RT&A, Special Issue № 6 (81), Part-1,
Volume 19, December 2024

THE CALCULATİON OF FİRE AND EXPLOSİON HAZARD PRESSURE İN THE ROOM

Gulnara Zeynalova[1], Gafar Ismayilov[1], Ali-Heydar Shahmarov[2]

•

[1]Azerbaijan State Oil and Industry University
[2]Azerbaijan University of Architecture and Construction
gulnara.zeynalova93@mail.ru
asi_zum@mail.ru

Abstract

According to the normative document, the comparison of the calculation results of explosion pressure of the gas-air mixture in the room carried out in the work showed that the obtained result does not correspond to the established limit. This fact testifies to the unsuitability of the developed calculation methods. When determining the explosion pressure, it is necessary to use the explosion power hypothesis instead of HWS (hot water supply) energy hypothesis. The results of the calculation of the explosion parameters of the gas-air mixture based on the energy hypothesis using the concept of "TNT equivalent" do not correspond to the results of experimental studies.

This fact indicates the unsuitability of the calculation methods developed and approved in accordance with "the established procedure". The calculation results obtained according to the approved methods mislead consumers.

Keywords: gas-air mixture, explosion pressure, overpressure, fire hazard, hazard factor, probability

I. Introduction

In order to determine explosion hazard categories in the room, the indicator of "explosion overpressure" is used. If the overpressure exceeds 5 kPa, premises are classified as explosion and fire hazardous place. To determine the overpressure equation [1] is used:

$$\Delta P = 100(P_{max} - P_0)mZ/(V_{ac}\rho C_{st}K_l) \quad (1)$$

where: P_{max} – maximum explosion pressure, which cannot be greater than 900 kPa; P_0 – initial pressure equal to 101 kPa; m – mass of combustible gas in kg; Z – coefficient of participation of combustible gas in the explosion, for methane Z = 0,5; V_{ac} – available room capacity, м^3; ρ – gas density kg/m^3; C_{st} – stoichiometric concentration of GG by % (volume), for methane C_{st} = 9,35 %; K_l – coefficient that takes into account the leakiness of the room, K_l = 3.

The amount of gas entering the room is determined on the basis of the following assumptions:

- The most unfavorable variant of the accident or period of operation in which the largest number of GG (gas generators) are involved in the explosion is selected as the calculated one;
- The entire contents of the apparatus enter the room;
- Gas leaks simultaneously from the pipelines supplying the apparatus through the forward and reverse flow during the time required to shut down the pipelines;
- Liquid evaporates from the container, from the liquid spillage surface and from freshly painted surfaces.

For an example of implementation of the described methodology, let us determine the explosion pressure in the room with a volume of 80 m^3, in which there is a block of 1 m^3, operating at a methane pressure of 4 MPa. At complete depressurization of the block, 40 m^3 of gas from the block and 60 m^3 of gas enters the room through the direct and return flows feeding the block. The total gas flow into the room reaches 100 m^3. The density of methane is 0,714 kg/m^3.

Substituting the data into the above equation gives an overpressure value in the room equal to 1850 kPa.

Comparing the obtained value of overpressure with the limit value of 900 kPa, we notice that the obtained result does not correspond to the established limit. A deeper analysis of the situation revealed another inconsistency of the explosion process with the physics of the phenomenon in question: gas exploded in the room in the absence of oxygen in the air, so the volume of gas entering the room was greater than the volume of the room.

II. Methods

What will be the excess pressure in case of gas explosion in the room?

To answer this question, it is sufficient to determine the volume of gas in the room corresponding to the stoichiometric composition of the gas-air mixture. For methane, the stoichiometric gas concentration is 9,35 %. If the capacity of the room is 80 m^3, the volume of gas involved in the explosion will be about 7,5 m^3, its mass is m = $V_{ac}\,\rho C_{st}/100$. If we substitute this mass of gas into the equation, the equation is reduced to the following form.

$$\Delta P = (P_{max} - P_0)Z/K_l \tag{2}$$

The overpressure in the room in an explosion of a stoichiometric gas-air mixture is 133 kPa.

