Prognostication of fire of oil and oil products storage tank farms and engineering and technical solutions

A V Zvyagintseva\textsuperscript{1,5}, L A Mezhova\textsuperscript{2}, S A Sazonova\textsuperscript{3}, L V Stenyukhin\textsuperscript{4},
P V Chertkov\textsuperscript{4}

\textsuperscript{1}Department of Chemistry and Chemical Technology of Materials, Voronezh State Technical University, 84, October 20th Anniversary Street, Voronezh, 394006, Russia
\textsuperscript{2}Department of Geography and Tourism of the Federal State Budgetary Educational Institution of Higher Education, Voronezh State Pedagogical University, Russia
\textsuperscript{3}Department of Technosphere and Fire Safety, Voronezh State Technical University, 84, October 20th Anniversary Street, Voronezh, 394006, Russia
\textsuperscript{4}Department of Applied Mathematics and Mechanics, Voronezh State Technical University, 84 October 20th Anniversary Street, Voronezh, 394006, Russia
\textsuperscript{5}Kuban State University Branch, Novorossiysk, Russia

E-mail: zvygincevaav@mail.ru

Abstract. The object of the study is «Severnaya oil depot of the Lipetsk region». This article defines the occurrence and development of a fire in the tank and the dependence of a number of factors, also indicates the type of flammable liquid, the presence of an explosive concentration inside the tank, the place of the fire, the design features of the tank, the presence and condition of fire protection systems. Also, an assessment of the object from the position of fire hazard was carried out, the calculation of forces and means ensuring their timely and effective connection in cases of fire. The necessity of using modern extinguishing means to eliminate the resulting fire is shown.

1. Introduction
All oil and petroleum products storage facilities are fire and explosion hazardous; therefore, man-made accidents and incidents at the oil depot lead to significant material losses, and harm the environment, endangering human health and life.

The conducted analysis of fires suggests that the largest number of fires at oil refining facilities occurs precisely at oil storage facilities and/ or accounts for 48\% of all fires.

Analysis of statistical data by causes and places of occurrence. The main places of occurrence of fires were fires in tanks and pumping stations; the main causes of fires were both fire and repair work, and sparks of electrical installations. Fires in tank farms cause significant damage, and in some cases, loss of life.

2. Analysis of the occurrence and development of man-made fires
Analysis of statistical data by causes and places of occurrence. Statistics of fires at oil depots in the Russian Federation in accordance with figures 1-3.
Analysis of statistical data on the number of departures of fire departments of seasonal departures. The largest number of fires in tank farms occurred in the summer - this is due both to an increase in ambient temperature, which increases the explosion and fire hazard of petroleum products, and to welding and repair work carried out in the summer. At the same time, it is established that the most intensive fire departments work in the winter period. The table shows that the average duration of extinguishing a winter fire in the tank is 8.46 hours, while in autumn - 6.56 hours, in summer - 5.43 hours, in spring - 6.69 hours.

The longest duration of extinguishing a fire in tanks is in winter, and at ambient temperatures below -25 °C, the average duration of extinguishing is more than 10 hours. The data is presented in table 1.
Table 1. Statistical data.

| №  | Time of year                  | Average duration of fire extinguishing, h |
|----|------------------------------|------------------------------------------|
| 1  | spring                       | 6.69                                      |
| 2  | summer                       | 5.43                                      |
| 3  | autumn                       | 6.56                                      |
| 4  | winter                       | 8.46                                      |
| 5  | winter (when the air temperature is below -25 °C) | 10.10                                    |

Most of the fires that occurred in the winter were of a protracted nature and required the concentration of a significant amount of forces and resources. In all cases, the extinguishing was carried out by mobile fire equipment, since stationary installations for various reasons were not operational. The successful extinguishing of fires in tanks and tank farms, the elimination of accidents associated with them, to a decisive extent depend on the coordination of actions of the management bodies (divisions) of the fire protection garrisons and engineering and technical services of facilities for extinguishing fires at oil product storage facilities. The tank farm «Severnaya neftebaza», which will be discussed, is one of the most fire-hazardous objects in the garrison of the fire protection of the city of Lipetsk.

