PROBABILITY OF IGNITION SOURCE OCCURRENCE AT HAZARDOUS OIL AND GAS PRODUCTION FACILITIES

Malik Abdullayev, Samira Mansurova, Sevda Shikhiyeva,
Fahmin Azizli, Hecer Ismayilova

•

Azerbaijan State Oil and Industry University
malik.abdullayev.52@mail.ru
mansur_s74@mail.ru
sevda.shikhiyeva.az@gmail.com
fehminnecmin@gmail.com
ismayilova.hecer@bk.ru

Abstract

It is known that the final result of risk analysis is the determination of the consequences of explosions and fires at a hazardous facility. One of the most important indicators used in performing a risk analysis is the probability of occurrence of an ignition source.
The presented work proposes a method for taking into account the probability of mixture ignition. It is indicated that such an assessment is more plausible and consistent with observations and does not contradict the need for personnel participation in localizing an emergency release.

Keywords: emergency release, risk, ignition source, probability, oil spill, gas-air mixture

Introduction

The final stage of risk analysis is to determine the consequences of explosions and fires at a hazardous production facility (HPF). The final result of a risk analysis can be obtained if there is a reliable base of initial data, reference (statistical) data, a meaningful physical model of the processes of explosions and fires, and a completed mathematical model of analysis.

The input data includes the following:

- List of blocks included in the HPF;
- Technological diagram of connecting blocks;
- Performance of installations consisting of analyzed blocks;
- Characteristics of the blocks, including their volume, operating pressure, degree of filling, name of the products filling the block;
- Distribution of personnel on the territory of the hazardous production facility (HPF).

Reference data includes:

- Physico-chemical properties of the products filling the blocks, including properties characterizing their explosion and fire hazard;
- Statistical data on partial and complete depressurization of blocks;
- Data on lightning activity in the area where hazardous production facilities are located (HPF).

One of the most important indicators used in performing a risk analysis is the "probability of occurrence of an ignition source" indicator.

Table 1, based on data from [1], presents the distribution of fires and explosions by ignition sources.

Distribution by ignition sources.

The share of explosions and fires initiated by lightning discharges is 9.7%.

To determine the probability of an ignition source, we use the methodology of Appendix 3 GOST 12.1.004–91 [2] for calculating the probability of a direct lightning strike on an object, taking into account other ignition sources.

For a stationary object, the probability of a direct impact is determined by the relationship

$$P_{is} = 1\text{-}e^{-N_{ls}\,t} \quad (1)$$

where, N_{ls} is the number of direct lightning strikes into an object in 1 year; t-duration of the observation period equal to 1 year.

Table 1: *The distribution of fires and explosions by ignition sources*

İgnition source	Total quantity, pcs.	%
Hot work:	10	32.3
Mechanical sparks	5	16,1
Fire technological installations;	3	9,7
Lightning strike;	3	9,7
Electric sparks;	4	12,5
External ignition sources;	2	6,5
Static electricity discharge;	1	3,2
Vehicle;	1	3,2
Careless handling of fire;	1	3,2
Other.	1	3,2
Total	**31**	**100**

For round objects

$$N_{ls} = (2R+6H)^2 \cdot n_{ls} \cdot 10^{-6} \quad (2)$$

Here R - is the radius of the cloud within the boundaries of the lower concentration flammable limit (LCFL) or the radius of the flammable liquid spill, m; H - is the height of the cloud, equal to R_{LCFL} for a hemisphere with a ground-based gas release, m; during a spill FL-N=0. n_{ls} is the average number of lightning strikes per 1 km² of the earth's surface [3, 4].

Let's perform a control calculation to determine the number of direct lightning strikes into an object occupying an area of territory that accounts for 1 lightning strike per year. This area is equal to f1=1000000/3=333000 m². Base radius R= $(333000/3.14)^{0.5}$=325.6 m. For control calculation we take H=R. Then $N_{ls} = (2\cdot325.6+6\cdot325.6)^2 \cdot 3\cdot10^{-6} = 20.35$ 1/year. The number of strikes of a discharge into an object occupying an area with the number of lightning strikes equal to 1 per year turns out to be 20.35 times greater than the number of lightning strikes.