The fire hazard category of the room after the explosion pressure adjusting remains unchanged (A), however, if it is necessary to determine the value of the impact zone radius, the result will be significantly different from the value obtained according to the NPB methodology.

According to the thermodynamics of gas oxidation process during a cloud explosion in an open space, the overpressure cannot be higher than 900 kPa. However, the format of the equation presented in the NBP allows any flow pressure not limited by this limit to be plotted. Due to the inconsistency of the presented equation with the physical meaning of the process at cloud explosion, for calculation of cloud explosion parameters we use the methodology of PB 09-540-03[2], as well as the data of W. Marshall [3] and S.I. Taubkin [4]. In accordance with this methodology, the overpressure of the explosion is determined depending on the TNT equivalent mass of the gas involved in the explosion and the dimensionless coefficient K, taken in accordance with Table 1.

Table 1: *Classification of destruction zones*

Class of destruction zones	Coefficient K	ΔP, кПа
0	1	500-800
1	3,8	100
2	5,6	70
3	9,6	28
4	28	14
5	56	2

The radius of the destruction zone is determined by the expression

$$R = K(W_т)^{0,333}/(1 + (3180/W_т)^2)^{0,167} \tag{3}$$

The TNT equivalent value W_T for a gas-air mixture is determined by the equation

$$W_т = 0{,}4\dot{q}zm/0{,}9/q_т \tag{4}$$

where

0,4 is the coefficient that takes into account the share of the explosion energy of the gas-air medium spent directly on the formation of the shock wave;

0,9 - fraction of TNT explosion energy spent directly on shock wave formation;

q`– specific heat of combustion of gas, kJ/kg;

q_T – specific energy of TNT explosion, equal to 4520 kJ/kg;

z – fraction of the gas mass involved in the explosion;

m – mass of gas in the gas-air mixture cloud, kg.

To determine the cloud explosion overpressure beyond the limits set by the table (at ΔP>100 kPa and ΔP<2 kPa), we use the dependence ΔP = f(K) in the following form

$$\Delta P = P_{max}/(1 + K^3)^{0,5} \quad (5)$$

where, P_{max} is the maximum explosion pressure of gas-air mixture, kPa.

In accordance with the instructions of NPB - 105-03 it is allowed to take the value ΔP_{max} = 900 kPa. According to the data of Taubkin S.I. [4], the specified value of the maximum overpressure at explosion of methane-air mixture is 606 kPa. Using the equation [5] at any value of the coefficient K the overpressure is within the established limitation of its maximum value.

In the work of Marshall B [3] we find an indication that the fatal injury of people in an explosion is realized in different conditions in different ways. A person in an open area may be affected by an air shock wave with an overpressure of 500-800 kPa. In buildings and premises a pressure of 100 kPa is sufficient for this purpose. It is found that in buildings and premises a person dies not from the pressure of the explosion, but from fragments of building structures.

The conditional probability of human injury in accordance with the guidelines of NPB 105-03 and SP 12.13130.2009 is determined by the value of the probit function.

$$Pr = 5 - 0{,}26\ln V \quad (6)$$

Where, V – hazard factor determined by the equation

$$V = (17{,}5/\Delta P)^{8,4} + (290/i)^{9,3} \quad (7)$$

Here ΔP - is the overpressure of the explosion, kPa; i - is the impulse of the pressure wave, Pa/s.

To check the correctness of the conclusions of methodological and normative documents, let us perform a control calculation, the purpose of which is to determine whether the overpressure leading to fatal human injury (100 kPa) corresponds to the conditional probability of human injury equal to 100 %. As an example, we selected a cloud of methane-air mixture in which 500 nm^3 of gas is distributed. The calculation results are presented in Table 2.