Conclusion: of all the above types of fires, the most catastrophic consequences will be fires from accidental destruction of tanks and leakage of petroleum products.

3. Brief geographical and socio-economic characteristics of the Lipetsk region

Further, the paper considers the organization of fire extinguishing in a tank with a volume of 5000 m³, as well as a group of tanks with a volume of 5000, 2500, 2000, 1000 m³ at the Lipetsk oil depot of «Severnaya Neftebaza», intended for receiving, storing and shipping dark and light petroleum products. This object is of particular importance, both for the Lipetsk region and for the city of Lipetsk. The facilities of the Lipetsk oil depot of JSC Severnaya Neftebaza were built and put into operation in 1930. Reconstruction of structures and technological equipment was carried out in 1958, 1986-1990. The functional purpose of the shop is the reception, storage and release of petroleum products. The workshop consists of: production sites, a railway draining and filling overpass, a pumping station for light and dark petroleum products, a tank park for light and dark petroleum products, an auto-filling overpass, an administrative building, an operator's office building, storage and household premises.

Lipetsk oil depot «Severnaya Neftebaza» is classified:

- for its intended purpose: distribution-designed for receiving petroleum products by all types of transport and selling petroleum products directly to consumers, mainly by road in bulk and in containers;
- by transport links: railway-receives petroleum products along the railway line (dead end) in bulk in tank cars and covered cars in containers;
- according to the total capacity of the containers: Category II – 20,000 to 50,000 m³;
- by cargo turnover: group 3 – 50,000 to 100,000 tons / year inclusive.

The facilities of the Lipetsk oil depot «Severnaya Neftebaza» were built and put into operation in 1930. Reconstruction of structures and technological equipment was carried out in 1958, 1986-1990. The functional purpose of the shop is the reception, storage and release of petroleum products. The workshop consists of: production sites, a railway draining and filling overpass, a pumping station for light and dark petroleum products, a tank park for light and dark petroleum products, an auto-filling overpass, an administrative building, an operator's office building, storage and household premises. The area of the territory is 94308 m². The operator's office building is one-story, the walls and partitions are brick, the roof is combined (covered with roofing material on a reinforced concrete screed). The exterior walls are lined with plastic material of the «Siding» type. The building of the pumping station of dark
petroleum products (household premises, workshop, and boiler room) is one-story, the walls and partitions are brick, the roof is combined (covered with roofing material on a reinforced concrete screed). The buildings of the warehouses are one-story, the walls and partitions are brick, the roof is combined (covered with roofing material on a reinforced concrete screed). Metal storage rooms are of the garage type. The boiler room is of frame-panel type, the walls are reinforced concrete, the roof is combined (covered with roofing material on ribbed reinforced concrete slabs), it is in non-working condition (the equipment has been dismantled).

The repair box is of a modular type, sheathed with sheet metal on metal arches.

Up to 10 railway tanks of light and dark petroleum products with a total volume of up to 600 m$^3$ can be located on the railway overpass at the same time. The fleet of light oil products has up to 20 thousand m$^3$ (diesel fuel, gasoline).

The features of the technological process at the oil depot are as follows:

- delivery of petroleum products by railway transport to the territory of the Kosyrevsky workshop;
- draining of petroleum products on the railway draining and filling overpass and receiving petroleum products for storage in its own tank farm;
- transportation of petroleum products through technological pipelines within the territory of the workshop;
- filling of petroleum products into tankers on their own automobile overpass.

Operations with petroleum products are carried out within its own territory.

The most dangerous production sites at the oil depot are:

- railway draining and filling overpass;
- tank farm of light oil products;
- pumping station for pumping light petroleum products;
- a platform for automated filling of petroleum products into fuel trucks.

The following petroleum products are received, stored and released at the oil depot: AI-80, Regular-92, Premium-95 gasoline, summer and winter diesel fuel, engine oils.

The fire protection system of the oil depot includes:

An administrative building-the installation of an automatic security and fire alarm system «Granit 16» (located in the security room).

