PRACE NAUKOWE Akademii im. Jana Długosza w Częstochowie
Technika, Informatyka, Inżynieria Bezpieczeństwa 2016, t. IV, s. 59–68

http://dx.doi.org/10.16926/tiib.2016.04.05

Borys V. Bolibrukch[1], I.M. Krasutska[2]
[1]Lviv State University of Vital Activity Safety
e-mail: bolibrykh@ukr.net
[2]Humanitarian Pedagogical Academy

FORECASTING OF EMERGENCY SITUATION AT FACILITIES WITH AMMONIA PRESENCE

Abstract. The work is dedicated to the problem of forecasting of emergency situations (ES) risks appearance at the facilities with ammonia presence. The ES forecasting at certain conditions is observed. The ways of modeling crashes are proposed and the probability of emergency situations is determined to select the means of individual protection for the personnel of the fire-rescue units.
Keywords: forecasting, mathematical modeling, ammonia freezing equipment (AFE).

PROGNOZOWANIE WYSTĘPOWANIA SYTUACJI KRYZYSOWYCH NA INSTALACJACH WYKORZYSTUJĄCYCH AMONIAK

Streszczenie. Praca poświęcona jest problemowi przewidywania sytuacji kryzysowych (groźba katastrofy) na obiektach z amoniakiem. Omówiliśmy przewidywanie sytuacji kryzysowych w określonych warunkach. Omówiono niektóre metody symulacji wypadków i określenia prawdopodobieństwa wystąpienia sytuacji awaryjnej, zaproponowano wybór środków ochrony indywidualnej dla strażaków i jednostek ratowniczych.
Słowa kluczowe: prognozowanie, symulacje matematyczne, zamrażanie amoniaku.

Formulation of the problem

In order to ensure the effective protection of firefighters - rescuers during the emergency elimination on facilities with ammonia presence it is necessary to develop a model of emergency risks and the algorithm of realization of emergency responses. Determining the appropriate level of firefighters- rescuers protection depends on the presence of dangerous factors of man-made emergency (fire, depressurization and ammonia leakage, gas and air formation and explosion, etc.)

The problem of reliable protection of firefighters-rescuers during the emergency elimination on facilities with ammonia presence caused not only by its dangerous concentrations but, also, by the possibility of fires in specified objects, in particular, in ammonia-refrigerating systems (AFE) [1].

The compressors are located in a condenser section that increases the ammonia pressure from 1 MPa to 1.5 MPa. The temperature of ammonia in conditions of fire reaches 651° C.

The risk of fire appearance in the compression compartment consists of fire hazard in compressor installation and fire hazard in a room. The fire hazard of the compressor is determined by a danger of ammonia and oxygen mixture explosion inside the compressor.

Risk of fire in a room is determined by a danger of explosion appearance of an ammonia and oxygen mixture in a volume of a room at the exit of the ammonia pipelines during the accident. The occurrence of an explosion in the compressor caused simultaneously by the appearance of a flammable gas, an oxidant and a source of ignition in a cylinder.

Under the conditions of the technical process ammonia is constantly presented in the cylinder of the compressor, that's why the probability of a dangerous gas appearance in the compressor (according to expert evaluation) is equal to 0.5.

The appearance of the oxidant (air) in the cylinder of the compressor is possible when the suction valve is jammed. In this case, the air penetrates inside the cylinder through a packing seal. When jamming is occurred in the suction valve the monitoring system of the pressure starts to operate and shuts off the compressor in 10 seconds after the valve jamming. The survey showed that 6 cases of jamming valves occurred during one year.

After analyzing the possibility of dangerous physical (material science) situations appearance, it can be concluded that the main causes of it are cracks, corrosion, erosion and deterioration and fatigue of materials of the installation relevant elements (AFE) [2].

After examining mutual influence of main elements failures in the installation from the position of the theory of probability, we can estimate the safety coefficient p_n according to "technical reliability" of basic elements with the help of the ratio [2] (known in the theory of probability and mathematical statistics [3–7]):

$$p_n = \exp\left(-\sum_{i=1}^{n}\frac{\tau}{\lambda_i}\right) \tag{1}$$

where n – the amount of the main components correspondingly to the installation element; λ_i – the mean time between failures of i -th corresponding installation element; τ – the time of installation.