As follows from the analysis of the calculation results, an overpressure of 100 kPa corresponds to a conditional probability of injury to people equal to 81 %. The conditional probability of 100 % corresponds to an overpressure of about 500 kPa. Obviously, the equation of the Probit-function presented in the normative documents corresponds to the scenario of ESW (explosive shock wave) impact on a person located at the outdoor site.

In order to determine the ECD in the room, the equation of the probit function must be transformed to the following form:

$$Pr = 7{,}4 - 0{,}25\ln V \quad (8)$$

The results of the calculation are presented in Table 3.

The change of dependence for the probit-function provided convergence of the result of the explosion wave impact on a person in the room, the conditional probability of his injury is equal to 100 % at the pressure of ESW of 100 kPa.

IV. Discussions and Results

The results of the calculation of the explosion parameters of the gas-air mixture based on the energy hypothesis using the concept of "TNT equivalent" do not correspond to the results of experimental studies.

This fact indicates the unsuitability of the calculation methods developed and approved in accordance with "the established procedure". The calculation results obtained according to the approved methods mislead consumers.

Table 2: *The results of calculations of hazard factor, overpressure of the explosion and impulse of the pressure wave*

Coefficient K	g m	ΔP кПа	Impulse i Pa/s	Hazard factor V	Probit function	CPIP %
0,43	0,99	818,10	4071,32	0,00	11,39	100,00
0,88	2,02	655,50	1989,40	0,00	9,66	100,00
1,33	3,06	464,22	1316,29	0,00	8,66	100,00
1,78	4,09	329,87	983,52	0,00	7,95	99,82
2,23	5,13	244,46	785,05	0,00	7,41	99,11
2,68	6,16	188,89	653,23	0,00	6,96	97,06
3,13	7,19	151,05	559,32	0,00	6,59	93,61
3,58	8,23	124,14	489,01	0,01	6,26	88,93
4,03	9,26	104,27	434,41	0,02	5,98	83,23
4,48	10,30	89,15	390,77	0,06	5,72	76,69
4,93	11,33	77,33	355,11	0,15	5,49	69,45
5,38	12,37	67,90	325,40	0,34	5,28	61,65
5,83	13,40	60,23	300,29	0,72	5,08	53,38
6,28	14,44	53,90	278,77	1,44	4,90	46,04
6,73	15,47	48,61	260,13	2,75	4,74	39,05
7,18	16,50	44,12	243,83	5,02	4,58	33,15
7,63	17,54	40,29	229,45	8,83	4,43	28,15
8,08	18,57	36,97	216,67	15,05	4,30	23,89
8,53	19,61	34,09	205,24	24,91	4,16	20,26
8,98	20,64	31,56	194,95	40,18	4,04	17,15
9,43	21,68	29,34	185,65	63,32	3,92	14,48
9,88	22,71	27,36	177,19	97,69	3,81	12,19
10,33	23,74	25,59	169,47	147,83	3,70	10,22
10,78	24,78	24,01	162,40	219,79	3,60	8,53
11,23	25,81	22,58	155,89	321,51	3,50	7,08
11,68	26,85	21,29	149,89	463,35	3,40	5,84
12,13	27,88	20,11	144,33	658,59	3,31	4,78
12,58	28,92	19,05	139,16	924,20	3,22	3,87
13,03	29,95	18,07	134,36	1281,59	3,14	3,10
13,48	30,99	17,17	129,87	1757,57	3,06	2,45
13,93	32,02	16,35	125,68	2385,47	2,98	1,91
14,38	33,05	15,59	121,74	3206,43	2,90	1,46
14,83	34,09	14,88	118,05	4270,86	2,83	1,09
15,28	35,12	14,23	114,57	5640,16	2,75	0,79
15,73	36,16	13,62	111,29	7388,65	2,68	0,56
16,18	37,19	13,06	108,20	9605,84	2,62	0,38
16,63	38,23	12,53	105,27	12398,89	2,55	0,25
17,08	39,26	12,04	102,50	15895,55	2,48	0,17
17,53	40,29	11,58	99,87	20247,28	2,42	0,12
17,98	41,33	11,15	97,37	25632,97	2,36	0,10
*) CPIP – conditional probability of injury to people						