There is a television surveillance system for the territory of the oil depot with the output of the image to the office of the head of the security department. Notification of personnel is carried out by means of an electric siren; the siren switch is located in the electrical panel under the stairwell of the first floor of the administrative building. There are 2 motor pumps in service: «Magirus» and MP-1600, in the summer they are located near fire reservoirs, in the winter – in the building of the fire station (table 1).

| №  | Name of the motor pump | Weight, kg | Pump supply | Pressure Maximum geometric suction height, m | Water intake time, sec |
|----|------------------------|------------|-------------|---------------------------------------------|------------------------|
| 1  | «Magirus»              | 189        | 74l/sec     | 15 bar                                      | 7.5                    | 30                     |
| 2  | MP-1600                | 660        | 1600 l/min  | 9 MPa                                       | 7                      | 40                     |

4. Technology and hardware design
The tank farm of dark petroleum products with a total capacity of 675 m$^3$ (520 tons) along the perimeter also has a collapse. The boning meets the requirements of the SNIP. The allocation of separate tanks for each type and brand of fuel allows you to receive any type of fuel from railway tanks and release it to
tank trucks at the same time.

Petroleum products are delivered by rail in tanks with a capacity of 60 m$^3$. At the same time, tanks arrive in the amount of one with one type of fuel or a group of two or five with different types of petroleum products. Up to 2 railway tanks of light oil products and 2 railway tanks of dark oil products are drained at the same time.

There is a two-way loudspeaker connection between the overpass and the metering and metering point. An audible alarm is provided when the maximum upper level is reached in tanks and tanks and «dry running».

Before draining railway tanks, it is necessary to close the gate on the storm sewer pipeline in the control well on the overpass and open the gate on the emergency pipeline to the emergency well equipped with a level sensor.

In the event of an emergency spill, the fuel will fill the trays of the trestle pallet and emergency wells to the level $h = 0.9$ m, after which the emergency pump will automatically turn on, the valve is always open on the suction and discharge lines of which, and will pump the fuel into the emergency tank, and from there by the same or mobile pump to the tanker.

Manual control of the emergency pump is provided from consoles installed on the overpass and the metering and metering point, as well as a lock is provided that excludes the operation of the pump in the absence of the pumped liquid in the pump housing, metal pallets for pumps, filters and valve covers are provided to collect possible spills and leaks along the flange connections.

Diesel fuel pumps are interchangeable (1 worker. 1 backup), they have common suction and discharge manifolds. Jumpers on the discharge and suction manifolds of the pumps provide:

- interchangeability of pumps for pumping gasoline in case of failure of one of them;
- the possibility of pumping any oil product in the absence of electricity by a pump powered by a second power source — a diesel electric installation.

The strapping of the pumps is made in such a way that, if necessary, tank draining operations can be carried out through the same pipe. The working pumps are controlled from the consoles installed on the draining and filling railway overpass.

The network of technological pipelines provides for the following operations:

- discharge of railway tanks;
- storage of light oil products in tanks;
- storage of dark petroleum products in tanks;
- filling in tankers.

The number of pipelines for the reception and release of petroleum products is accepted, based on the number of groups of sold petroleum products and the simultaneity of the operations carried out. The diameter of the pipelines is accepted according to the maximum performance of the pumping units. Manually operated valves are used as shut-off valves. On pipelines supplying petroleum products to filling plants, pumps have drainage fittings DY 20 with shut-off valves for draining the remnants of petroleum products or washing water. For emptying pipelines that supply petroleum products from the railway overpass to the pumping station, as well as to the tank farm, shut-off valves are provided on the combined pipeline (suction collector) located in the pumping station. Loading ramps are designed for the release of petroleum products to tankers. On the loading ramp for the supply of gasoline and diesel fuel, filling systems are installed in ASN-5M type tankers with a canopy.

Gasoline-LVZH, which are mixtures of light hydrocarbons. Gasoline during gorenje warms up in depth, forming an ever-increasing homothermal layer. The growth rate of the heated layer is 0.7 m/h, the temperature of the heated layer is 80-100 °C, and the flame temperature is 1200 °C.

