, steam or heated gases (it is allowed to warm the frozen connecting fittings, branches and trunks with soldering lamps and torches);
12) to prepare the space for warming participants of extinguishing and to gather the reserve of protective clothing for the personnel in these places.
Currently, in the country, the leading tactical unit for eliminating fires and conducting emergency rescue operations in accidents, crashes, natural disasters and other emergencies that are accompanied by fires on the railway transport is the fire train (324 fire trains are functioning). However, the use of fire trains in winter in the Northern regions of our country is complicated by the disadvantages listed above.

At the beginning of the two thousandth years in the Russian Federation, the production of modern fire equipment was established, which can be used to extinguish various fires, including on railway transport in low temperature conditions.

GAZ-59402 "Purga" motor car proved to be more efficient when working in Northern conditions. Figure 4 illustrates the appearance of the GAZ-59402 "Purga" fire engine.

**Figure 4.** Fire engine GAZ-59402 "Purga" with combined stroke

In the event of a fire on the stretch (see Fig. 2), the GAZ-59402 Purga fire truck can be used efficiently in combination with a fire extinguishing installation with temperature-activated water, which can get on the rails at the nearest station to the site of an accident or fire.

For fire extinguishing in premises (cars, warehouses, etc.) containing dangerous goods, the most promising from our point of view are automatic autonomous modular fire extinguishing devices, for example, an automatic fire extinguishing device [14].

Special charges made of gunpowder or other pyrotechnic compounds are used as an energy source in autonomous fire extinguishing installations.

For a long time, the attention of researchers was focused on gasifying systems such as explosives, gunpowder and solid rocket fuels. Here, a great role in the development of the idea of the combustion mechanism was played by N. N. Semenov's students A. F. Belyaev and P. F. Pochil [16], [17], [18], [19], [20]. It is necessary to note the progress made in the creation of the theory of non-stationary combustion of gunpowder (Ya. B. Zeldovich, B. V. Novozhilov et al.). It is interesting that in most cases the description of non-stationary effects does not depend on the complex situation of the transformation of substances during combustion and can be carried out in a generalized form.

In our opinion, the combustion of pyrotechnic structures of this type is one of their disadvantages, namely, in certain conditions, installations using such structures can themselves be a source of ignition.

For the first time, the possibility of gas-free combustion was suggested in [23], which revealed the absence of combustion rate dependence on pressure for a single thermite system. Later the actuality of
Gas-free combustion was proved by E. I. Maximov, V. M. Shkiro and A. G. Merzhanov [24], who specially developed a gas-free composition based on iron-aluminum termite and studied in detail the mechanism and uniformity of its combustion. For a long time, such combustion in its pure form was considered exotic. Just after an extensive class of combustion reactions in metal-nonmetal systems was discovered, gas-free combustion became widespread.

In our opinion, this type of system has a great future as a source of energy for autonomous fire extinguishing devices.

However, partial gasification of components is always possible during combustion, and the concept of gas-free combustion needs to be clarified. Low calorie content is sometimes achieved by diluting the initial high calorie mixtures with the final products of the reaction. During the transition to vacuum pressures, the gas-free combustion mode is usually violated. It is possible to specify three types of systems, implementing the gas-free combustion mode.

1) Systems with refractory components.
2) Low-calorie termite systems.
3) Homogeneous systems with low-temperature exothermic reactions that can occur in the combustion mode (layer-by-layer polymerization, recombination of radicals at cryogenic temperatures).

The first two types of systems are currently most common.

For example

\[ \text{Ti} + \text{C} = \text{TiC} \text{ (1st type)} \]
\[ \text{Cr}_2\text{O}_3 + 2\text{Al} = 2\text{Cr} + \text{Al}_2\text{O}_3 \text{ (2nd type)} \]

This article analyzes both the first and second types of systems as a chemical energy source.

When trying to use systems of the first type as a chemical heat generator (CHG), a rather significant flame was observed, since in order to more completely oxidize C or S (in the Fe + S = FeS system), an oxidizer (NaNO3) had to be added. Therefore, the systems of the 2nd type were studied in more detail.

However, due to the existence of an oxide film on the surface of aluminum, the ignition temperatures of aluminum and its mixtures with oxides are quite high.

Iron-aluminum compounds have a relatively low ignition temperature (FeO: Al = 50:50, 810°C), but a high combustion temperature of about 3000 K.

Conversely, chromium-aluminum compounds have a high ignition temperature (Cr2O3: Al = 73:27, 1180°C), but the combustion temperature is about 2000 K.