The main elements of ammonia freezing equipment according to “technical reliability” can be divided into 2 groups. The following ratios are performed [1]:

$$p_1 = \exp\left(-\frac{\tau}{\lambda_1}\right); \tag{2}$$

$$p_2 = \exp\left(-\frac{\tau}{\lambda_2}\right);\ p_3 = \exp\left(-\frac{\tau}{\lambda_3}\right);\ p_4 = \exp\left(-\frac{\tau}{\lambda_4}\right);\ p_5 = \exp\left(-\frac{\tau}{\lambda_5}\right);$$

$$p_6 = \exp\left(-\frac{\tau}{\lambda_6}\right);\ p_7 = \exp\left(-\frac{\tau}{\lambda_7}\right);\ p_8 = \exp\left(-\frac{\tau}{\lambda_8}\right);\ p_9 = \exp\left(-\frac{\tau}{\lambda_9}\right);$$

$$p_{10} = \exp\left(-\frac{\tau}{\lambda_{10}}\right);\ p_{11} = \exp\left(-\frac{\tau}{\lambda_{11}}\right);\ p_{12} = \exp\left(-\frac{\tau}{\lambda_{12}}\right), \tag{3}$$

The following pairs p_1, λ_1 meet the safety of pipelines; p_2, λ_2 – the safety of a compressor machine; p_3, λ_3 – the safety of a transitional vessel (TV) p_4, λ_4 – the safety of a condenser (C); p_5, λ_5 – the safety of a line receiver; p_6, λ_6 – the safety of a circulation receiver; p_7, λ_7 – the safety of a pump for a pumping refrigerant into a refrigerating chamber (P to RC); p_8, λ_8 – the safety of a switchgear (SG); p_9, λ_9 – the safety of an evaporator (E); p_{10}, λ_{10} – the safety of flanged connections; p_{11}, λ_{11} – the safety of locking devices; p_{12}, λ_{12} – the safety of AFE connected with external influences.

The first group consists of pipelines (p_1, λ_1). It was established that during the 10 years AFE operation process the change of pipelines safety indicators is negligible. Thus it says about its reliability during a long time [2]. The second group of elements includes such installation elements as the compressor, the condenser, the receivers, the pumps, etc. (p_2, λ_2 – p_9, λ_9) (3). It is established that the value of safety coefficient decreases sharply during the first three years of AFE operation. This means that because of a more complex structure and a higher intensity of a wearing out than in elements of the first group, in a relatively short period of time their reliability drops incredibly [2]. Therefore, during the management of security works of the installation it is necessary to plan and hold maintenance of relevant installation elements on time and with certain periodicity, which will increase their reliability and allow further operation [2].

During operating refrigerating systems, a danger of explosion exists as well. The reasons can be various [8]: the loss of mechanical strength of refrigeration equipment, corrosion, local overheating, cracks, exceeding the maximum allowable pressure etc.

To effectively analyze the risk of accidents at AFE the algorithm of risk evaluation is proposed [9].

The advantages of the algorithm are the following:

- The value of acceptable risk is not defined but is set;
- The number of controlled parameters is a function of given value risk, which can increase the awareness of the condition of the controlled object;
- Clearly stated range of changes in the value of accidents risk ΔP depends on the quantity and quality of controlled parameters;
- A high level of algorithm automaton which is planned (meaning the decreasing of the overall processing time to control points as a result of the preceding two paragraphs).

The first stage in developing the risk evaluating algorithm in accidents appearance is analyzing the hazards which are specific generally for the technical process at facilities and for each element of the installation. In particular, 7 major paragraphs can be defined. [9]

1. Defining of the forecast emergency situations possibility for kinds of accidents which are observed.

2. Defining the required range of varying probabilities to provide sufficient level of security.

3. Defining the indicator of sustainability prognosis.

4. Defining the required number of parameters to ensure the effectiveness of the forecast, which is set in p. 1 - 3.

5. Defining of the physics (nature) of the process of the accident appearance and its connection to characteristics of p. 4.