To determine the probability of lightning strikes from a cloud of gas-air mixture, it is necessary to adjust the N_{ls} dependence taking into account the lack of electrical conductivity of the gas-air mixture. To do this, we eliminate the height part by equating the H term of the equation to zero. Then the equation for an object that does not generate electricity is transformed to the form:

$$N_{ls} = (2R)^2 \cdot n_{ls} \cdot 10^{-6}$$

When studying the possibility of igniting a cloud of a gas-air mixture (GAM), we take R = R_{LCFL}, and when studying the possibility of a liquid spill, R = D/2, where D - is the diameter of its spill.

To check the obtained dependence, we perform a control calculation. Let's find the number of lightning strikes into a hot water cloud with a radius of the lower concentration limit of ignition (LCFL) equal to 325.6 m.

$$N_{ls} = (2\cdot325.6)^2 \cdot 3\cdot10^{-6} = 1.27 \text{ 1/year}$$

The non-convergence of the result reaches 27%. The source of calculation error is the incorrect representation of the object area in the form of a square of twice the radius of the

LCFL. A more accurate value of N_{Is} can be obtained after specifying the area of projection of the GAM cloud onto the Earth's surface in the form

$$N_{Is} = \pi \cdot R^2 \cdot n_{Is} \cdot 10^{-6}$$

Check: N_{Is}=3.14·325.6² ·3·10⁻⁶ =0.9992 1/year.

To take into account other ignition sources, we introduce an additional factor k=10 into the N_{Is} equations. Then it is converted to mean

$$N_{Is} = 10\pi \cdot R^2 \cdot n_{Is} \cdot 10^{-6}$$

After substituting the obtained value of N_{Is} into the original equation, we finally obtain a formula for calculating the probability of the appearance of an ignition source affecting a cloud of hot water or a spill of flammable liquid within the boundaries of the possible ignition of an object:

$$P_{is} = 1-e^{-x}$$

where,

$$x = 10\pi \cdot R^2 \cdot n_{Is} \cdot \tau \cdot 10^{-6}, \quad (4)$$

Let's plot the dependence $P_{is} = f \cdot (R_{LCFL})$ at $x = 10\pi \cdot R^2_{LSFL} \cdot n_{Is} \cdot \tau \cdot 10^{-6}$.

Analysis of the graph presented in Figure 1 allows us to draw the following conclusions:

1. The larger the affected object (GAM clouds of hot water or a spill of hot liquid), the more realistic the completion of an emergency release by ignition of a flammable substance.

2. Small targets are characterized by a low probability of ignition of the emission.

3. The dependence of the probability of the appearance of an ignition source Reese on the size of the affected object allows us to establish the probability of distribution of the consequences of the release according to accident scenarios. The release may result in combustion or dispersion. Possibility of ignition or dispersion. The probability of ignition is equal to the probability of the appearance of an ignition source, that is, $P_{ignit} = R_{is}$. The probability of release dissipation is equal to the difference $P_{disp} = 1-P_{is}$.