Table 3: *The results of calculations of P_r*

Coefficient K	g m	ΔP кПа	Impulse i Pa/s	Hazard factor V	Probit function	CPIP %
0,9456	6,26	625,69	1859,50	0,00	13,11	100,00
1,7056	11,29	348,12	1030,92	0,00	11,27	100,00
2,4656	16,32	212,57	713,15	0,00	10,13	100,00
3,2256	21,35	144,59	545,12	0,00	9,29	100,00
3,9856	26,39	105,99	441,17	0,02	8,64	100,00
4,7456	31,42	81,84	370,52	0,10	8,10	99,85
5,5056	36,45	65,60	319,37	0,41	7,63	99,57
6,2656	41,48	54,09	280,63	1,36	7,23	98,51
7,0256	46,51	45,58	250,28	3,94	6,88	96,42
7,7856	51,54	39,09	225,85	10,23	6,56	93,24
8,5456	56,58	34,00	205,76	24,33	6,27	89,01
9,3056	61,61	29,92	188,96	53,73	6,00	83,82
10,0656	66,64	26,60	174,69	111,52	5,76	77,76
10,8256	71,67	23,85	162,42	219,48	5,53	70,92
11,5856	76,70	21,55	151,77	412,54	5,32	63,38
12,3456	81,73	19,59	142,43	744,95	5,13	55,21
13,1056	86,76	17,91	134,17	1298,57	4,94	47,69
13,8656	91,80	16,46	126,81	2193,82	4,76	39,99
14,6256	96,83	16,19	120,22	3604,06	4,60	33,56
15,3856	101,86	14,08	114,28	5773,92	4,44	28,16
16,1456	106,89	13,10	108,91	9042,54	4,29	23,63
16,9056	111,92	12,23	104,01	13872,69	4,15	1983
17,6656	116,95	11,45	99,53	20886,68	4,01	16,62
18,4256	121,99	10,75	95,43	30910,51	3,88	13,92
19,1856	127,02	10,11	91,65	45027,35	3,76	11,65
19,9456	132,05	9,54	88,16	64642,08	3,63	9,74
20,7056	137,08	9,02	84,92	91558,33	3,52	8,13
214656	142,11	8,55	81,91	128070,14	3,41	6,77
22,2256	147,14	8,11	79,11	177069,97	3,30	5,63
22,9856	152,17	7,71	76,50	242175,58	3,19	4,67
23,7456	157,21	7,35	74,05	327877,97	3,09	3,86
24,5056	162,24	7,01	71,75	439713,33	2,99	3,17
25,2656	167,27	6,69	69,56	584461,66	2,90	2,60
26,0256	172,30	6,40	67,56	770375,49	2,81	2,10
26,7856	177,33	6,13	65,65	1007441,96	2,72	1,68
27,5456	182,36	5,88	63,83	1307682,22	2,63	1,32
28,3056	187,39	5,64	62,12	1685492,09	2,55	1,00
29,0656	192,43	5,42	60,50	2158028,43	2,46	0,72
29,8256	197,46	5,22	58,59	2745646,08	2,38	0,46
30,5856	202,49	5,02	57,49	3472390,43	2,30	0,22
31,3456	207,52	4,84	56,10	4366551,28	2,23	0,00
*) CPIP – conditional probability of injury to people						

References

[1] NPB 105-103 (normative document).

[2] PB 09-540-03 "General rules of explosion safety for explosion and fire hazardous chemical, petrochemical and oil refining industries".

[3] Marshall V. The main hazards of chemical industries. M., Mir, 1987.

[4] Taubkin S.I.. Fire and explosion, peculiarities of their expertise. VNIIPO, M., 1999, 600 p.

[5] Mazur I.I., Ivantsov O.M.. Safety of Pipeline Systems. M., Publishing house. "ELIMA", 2024, 1100 p.