6. Defining the relationships of characteristics of p. 4.

7. Defining and justification the resource costs to receive a given quality of the forecast level.

Modelling the risk of accidents appearance

The level of the risk (the degree of an expected failure) can be represented as the multiplication of the probability of unwilled consequences by corresponding amount of losses similarly as in the works [3,10]:

$$R = \sum_{i=1}^{9} R_i = \sum_{i=1}^{9} p_i \cdot Z_i \,, \tag{4}$$

where R – the amount of the risk; p_i – the probability of unwilled consequences (4), (5); Z_i – the amount of damages (losses).

To evaluate the risk the value of the average deviation module ΔZ is also used (here n = 12 (5)) [3, 10]:

$$\Delta Z = \sum_{i=1}^{n} p_i \cdot (Z_i - \overline{Z}) \,. \; \overline{Z} = \frac{1}{n}\sum_{i=1}^{n} Z_i \tag{5}$$

Also, the standard deviation is determined [4–6]:

$$\sigma = \sqrt{\sum_{i=1}^{n} p_i \cdot (Z_i - \overline{Z})^2} \,, \tag{6}$$

Taking into consideration the negative deviation from $\overline{Z}$ characteristic, the level of the risk is estimated by S_Z semi-variation indictor and its value is determined by using the ratio [7]:

$$S_Z = \sqrt{\sum_{i=1}^{n} p_i \cdot (Z_i - \overline{Z})^2 \cdot I_{vi} \,/ \sum_{i=1}^{n} p_i \cdot I_{vi}} \,, \tag{7}$$

where $I_v = \{I_{vi}\}$ – the indicator of adverse variances which correspond to:
0, for favorable variance (I_{vi}=0),
1, for adverse variance (I_{vi}=1).

In relative aspect, the risk is estimated with the help of the variation coefficient δ_Z [6,7]:

$$\delta_Z = \sigma \frac{1}{\overline{\overline{Z}}} = \frac{1}{\overline{\overline{Z}}} \sqrt{\sum_{i=1}^{n} p_i \cdot (Z_i - \overline{Z})^2} \,. \tag{8}$$

Based on the variation coefficient value δ_Z such scale is used to evaluate the level of risk and related risk areas [7,10]:

0.0 - 0.1 the minimum risk; 0.1 - 0.25 the low risk;

0.25 - 0.5 the acceptable risk; 0.5 - 0.75 the critical risk;

0,75 - 1,0 the catastrophic risk.

For pipelines, the usage time which less than ten years AFE, the semi-variation coefficient is also used [7,10]:

$$S_{ZV} = \sqrt{\sum_{i=1}^{n} p_i \cdot (Z_i - \overline{Z})^2 \cdot I_{vi} / \left(\overline{Z} \cdot \sum_{i=1}^{n} p_i \cdot I_{vi} \right)}. \qquad (9)$$

An indicator of risk evaluation may also be the coefficient of possible losses, taking into consideration the amount of losses relatively to the sum of the absolute values of probable losses and gains [5,10]:

$$K_Z = M_{ZV} / (M_{ZV} + M_{ZP}). \qquad (10)$$

where M_{ZV}, M_{ZP} – is correspondingly the probable values of favorable and adverse variances according to indicator values θ_V , θ_P when considering planned levels of losses *Z* and profits Ω.

As the detailed analysis of critical situations shows, M_{ZV}, M_{ZP} – the conditional mathematical expectations regarding deviations are the following [5]:

$$M_{ZV} = \sqrt{\sum_{i=1}^{n} p_i \cdot (Z_i - \overline{Z})^2 \cdot I_{vi} / \left(\sum_{i=1}^{n} p_i \cdot I_{vi} \right)} - \theta_V , \qquad (11)$$

$$M_{ZP} = \sqrt{\sum_{i=1}^{n} P_i \cdot (\Omega_i - \Omega)^2 \cdot I_{vi} / \left(\sum_{i=1}^{n} P_i \cdot I_{vi} \right)} - \theta_P . \qquad (12)$$

Possible loss ratio values gains the meanings $K_Z \in [0; 1]$, where

$K_Z = 0$, if damages are absent and $K_Z = 1$, unless possible additional profit will be proved.