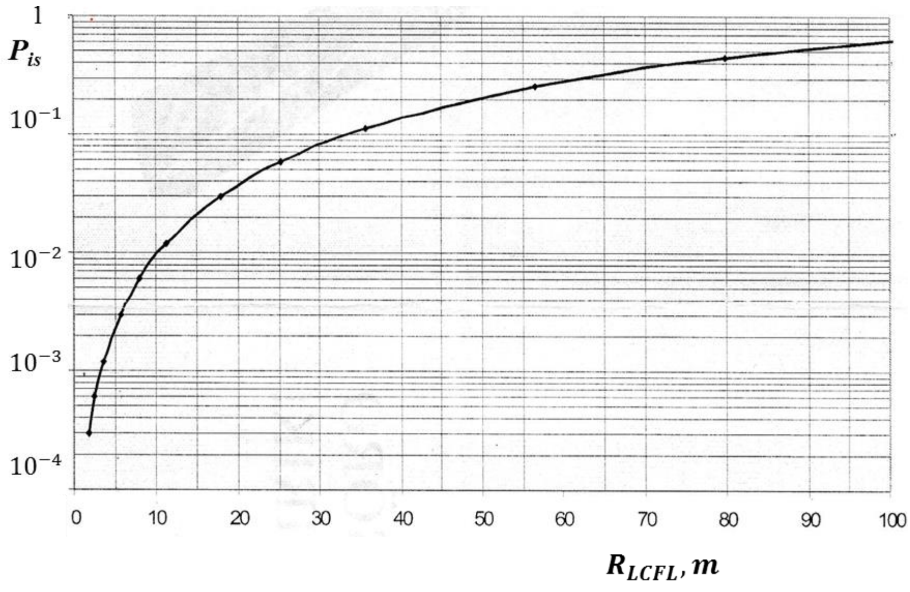

Figure 1: *Probability of the appearance of an ignition source*

4. The probability distribution of accident scenarios, adopted in GOST R 12.3.047–98, is incorrect in that this distribution does not depend on the size of the affected object.

Let us find the dependence of the frequency of implementation of the scenario with ignition of the emission on the size of the hot water cloud or the diameter of the gas liquid spill (GAM):

$$N_{ignit} = N_{depr} \cdot P_{is} \quad (5)$$

where

N_{ignit} is the ignition frequency of hazardous product emissions, 1/year;

N_{depr} - frequency of unit depressurization, 1/year;

R_{is} - is the probability of manifestation of the ignition source, fraction.

The release frequency in accordance with the database [5] is: with partial depressurization - $1 \cdot 10^{-4}$ 1/year, with complete depressurization - $1 \cdot 10^{-5}$ 1/year. When using the Methodology database [6], the specified values must be adjusted.

The probability of a fire scenario occurring depends on the size of the target. With partial depressurization, the emission volume is less than with complete depressurization. In accordance with this, the probability of ignition of the emission during partial depressurization is less than during complete depressurization. Let us assume that with partial depressurization the volume of gas in the release is 10 m^3, and with complete depressurization it is 1000 m^3.

Let us find R_{LCFL} for each case of depressurization.

For partial depressurization $R_{LCFL} = 1.633(10/5)^{0.333} = 2.06$ m. This value corresponds to the probability of the appearance of an ignition source

$$P_{is}=1-2.73^{-x}$$

where, $x=R^2_{LCFL} \cdot n_{Is} \cdot \tau \cdot 10^{-5}$. $x=3.14 \cdot 2.06^2 \cdot 3 \cdot 1 \cdot 10^{-6} = 4 \cdot 10^{-4}$. $R_{LCFL}=1-2.73^{-0.0004}=4 \cdot 10^{-4}$

In case of partial depressurization of a block with the release of 10 m^3 of gas, the probability of the scenario with the ignition of a hot water cloud being realized is (GAM) 0.0004.

If the block is completely depressurized, $R_{LCFL}=1.633(1000/5)^{0.333} = 9.53$ m.

For this case, $x = 3.14 \cdot 9.53^2 \cdot 1 \cdot 10^{-5} = 8.56 \cdot 10^{-3}$. The probability of the scenario with the ignition of a hot water cloud being realized will be (GAM)

$P_{disp} = 1-2.73^{-0.000856} = 8.59 \cdot 10^{-3}$. The probability of cloud dispersal without its ignition during partial depressurization will be P_{disp} = 1-0.0004 = 0.9996. If the unit is completely depressurized, the probability of the release dissipating without igniting the cloud will be P_{disp} = 1-0.00856 = 0.991.