Gasoline AI-80-a mixture with alcohols - the composition of the mixture % (wt): gasoline AI-80-8 %, isobutanol - 6-8 %, methanol - 14.5-15 %, water 0.08-0.15 %, $T_{vsp}$ – 35 °C, $T_{svosp}$ - 375 °C. The
temperature limit of flame propagation: lower - 35 °C, upper - 17 °C.
Gasoline AI-92-density 729 kg/m³, Tvsp. – 38 °C, Tsvosp - 435 °C. The temperature limit of flame propagation: lower - 38 °C, upper - 5 °C.
Gasoline AI-95-density 736.2 kg/m³, Tvsp. – 37 °C, Tsvosp - 380 °C. The temperature limit of flame propagation: lower - 37 °C, upper - 10 °C.
Diesel fuel - Tkip. - 150-322 °C, Tvsp. - 37-100 °C, Tsvosp-210-370 °C, Tsvosp. - - 122 °C.
Extinguishing media:
- in large spills – sprayed water, foam, PSB powder;
- in the premises-volumetric extinguishing.

At the facility there is a mobile tank based on the ZIL-130 vehicle and a tank trailer with a foaming agent PO-6K with a volume of 4000 liters each, which are located in a warm box.
All buildings, structures and the tank farm are equipped with primary fire extinguishing means according to SNiP 2.11.03-93 «Warehouses of oil and petroleum products. Fire safety standards».
This object is protected by «Severnaya Neftebaza» with a population of 3 people, it is armed with a fire truck AC-40(131)63A and MP-1600 («Magirus»). In addition, the object is protected by the State Institution «1 detachment of the federal fire service for the Lipetsk region» located on the territory of the city of Lipetsk in the area of the exit of the PCH, in the duty calculation of which there are: APP(3221); AC-40 (130)63B; AC-3.0-40(43206); AC-5.0-40(43114); AL-30 (43114).
In the event of a fire at the Lipetsk oil depot of JSC "Severnaya Neftebaza", according to the departure schedule and the plan for attracting forces and means to extinguish fires in the Lipetsk region, fire departments arrive at the facility by calling number 3, in the case of a prolonged fire, the forces and means of the OPS-6 stronghold of the city of Mud are attracted. The tanks store gasoline AI-80, AI-92 with a flash point of less than 28 °C. The pumping and pumping of gasoline from the tanks is carried out by the pumping station of the tank farm from the drain-filling overpasses. If a fire occurs, it is possible to pump gasoline from the tanks into the tank of fuel trucks or railway tanks, as well as neighboring tank groups. All the tanks of the light oil products fleet are located in two groups, limited by collapse. In group № 1 there are reservoirs № 1, 2, 3, 4. In group № 2 there are reservoirs № 1, 2, 4, 5.
Figure 4. The general plan «Severnaya neftebaza».

Table 3. Extract from the plan to attract forces and means of the OPS support point № 6 from the city of Yelets to the nearest districts of the Lipetsk region to extinguish large fires

| Attracted forces and means | Quantity, units | Travel time (min) |
|---------------------------|-----------------|------------------|
| AC-40 (131)137            | 1               | 33               |
| AC-40 (130)63B            | 1               | 33               |
| AR-2 (131)                | 1               | 33               |
| PNS-110 (131)             | 1               | 33               |

Total: 2 AC, 1 AR, 1 PNS

The perimeter of the embankment of the park is 626 m with an embankment height of 1.5 m and a width of 0.8-1 m. The collapse is made of soil. The distance between the tanks in group № 1 is: between RVS № 3 and RVS № 4 – 26 m; between RVS № 3 and RVS № 1 -27 m; between RVS № 3 and RVS № 2-35 m. Each tank of the light oil products fleet has a stationary foam fire extinguishing system with the output of dry pipes. The dry pipes are located within the boning area. The supply of the foaming agent solution is carried out from the mobile fire equipment on table 3.

5. Forecasting and evaluation
As an option for a possible fire in the diploma project, I accepted a fire in tank № 3 of the tank farm for storing light petroleum products of the Lipetsk oil depot «Severnaya neftebaza».
Tank № 3 of the RVS-5000 is located in the group: tank № 1 - 2500 m$^3$ of AI-80 gasoline, tank № 2-2000 m$^3$ of AI-80 gasoline, tank № 4-1000 m$^3$ of A-92 gasoline.