Additionally, the coefficient elasticity of the possible losses e_θ is determined according to value θ_V,, which makes it possible to determine on what percentage the risk ratio will change when planned value of the corresponding figure will change by 1% [5]:

$$e_\theta = \frac{\theta_V}{K_Z} \cdot \frac{\partial K_Z}{\partial \theta_V}. \qquad (13)$$

It is established that the larger according to the absolute value the coefficient of elasticity e_θ, the greater the level of the risk is.

In some cases, to distribute asymmetrically specific performance indicators of organizations the analyze of the risk criteria defined on the basis of relations (6) - (14) may not be sufficient, especially when the corresponding values θ_V,, are close to the section borders (e.g. when it is not clear whether the organization belongs to a group with a medium risk, or to a group with a high-risk) [10]. Then, to analyze the situation the asymmetry coefficient K_{as} is used [5]:

$$K_{as} = \sum_{i=1}^{n} p_i \cdot (Z_i - \overline{Z})^3 / \sigma^3 . \tag{14}$$

If the asymmetry coefficient K_{as} equals zero, then the chart of the density probability function of the random value will be symmetric according to its expectations value. The maximum meaning of the asymmetry coefficient indicates the minimal risk if the profit is chosen for evaluation and vice versa, the lowest coefficient K_{as} characterizes the minimum risk if the damage meaning was chosen to estimate [5]. Because the technical condition of AFE is being observed, then instead of considering profit we observe status AFE operation, when the probability of emergency is almost absent.

For relative expression of risk considering asymmetry the coefficient of asymmetry variation is used [5]:

$$\delta_{as} = K_{as}^* / \overline{Z} . \tag{15}$$

where $K_{as}^* = 1/(K_{as} + 1)$, if $K_{as} \geq 0$; $K_{as}^* = 1 - K_{as}$, if $K_{as} < 0$.

In case of evaluating of losses (damages) indicators the best variant with a greater coefficient of asymmetry variation is considered.

When the performance analysis shows that a couple of variants of the technical condition of AFE have approximately equal probable meaning, standard deviation, semi quadratic deviation and even coefficients of asymmetry meaning to compare the conditions risk kurtosis (mex) and variations kurtosis (dex) are used [5]:

$$\mu_{ex} = \sum_{i=1}^{n} p_i \cdot (Z_i - \overline{Z})^4 / \sigma^4 - 3; \quad \delta_{ex} = \mu_{ex}^* / \overline{Z} . \tag{16}$$

where $\mu_{ex}^* = 1/(\mu_{ex} + 1)$, if $\mu_{ex} \geq 0$; $\mu_{ex}^* = 1 - \mu_{ex}$, if $\mu_{ex} < 0$.

When considering the performance evaluation procedures of the effective functioning of AFE the maximum meaning of kurtosis (accordingly minimum –

the coefficient of kurtosis variation) values indicate about approaching of the performance indicator to its excepted value that corresponds to the minimum level of the risk [5–7].

The optimization of forming of high-quality solutions for AFE security at risk conditions are considered as a solution to the problem under the conditions of uncertainty [11–12].

To evaluate the quality measures of the decision taken at every stage of preparation vectors should be defined as $\overline{X}_v$ - the initial conditions (initial data set) and $\overline{Y}_p$ - the set of values that characterize the decision taken. The quality of the taken decision which is described by using risk functions (losses) $R_V(\overline{X}_v, \overline{Y}_p)$, which brings the solutions $\overline{Y}_p$ for given values $\overline{X}_v$ [11-12]. Considering the regression model for stages of the method of risk evaluation improving, under which the present value of conduct estimation parameter $\overline{X}_v$, which corresponds to the optimal value of the decision. For possible values ω and $\overline{X}_v$ the value $\overline{Y}_{opt}$ of losses the functions $F_p(\omega, \overline{Y}_p)$ [11-12] are used. When appropriate risk losses defined as a conditional mathematical expectation $F_p(\omega, \overline{Y}_p)$, if $\overline{X}_v$, $\overline{Y}_p$ are evaluated at every stage of calculations [11-12]:

$$\overline{Y}^*_{opt}(\overline{X}_v, \overline{Y}_p) = M(F_p(\overline{Y}_{opt}, \overline{Y}_p), \overline{X}_v) = \int F_p(\omega, \overline{Y}_p) f(\omega, \overline{X}_v) d\overline{X}_v \tag{17}$$

where $f(\omega, \overline{X}_v)$ – the function of probability distribution that characterizes the quality of evaluation process; M – the symbol of mathematical expectation.

