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Elimination of the consequences of an emergency situation at a fire and explosion hazardous facility with the presence of flammable liquids

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Abstract. The safety of technological processes and order of elimination of the emergency situations arising on fire and explosion hazardous objects with availability of flammable liquids and vapours, the reasons and the mechanism of appearance of an emergency situation is considered. The analysis of process of emergence of an emergency situation on potentially hazardous production facility in Russia and St. Petersburg is made. Mechanisms of development of an emergency on the object containing fire and explosion hazardous and easily flammable liquids at various scenarios of passing of an emergency situation are constructed: floods, ignitions and manifestations of secondary dangerous factors. Priority tasks for carrying out effective and safe mitigation of consequences of the arisen emergency situation are designated. The technology and models elimination of an emergency situation on the object containing fire and explosion hazardous and easily flammable liquids on the example of explosion with the subsequent burning of the gas mixture formed in a consequence of evaporation of oil products in reservoir park of Ruchi oil depot in the city of St. Petersburg is developed. Recommendations for the officials controlling actions for elimination of an emergency situation on this object are developed.

1 Introduction

Today, the world community pays great attention to oil and gas production and processing enterprises, as well as storage and transportation facilities [1-3]. Since they are explosive objects, the occurrence of an emergency situation on them can incur not only significant economic losses for the state, but also lead to an environmental and social disaster with a large number of human victims [4-7].

In this regard, these facilities should be subject to strict control in the field of industrial and especially fire safety [8]. The main emergency that can occur at these facilities is the occurrence of a fire, the main danger of which is that it can develop unpredictably [9, 10].

At the moment, the experience of past accidents at enterprises with flammable liquids is being considered in detail and actively, and the results of emergency management are being analyzed [11, 12]. Innovative ideas are often put forward on how to prevent such accidents, as well as on risk modeling and management [13-15]. Considerations about the management of emergency situations at the enterprises of flammable liquids are also popular [16-18]. The ways of liquidation of consequences of accidents and emergency situations of the considered character are offered for discussion [19, 20].

2 Method of research

Currently, there is a tendency of increasing attention to ensure the safety of not only oil and gas producing and processing enterprises, but also the storage and transportation, which represent a fire and explosion hazardous facilities [21-23]. Therefore, the problem pointed to the need to identify and justify the conditions for the safe and efficient management of actions on liquidation of emergency situations and preventive actions to prevent occurrence of emergency situations at potentially hazardous facilities that contain explosive and flammable liquids [24].

According to the results of the study of thematic literature, legal documents and acts as well as other related documents that provide comprehensive data on the topic, the analysis of the process of occurrence of such emergencies was carried out [25, 26]. Also, the analytical picture was supplemented by a detailed study and generalization of previous experience in the prevention and elimination of such situations at the facility containing explosive and flammable liquids [27].

After abstracting the potentially hazardous properties of substances and technical features of storage facilities, and their subsequent generalization with a variety of objects on which hazardous substances can be stored, an exhaustive classification of flammable and explosive

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liquids and their containing warehouses, supplemented by already available at the moment classifiers [28, 29].
Concretization of factors and mechanisms of emergency situations with various negative impacts of the environment and the human factor, together with the formalization of such incidents and their consequences, formed the basis for the development of a model of emergency response at the facility containing explosive and flammable liquids [30, 31].

3 Results

The objects of the simulation were taken following the tanks at the tank farm " Ruchi " in the city of Saint-Petersburg: tank №86 group of tanks №2, tanks №69, 70, 74, 75 group of tanks №10, as well as tank №1 with fire diking according to the characteristics of the tank farm OOO "PTK-TERMINAL" (table 1).

Units of measurement:

- l – litre;
- m – meter;
- s – second.

3.1 Example of application of the technique

As an example of application of the fire extinguishing modeling technique on the object containing explosive and flammable liquids, the variant of extinguishing the tank №86 of the group of tanks №2 is considered.
Intensity of water supply for cooling the burning tank ($J_{req.brn.}$):

$$J_{req.brn.} = 0{,}8\frac{l \cdot m^2}{s}. \quad (1)$$

Intensity of water supply for cooling the adjacent tank ($J_{req.adj.}$):

$$J_{req.adj.} = 0{,}3\frac{l \cdot m^2}{s}. \quad (2)$$

The intensity of the supply of the foam solution to extinguish gasoline ($J_{req.foam.}$):

$$J_{req.\,foam} = 0{,}08\frac{l \cdot m^2}{s}. \quad (3)$$

Tank characteristics:

- type – RVS-5000;
- height (h_t) – 12 m;
- diameter (d_t) – 22.8 m;
- surface area (S) – 408 m2;
- circumference (P_t) – 72 m.

Required water consumption for cooling the burning tank ($Q_{cool.brn.}$):

$$Q_{cool.brn.} = P_t \cdot J_{req.brn.} = 72 \cdot 0{,}8 = 57{,}6\frac{l}{s}, \quad (4)$$

where:

- P_t – circumference;
- $J_{req.brn.}$ – intensity of water supply for cooling the adjacent tank [32].