Structurally, tank № 3 is a vertical cylinder made of steel sheets and has the following dimensions:

- the diameter of the tank is 23 m;
- the height of the tank on the top of the roof is 12 m;
- circumference of 72 m;
- the area of the evaporation mirror is 408 m$^2$.

The tank farm has an earthen collapse along the perimeter of each group of ground tanks according to Snip 2.11. 03-93 «Warehouses of oil and petroleum products. Fire safety standards». The valves on the technological pipelines of these tanks are located in underground wells inside the collapses.

Tank № 3 stores gasoline A-92, which has the following characteristics:

- self-ignition temperature + 435 °C;
- flame temperature + 1100 °C;
- the rate of increase of the heated layer is 0.08 m·h$^{-1}$;
- density of 729.5 kg·m$^3$;
- average burnout rate of 0.3 m·h$^{-1}$;
- average heating speed of 0.1 m·h$^{-1}$;
- lower temperature limit of flame propagation (-38 °C);
- the upper temperature limit of flame propagation (+5°C).

We assume that the fire is in tank № 3 with subsequent spread to neighboring tanks within the group.

Initial data: as a result of an explosion (the most likely situation from the practice of fire extinguishing), a partial destruction and collapse of the roof inside the tank occurs, followed by the burning of liquid on the entire free surface of the tank mirror area.

Thus, we come to the conclusion: this condition satisfies the fact that the neighboring tank does not lose its bearing capacity from the impact of radiant energy in a fire before the trunks are fed to cool them. The burning rate of flammable liquids exceeds the heating rate, and, consequently, there will be no release of petroleum products. The temperature on the wall of the burning tank below the level of the liquid mirror cannot exceed much the temperature of the liquid itself, as a result of which, at a high level of burning liquid in the tank, the walls do not deform. And vice versa, the wall of the burning tank above the level of the mirror of the combustible liquid under the influence of the flame for the first time after a minute of free burning becomes very hot and begins to deform. In real fire conditions, after 15-20 minutes from the start of the fire, the free side of the metal tank will warm up and deform if no measures are taken to cool it.

6. Conclusion

As a result of the work done, during the implementation of the diploma project, on forecasting and assessing the situation in the event of a fire in a group of tanks №1, №2, №3, №4 we come to the conclusion that extinguishing these tanks is particularly difficult, both with the involvement of a large number of forces and means, and ensuring the safety of participants in extinguishing and fire equipment. At the same time, such fires lead to the destruction of a large amount of petroleum products, production and technological equipment, cause significant damage and create an extremely unfavorable environmental situation. This is evidenced by the experience of extinguishing such fires at similar facilities in Russia.

Conclusion: the use of the UKTP «Blizzard» when extinguishing, allows you to extinguish fires of petroleum products in large-capacity tanks with great effect, with the least danger to personnel.

It is offered:
• the administration of the oil depot should loop a dead-end pipeline with a diameter of 100 mm for the required water output of 58 l/sec;
• the administration of the oil depot to increase the volume of fire reservoirs № 1, № 2, № 4, № 5 up to 200, 300, 250 m³, respectively;
• to the fire garrison of Lipetsk to purchase installations of combined fire extinguishing «Blizzard» 10.20.30;
• to offer the administration of the facility to mount equipment for layer-by-layer extinguishing, large-capacity tanks RVS – 3000-RVS-5000.