To predict an emergency situation at risk conditions the average deviation square of AFE condition parameters is minimized according to a given vector $\overline{X}_v$. In this case the deviations module square $\Delta_*(\omega, \overline{Y}_p) = |\overline{Y}_p - \overline{Y}_{opt}|^2$ is limited to use.

The risk function for assessment of emergency quality prediction for AFE is determined together with the expression of

$$\overline{Y}^*_{opt}(\overline{X}_v, \overline{Y}_p) = M(|\overline{Y}_p - \overline{Y}_{opt}|^2, \overline{X}_v) = \int |\overline{Y}_p - \overline{Y}_{opt}|^2 f(\overline{Y}_p, \overline{X}_v) d\overline{X}_v, \tag{18}$$

which is minimized.

To evaluate the risk of emergency prediction the following three approaches are suggested: optimizing the quality and reliability of information, optimizing information capacity and optimization of human resource of stuff at the risk conditions [11–12]. The following approaches are proposed to consider not separate, but compound, additively, combining the risks on the part of each approach. As a result, the global optimization problem of AFE emergency risk prediction is solved considering three aspects: the aspect of quality and reliability - *qn*, the aspect of information capacity – *ic* and the risk aspect - *ar*. In this case, the information capacity includes standard and technical documentation (standards, regulations, instructions, and methodological developments).

Results and conclusions:

1. The technological process in ammonia freezing equipment is analyzed and the mutual failures of basic elements are identified according to "technical reliability" of the basic elements.
2. The algorithm for risk assessment in ammonia refrigeration system is proposed.
3. The model of the risk of accidents appearance in ammonia freezing equipment is developed in order to determine the necessary level of protection for firefighters-rescuers.

Literature

[1] Bakhvalov O. A., *Main accident causes during the operation of ammonia freezing equipment* / O. A. Bakhvalov // Refrigerating equipment. - 2001. - № 7. - P. 11–12.

[2] Khokhlov N.V., *The risk management* / N.V. Khokhlov - M .: UNITY-DANA, 2001. - 239 p.

[3] Kopytko B.I., Beregova G.I ., Bobyk A.I., *The theory of probability and the mathematical statistics. Textbook for High Schools. - K* .: Professional, 2007. - 560 p.

[4] Senio P.S., *The probability and mathematical statistics tutorial.* - 2nd ed., revised. and add. - K .: Knowledge, 2007. - 556 p.

[5] Pugachev V.S., *The theory of probability and mathematical statistics*. – M .: Science. Chief additional board of physical and mathematical literature, 1979. - 496 p.

[6] *The reliability of technical systems and anthropogenic risk* / Ed. M.I. Faleeva. - M: ZAO FYD "Business Express", 2002. - 368 p.

[7] Kunin P.P., *The Safety of technical processes and industries. Labor Protection* // P.P. Kunin, V.L. Lapin. - Moscow: Higher School. - 2002. - 327 p.

[8] Taraduda D. V., *The formation of algorithm of accidents risk estimates at the potentially dangerous facilities, which include ammonia refrigerators* / D.V. Taraduda, P. I. Shevchenko // Problems of emergencies. - X: UGZU, 2009. - Bun 10. - S. 161 - 170.
[9] Kachanov S.O., *The development of construction mechanism of standardized documents for system implementation of state supervision and control: Dis. on obtaining the degree of the Candidate of Science: special.* 05.01.02 "The standarization, certification and metrological support" / S.A. Kachanov. - Lviv, 2009. - 176 p.
[10] Katrenko A.V., *The decision theory* / A.V. Katrenko, V.V. Pasechnik, V.P. Pasko. - K .: Publishing Group BHV, 2009. - 448 p.
[11] Pryymak V.M., *The management decisions: a tutorial* / V.M. Pryymak. - K .: Atika, 2008. - 240 p.
[12] Hevko I.B., *Methods of management decisions: Textbook* / I.B. Hevko I.B. - K .: Condor, 2009. - 187 p.