Required water consumption for cooling the adjacent tank ($Q_{cool.adj.}$):

$$Q_{cool.adj.} = 0{,}5 \cdot P_t \cdot J_{req.adj.} \cdot N_{t.} = = 0{,}5 \cdot 72 \cdot 0{,}3 \cdot 3 = 32{,}4\frac{l}{s}, \quad (5)$$

where:

- P_t – circumference;
- $J_{req.adj.}$ – intensity of water supply for cooling the adjacent tank;
- N_t – the number of nozzles for cooling nearby tank [32].

The total consumption of water for cooling tanks ($Q_{cool.}$):

$$Q_{cool.} = Q_{cool.brn.} + Q_{cool.adj.} = = 57{,}6 + 32{,}4 = 90\frac{l}{s}, \quad (6)$$

where:

- $Q_{cool.brn.}$ – required water consumption for cooling the burning tank;

Table 1. Characterization of the tank farm, OOO "PTK-TERMINAL».

Group, №	**Tank, №**	**Tank V (m^3)**	**Surface area S (m^2)**	**h_t (m)**	**Type of oil product**	**The number of nozzles for cooling burning tank**	**The number of nozzles for cooling nearby tank**	**Number of GPS to extinguish the burning tank**
1	1, 2, 3	5000	408	12	Gasoline	6	3	6
2	86-89	5000	408	12	Gasoline	6	3	6
10	69	200	40	6.9	high-octane gasoline	3	2	1
	74	400	57	8.4		3	2	1
	70, 75	400	57	8.4		3	2	1

- $Q_{cool.adj.}$ – required water consumption for cooling the adjacent tank [32].

Required number of nozzles for cooling the burning tank ($N_{nz.cool.brn.}$):

$$N_{nz.cool.brn.} = \frac{Q_{cool.brn.}}{q_{nz.brn.}} = \frac{57,6}{21} = = 3\, nozzles\, RS - 70\,(two\ per\ \tan k) , \quad (7)$$

where:

- $Q_{cool.brn.}$ – required water consumption for cooling the burning tank;
- $q_{nz.brn.}$ – water consumption for cooling the burning tank (one nozzle PLS-20) [32].

Required number of nozzles for cooling adjacent tanks ($N_{nz.cool.adj.}$):

$$N_{nz.cool.adj.} = \frac{Q_{cool.adj.}}{q_{nz.adj.}} = \frac{32,4}{7} = = 6\, nozzles\, RS - 70\,(two\ per\ \tan k) , \quad (8)$$

where:

- $Q_{cool.adj.}$ – required water consumption for cooling the burning tank;
- $q_{nz.adj.}$ – water consumption for cooling the burning tank (one nozzle RS-70) [32].

Actual water consumption per tank (Q_{act}):

$$Q_{act.} = N_{nz.cool.brn.} \cdot q_{nz.brn.} + N_{nz.cool.adj.} \cdot q_{nz.adj.} = = 3 \cdot 21 + 6 \cdot 7 = 105 \frac{l}{s} > Q_{req.} , \quad (9)$$

where:

- $N_{nz.cool.brn.}$ – required number of nozzles for cooling the burning tank;
- $q_{nz.brn.}$ – water consumption for cooling the burning tank (one nozzle PLS-20);
- $N_{nz.cool.adj.}$ – required number of nozzles for cooling adjacent tanks;
- $q_{nz.adj.}$ – water consumption for cooling the burning tank (one nozzle RS-70) [32].

Number of GPS-600 to extinguish the burning tank ($N_{gps.ext.}$):

$$N_{gps.ext.} = S \cdot \frac{J_{req.foam}}{q_{foam.gps.}} = 408 \cdot \frac{0,08}{6} = 6\, GPS - 600 , \quad (10)$$

where:

- S – surface area;
- $J_{req.foam}$ – the intensity of the supply of the foam solution to extinguish gasoline;
- $Q_{foam.gps.}$ – foam consumption for extinguish the burning tank [32].

The required quantity of foam concentrate to extinguish a fire ($W_{f.c.ext.}$):

$$W_{f.c.ext.} = N_{gps.ext.} \cdot q_{gps.} \cdot K_s \cdot t_{ext.} \cdot 60 = = 6 \cdot 0,36 \cdot 3 \cdot 15 \cdot 60 = 5832 l , \quad (11)$$

where:

- $N_{gps.ext.}$ – Number of GPS-600 to extinguish the burning tank;
- $q_{gps.}$ – foam consumption for extinguish the fire;
- K_s – coefficient;
- t_{ext}. – extinguish time [32].

The required amount of foam concentrate to extinguish a possible oil spill in the fire diking (2 GPS-600) ($W_{f.c.dik.}$)

$$W_{f.c.dik.} = N_{gps.ext.(2)} \cdot q_{gps.} \cdot K_s \cdot t_{ext.} \cdot 60 = = 2 \cdot 0,36 \cdot 3 \cdot 15 \cdot 60 = 1994 l , \quad (12)$$

where:

- $N_{gps.ext.(2)}$ – 2 of GPS-600 to extinguish the burning tank;
- $q_{gps.}$ – foam consumption for extinguish the fire;
- K_s – coefficient;
- t_{ext}. – extinguish time [32].