References
[1] Ammon D C and Cochran SR 1987 Corrective action technologies: Congress Baltimore 84 611-6
[2] Zabetakis M G 1965 Bulletin 627 Bureau of Mines Washington 121
[3] Skripachev V O et al. 2020 Remote Sensing 12(371) 1-31
[4] Mezhova L, Lugovskoy A, Gladkiy Yu, Glazyeva A, Sushkova O, Vampilova L, Sokolova A and Lugovskyal W 2019 South of Russia: ecology, development 14(4) 98-110 10.18470/1992-1098-2019-4-98-110
[5] Skripachev V O et al. 2020 Remote Sensing Applications: Society and Environment 19 100328
[6] Tereshchenko M A, Bychenkov V I and Mozgovoi N V 2009 Thermal Engineering 566 522-5
[7] Zvyagintseva A V 2017 Alternative Energy and Ecology 16-8 (228-30) 89-103
[8] Zvyagintseva A V, Tenkaeva A S and Mozgovoy N V 2015 Bulletin of the Samara Scientific Center of the Russian Academy of Sciences 17(5) 276-82
[9] Dolzhnenkova V V and Zvyagintseva A V 2015 Bulletin of the Samara Scientific Center of the Russian Academy of Sciences 17(6) 70-81
[10] Neklyudov L M, Morozov O M, Kulish V G, Zhurba V I, Khaimovich P A and Galitskiy A G 2011 International Journal of Hydrogen Energy 361 1192-5
[11] Smith C A 1985 Fire Prot 11 14-6
[12] Hoshino Makoto and Hayashi Koji 1990 Bulletin Japan Association Fire Science and Engineering 39(2) 9-17
[13] Li J, Li W, Karimi I A and Srinivasan R 2007 AIChE Journal 53(10) 2659-80
[14] Li W, Hui C W, Hua B and Tong Z 2002 Industrial & Engineering Chemistry Research 41(26) 6723-34
[15] Reddy P C, Karimi I A and Srinivasan R 2004 AIChE Journal 50(6) 1177-97
[16] Zvyagintseva A V and Samofalova A S 2020 AIP Conference Proceedings 7 Serie: Physics, Technology, Innovations 2313 060020
[17] Zvyagintseva A V 2020 Bulletin of the Russian Academy of Sciences: Physics 849 1097-9
[18] Zvyagintseva A V 2020 IOP Conference Series: Materials Science and Engineering 919 62054
[19] Zvyagintseva A V 2020 International Journal of Hydrogen Energy 45-6 24991-5001
[20] Zvyagintseva A V and Kravtsova Y G 2007 NATO Security through Science Series A: Chemistry and Biology 661-4
[21] Zvyagintseva A V and Kravtsova Y G 2007 NATO Security through Science Series A: Chemistry and Biology 665-9
[22] Gulida E M and Kozak Ya Ya 2020 Bulletin of Prydniprovs’ka State Academy of Civil Engineering and Architecture DOI:10.30838/J.BPSACEA.2312.241120.69.700
[23] Degaev E N 2018 MATEC Web of Conferences 193 02032
[24] Korolchenko D A, Degaev E N and Sharovarnikov A F 2015 2nd International Conference on Material Engineering and Application (ICMEA) 17-22
[25] Kattge Aand Degaev J N 2016 Zeitschrift für Forschung, Technik und Management im Brandschutz 1 150-2
[26] Zvyagintseva A V 2008 NATO Science for Peace and Security Series C: Environmental Security Part F2 437-42
[27] Kulneva V V, Zvyagintseva A V, Sazonova S A and Akamsina N V 2020
Journal of Physics: Conference Series 22077.

[28] Zvyagintseva A V, Kulneva V V and Sazonova S A 2020 IOP Conference Series: Earth and Environmental Science 052047

[29] Zvyagintseva A V, Kulneva V V and Sazonova S A 2020 IOP Conference Series: Materials Science and Engineering 919(6) 062053

[30] Zvyagintseva A V, Samofalova A S, Sazonova S A and Kulneva V V 2020 Journal of Physics:Conference Series 1679(2) 022076

[31] Kulneva V V, Zvyagintseva A V and Sazonova S A 2021 IOP Conference Series: Earth and Environmental Science 666(2) 022035

[32] Xiang Z M, Guang M L and Chao L 2016 International Conference on Intelligent Manufacturing and Materials (ICIMM) DOI: 10.12783/dtmse/icimm 2016/6244

[33] Turekova I, Balog Kand Półka M 2012 Bezpieczeństwo i Technika Pozarnicza 25 29-36

[34] Lugovskoy A M, Mezhova L A, Lopatnikov D L and Sushkova O Y 2020 IOP Conference Series: Earth and Environmental Science 012076

[35] Mezhova L A, Sagova Z M, Lugovsky A M, Gorbunov V Sand Sushkova O Y 2020 IOP Conference Series: Earth and Environmental Science: History, Contemporary Issues and Prospects 012127