Example:

Determine the parameters of an oil spill fire and explosion of a gas-air mixture cloud at an oil separation installation.

Initial data:

The installation refers to on-site structures where there is service staff. The oil production capacity of the installation is 1000 m^3/hour, the gas factor of reservoir oil is 70 m^3/m^3, the pressure at the beginning of degassing is 8.5 MPa. The possibility of depressurization of the pipeline located in the circuit before the separator (first calculation option), the oil pipeline after the separator (second calculation option) and the gas pipeline (third option) is being considered.

Solution:

Determination of the volumes of gas and oil in the release. This problem is solved by the volume of gas capable of activating DVK sensors installed at a distance of 11.2 m from the possible release site. $V_k = (0.01 \cdot 11.2/0.041)^3 \cdot V_k = 20.38$ m^3. The results of the determination are presented in Table 2.

With an average release duration of 1 hour, the share of oil and gas extraction does not exceed 0.06% of the nominal value. The release may go unnoticed until the next operator walks through the installation.

The radius of the explosion affected area, determined using the TNT equivalent method, is overestimated by 10 times. In this regard, the greatest danger is the release of oil. If we take into account the dynamics of the development of an accident associated with an oil release, then a catastrophic release should be considered impossible, since the oil slick will be detected by personnel when walking around the installation before the gas control system is activated. The scenario of an accident with massive flooding of the installation with oil should be classified as hypothetical. The likelihood of such an accident occurring is negligible.

Table 2: *The determination of the volumes of gas and oil in the release*

	First option		Second option		Third option	
	Gas	oil	Gas	oil	Gas	oil
Volume of gas in the cloud, m^3	20,38		20,38		20,38	
Residual gas factor, % vol.		70		35,16		
Volume of oil and release, m^3		0,29		0,58		0
R_{LCFL}, m	2,24		2,24		2,24	0
Spill diameter, m		3,03		4,3		
Release frequency, 1/year	$1{,}0\cdot10^{-4}$	$1{,}0\cdot10^{-4}$	$1{,}0\cdot10^{-4}$	$1{,}0\cdot10^{-4}$	$1{,}0\cdot10^{-4}$	
Probability of an ignition source	$5\cdot10^{-4}$	$1\cdot10^{-3}$	$5\cdot10^{-4}$	$1{,}8\cdot10^{-3}$	$5\cdot10^{-4}$	
Radius from the affected area on an outdoor installation, R_0, m	0	1,5	0	2,15	0	0
Frequency of explosions (fires), 1/year	$5\cdot10^{-8}$	$1\cdot10^{-7}$	$5\cdot10^{-8}$	$1{,}8\cdot10^{-7}$	$5\cdot10^{-8}$	0

Conclusions

1. The probability of the appearance of an ignition source depends on the size of the hot water cloud within (GAM) the boundaries of the LCFL or the size of the flammable liquid spill.

2. The probability of ignition of an emission, established in the Methodology [6] and GOST as a constant value independent of the size of the flammable object, does not correspond to probability theory and cannot be used in risk analysis calculations.

3. Calculation of the probability of the occurrence of an ignition source connects the risk research procedures into a continuous chain, allowing to achieve the result of the analysis.

References

[1] RD 34.21.122–87. Instructions for the installation of lightning protection of buildings and structures. M., 2000, 65 p.

[2] GOST 12.1.004–91 "Fire safety".

[3] REI Rules for electrical installations.

[4] GOST 14249–89. Vessels and devices. Norms and methods of strength calculations. USSR State Committee for Standards. M., 1989, 82 p.

[5] RD 03-357-00. Methodological recommendations for drawing up an industrial safety declaration for a hazardous production facility. M., State Scientific and Technical Center for Safety in Industry Gosgortekhnadzor of Russia, 2000.

[6] Methodology for determining fire risk values at production facilities. Approved by order of the Ministry of Emergency Situations No. 404 dated July 10, 2009.