The total amount of foaming agent ($W_{f.c.total}$):

$$W_{f.c.total} = W_{f.c.ext.} + W_{f.c.dik.} = 5832 + 1944 = 7776 l , \quad (13)$$

where:

- $W_{f.c.ext.}$ – the required quantity of foam concentrate to extinguish a fire;
- $W_{f.c.dik.}$ – the required amount of foam concentrate to extinguish a possible oil spill in the fire diking (2 GPS-600) [32].

Water consumption required for 8 operationing GPS-600 (Q_{ext}):

$$Q_{ext} = N_{gps.wtr.} \cdot q_{gps.wtr.} = 8 \cdot 5,64 = 45 \frac{l}{s} , \quad (14)$$

where:

- $N_{gps.wtr.(2)}$ – 8 of GPS-600;
- $q_{gps.wtr.}$ – water consumption for GPS-600 [32].

Total water consumption (Q_{total}):

$$Q_{total} = Q_{cool.} + Q_{ext.} = 111 + 45 = 156 \frac{l}{s} , \quad (15)$$

where:

- $Q_{cool.}$ – consumption of water for cooling;
- $Q_{ext.}$ – water consumption for 8 GPS-600 [32].

The required number of compartments to extinguish the fire in the fire diking ($N_{cp.ext.dik.}$):

$$N_{cp.ext.dik.} = \frac{N_{ext.}}{n_{cp.}} = \frac{2}{1} = 2\ squads , \quad (16)$$

where:

- $N_{ext.}$ – number of extinguish compartments;
- $n_{cp.}$ – number of compartments [32].

The trunks of the GPS-600 to extinguish a burning tank will be fed with the help of ladders. In addition, for

Table 2. Summary table of calculation of forces and means for fire extinguishing.

Tank №	The required flow rate of fire extinguishing substances, $l\cdot s^{-1}$	The number of devices of the extinguishing substances, pcs.	Required stock of foaming agent, l	Number of fire engines, main / special pcs.	Limit distances for water supply, m	Number of personnel, number of units of GSPS ppl/pcs.
№86	45 + 111	8 GPS-600 + 3 PLS-20 + 6 nozzles «A»	7776	12 / 3	50	60/11
№№ 69, 70, 74, 75	39.5 + 168.8	7 GPS-600 + 8 PLS-20	6804	15 / 3	50	72/14
№1	259.4 + 79.2	6 GPS-600 + 12 GPS-2000 + 3 PLS-20 + 4 nozzles «A»	44712	15 / 3	50	72/14

the preparation and holding of the foam attack need 3 offices.

Required number of compartments for cooling ($N_{cp.ext.}$):

$$N_{cp.ext.} = N_{foam.} + \frac{N_{unbrn.}}{n_{cp.}} = 3 + \frac{6}{2} = 6 \ squads, \quad (17)$$

where:

- $N_{foam.}$ – number of compartments for foam attack;
- $N_{unbrn.}$ – number of not-burning tanks;
- $n_{cp.}$ – number of compartments [32].

The required number of compartments for fire extinguishing and protection ($N_{cp.total}$):

$$N_{cp.total} = N_{ext.} + N_{cp.exp.} + N_{res.} = \\ = 5 + 6 + 4 = 15 \ squads, \quad (18)$$

where:

- $N_{ext.}$ – number of extinguish compartments;
- $N_{cp.ext.}$ – number of compartments for cooling;
- $N_{res.}$ – number of reserve compartments [32].

3.2 Closure

Similarly, fire extinguishing models were developed for tanks №69, 70, 74, 75 of the group of tanks №10, as well as for the tank №1 with fire diking, the simulation results are shown in table 2.

Forecast of fire in the RVS-5000 №86: as a result of spontaneous combustion of pyrophoric deposits of petroleum products there was an outbreak of steam-air mixture in the area of respiratory valves, burns over the entire surface area S=408 m2.

Forecast for the development of a fire in RVS-200 No. 69 and RVS-400 №№ 70, 74, 75: as a result of the overflow of gasoline was flash steam-air mixture in the area of respiratory valves, burning mirrors in 4 tanks S=211 m2.

Forecast of fire in the RVS-5000 №1: as a result of a lightning strike, there was an outbreak of steam-air mixture in the area of breathing valves, burns over the entire area of the mirror S=408 m2 with the subsequent release of petroleum products in fire diking Ffd=3000 m2.

4 Discussion

The developed algorithm for creating a model of emergency response at a hazardous production facility allows to determine the number and procedure of forces and means of fire-rescue units and fire protection units, which was shown by the example of emergency modeling at the tanks of the oil depot "Ruchi", OOO "PTK-TERMINAL", in St. Petersburg.

Explosive objects with the presence of flammable liquids are used everywhere today. In view of this, the problem of security on them will exist as long as there are such objects [33, 34]. Further work on the topic under consideration involves the refinement and unification of the modeling algorithm, and then its specification when considering individual explosive objects in order to develop a set of measures to improve their security.

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