Experiments for optimizing the chemical heat generator were carried out.

As the initial components, a powder of chromium and iron oxides of the CH brand with a particle size less than 10 microns, and polydisperse aluminum of the ASD-1 brand (d ≤ 10 microns) were used.

The composition was prepared by mixing the initial reagents Cr2O3: Al = 0.73: 0.27 and Fe2O3: Al = 0.66: 0.34 in a mortar for 10-15 minutes.

The prepared mixture with a constant mass of 2.5 g was placed in a mold and formed a tablet with a diameter of 20 and a height of 10 mm.

All experiments were performed at atmospheric pressure and in the air environment. The tablet was ignited with a tungsten spiral (a wire with a diameter of 350 microns and a length of 150 mm) consisting of 10 turns of wire with an internal diameter of 2.2 mm. The length of the twisted part of the spiral was comparable to the diameter of the tablet. The alternating voltage 0 ≤ U ≤ 6 V was supplied from an autotransformer of the АОМН-40-74УХЛ-4 type. An automatic device that changed the voltage on the igniting coil provided a constant rate of heating. The voltage on the helix was controlled using a digital voltmeter V7-34A.

The ignition temperature was recorded in experiments with a chromel-alumel thermocouple with a diameter of 2.5 g was placed in a mold and formed a tablet with a diameter of 20 and a height of 10 mm.

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The ignition temperature was recorded in experiments with a chromel-alumel thermocouple with a diameter of 2.5 g was placed in a mold and formed a tablet with a diameter of 20 and a height of 10 mm.
Visual inspection revealed that the tablet is ignited in the area adjacent to the spiral, and the combustion process is carried out in layers from top to bottom. The resulting thermograms clearly recorded the inflection point, above which the temperature increases sharply. This value was taken as the ignition temperature $T_3$. For the composition of $\text{Cr}_2\text{O}_3 + \text{Al}$, $T_3 = 1200^\circ\text{C}$ is achieved in 16.1 sec. in comparison with iron-aluminum termite, this time increases by 25%. In the main series of experiments, the ignition temperature was recorded depending on the ratio of the mixture. It is shown that with an increase in the $\text{Cr}_2\text{O}_3$ content, $T_3$ increases from 980 to 1200 $^\circ\text{C}$.

At the considered stage of the process, the depth of transformation is relatively small and the determining factor is the temperature dependence used by the quasi-stationary theory of ignition of condensed substances by a hot shape of high thermal conductivity with a variable surface temperature.

Therefore, it is possible to estimate $T_3$ for the studied systems by the formula

$$\frac{(T_3 - T_\text{in})}{E} \frac{E}{RT_3^2} e^{\frac{E}{RT_3}} = \frac{2Qz}{c\sqrt{m}}$$

where $T_\text{in}$ - initial temperature; $c$ - specific heat capacity of the mixture; $z$-preexponent; $Q$-thermal effect of the reaction; $E$- activation energy; $m$- heating rate; $R$- gas constant.

The fact that the temperature of the cold end of the mixture changes slightly during the entire ignition period allows us to use the model of a semi-infinite shape.

For the composition of $\text{Cr}_2\text{O}_3 + \text{Al}$ ($Q = 2706$ $\text{J/g}$, $E = 186.4$ kJ/mol, $c = 0.25$ $/ (\text{g} \cdot \text{deg})$, $z = 3.3 \cdot 104$ c-1) calculation gives $T_3 = 1154$ $^\circ\text{C}$, and for composition $\text{FeO} + \text{Al}$ ($Q = 3247.2$ $\text{J/g}$, $E = 181.8$ kJ/mol, $c = 0.46$ $/ (\text{g} \cdot \text{deg})$, $z = 3.9 \cdot 107$ c-1) $- T_3 = 955$ $^\circ\text{C}$.

According to the results of calculations, it follows that spirals made of nichrome and similar materials are suitable for ignition, providing a temperature in the range of 900-1200 $^\circ\text{C}$.

3. Conclusion
The authors suggest the following for more effective fire suppression on the railway in the Arctic region:
- to use special technical devices to search for fire hydrant hatches (for example, VM-901 vortex metal detector);
- to ensure the performance of fire equipment in low temperature conditions, using a fire extinguishing system with temperature-activated water, which must be equipped with fire trains of the Northern railway;
- to use a combined GAZ-59402 "Purga" fire truck for rapid delivery of personnel and fire extinguishing agents to the place of fire on the railway. To equip the car with a fire extinguishing system with temperature-activated water.
- to equip wagons carrying dangerous goods with modular autonomous fire extinguishing systems.

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