Methodical Approach Cleaning Emergency Ventilation Systems Emissions of Harmful Substances

M N Zherlykina¹, S A Yaremenko², M S Kononova³

¹Department of housing and communal services, Voronezh State Technical University
Voronezh, Voronezh, 20-letiya Oktyabrya ,84, 394000 Russia,
²Faculty engineering systems and structures, Voronezh State Technical University
Voronezh, Voronezh, 20-letiya Oktyabrya ,84, 394000 Russia,
³Department of housing and communal services, Voronezh State Technical University
Voronezh, Voronezh, 20-letiya Oktyabrya ,84, 394000 Russia

E-mail: zherlykina@yandex.ru

Abstract. In the event of an emergency situation at an industrial site with the release of ventilation systems into the atmosphere, a cleaning device is required, which should ensure that the excess of the explosive concentration in the surface layer of the atmosphere is above the normative value. Quantitatively, the release of explosives depends on the degree of depressurization of the system, its volume and pressure in it, the speed of the formation of the team to close the shut-off organs and its execution. The purification device of emergency emissions should have the properties of adequate counteraction to the specified accident factors for equipment that does not have internal self-protection. The emergency emissions are of a probabilistic nature, and therefore the structure of the treatment equipment and its operating conditions must differ from the structure and conditions when cleaning only technological emissions. The cleaning equipment must be able to neutralize large mass outlays of emissions in a short period of time, the operation of the equipment must be built on the principle of waiting for work, that is, in the automated mode, the time of entry into operation should be determined when hazardous concentrations of explosives in the room occur. The performance of the exhaust emergency ventilation and the moment of its activation are determined by the conditions for reaching the concentration of explosives in the room not exceeding 0,1 of the lower concentration limit of flame propagation in gasair explosive mixtures and ensuring dispersion of surface concentrations not higher than the established standard values, and for non-explosive mixtures – Only the second condition

1. Introduction
An accident is a deviation from maximum permissible operating conditions industrial enterprise, which may cause a negative impact on the environment. Prevention accidental releases is a probabilistic measure, because accidents occur due unforeseen damage equipment or erroneous actions of maintenance personnel, which caused release of gaseous or liquid substances into production premises or the environment.

Accidental emissions occur as a result of industrial accidents with an approximate ratio causes according [1]: errors in design – up to 8 %, low quality construction and installation works –
15…20%, strength failure, equipment defects – up to 10 %, violation of technical operation rules – 4…64 %, natural disasters – up to 2 %, other – 3…9 %.

According static data, probability of an accident with release a harmful substance at chemically hazardous enterprises is 10 per year. According to static data, probability consequences accidents when a fire-explosive substance is spilled with formation of a toxic zone is 0.704, probability of combustion or explosion spills is 0.2 and safe dispersion is only 0.03.

2. Methodology

In case an emergency, according classification given [2], three situations in industrial premises are considered:

- concentrations of harmful substances increase by no more than one order of magnitude;
- concentrations that are many times higher than the MPC are created;
- fire-and-explosion concentrations are created. In this case, it is necessary to prevent possibility a secondary accident from an explosion or fire, emergency ventilation system should not allow formation of high concentrations in certain points air environment premises.

The resulting concentration harmful substance in the room during an emergency release is determined dependence [3].

\[ c_s = \frac{G_o}{n_a \cdot V} + \left( c_i + \frac{G_o}{n_a \cdot V} \right) \exp(-\tau \cdot n_a), \]  

(1)

when \( n_a \) – multiplicity air exchange in room at time accident, 1/h, \( V \) – room volume, m\(^3\), \( G_o \) – hourly release a gaseous substance in accident, \( \tau \) – time change in concentration \( c_i \) in time from the moment of occurrence an emergency release to moment of activation emergency ventilation, provided that initial concentration is equal to maximum permissible values in working area (MPC). The formula that determines change in concentration for this time period:

\[ c_i = \frac{G_o}{n_a \cdot V} + \left( \frac{MPC - G_o}{n_a \cdot V} \right) \exp(-\tau \cdot n_a), \]  

(2)

when \( n_a \) – multiplicity of air exchange during normal technological process. From the moment the emergency ventilation is switched on until the emergency discharge is stopped the concentration change is described by the equation:

\[ c_2 = \frac{G_o}{n_a \cdot V} + \left( c_{i1} - \frac{G_o}{n_a \cdot V} \right) \exp(-\tau \cdot n_a), \]  

(3)

when \( c_{i1} \) – concentrations harmful substance at time switching on emergency ventilation, calculated according to dependence (2). For a long period of emergency release, maximum concentration in room will be equal to:

\[ c_k = \frac{G_o}{n_a \cdot V}, \]  

(4)

when concentration \( c_k \) specifies required cleaning device to neutralize emergency emissions.

3. Discussion

When device of emergency ventilation should be guided following provisions:

- exhaust devices must be positioned in accordance with expected movement of released emissions;
- exhaust pipes or shafts must have a height that prevents accidental emissions from entering areas of the aerodynamic shadow or aerodynamic support;
- in multi-span buildings, the supply air must be supplied at high speeds to avoid the formation of explosive and fire hazard zones;
- in order to prevent the destruction air ducts when explosive mixtures enter them, they must be equipped with explosive fragments or break-through membranes, through which the gas enters the fireproof chambers and then into the cleaning device;
- air directed along the room helps to reduce spread of harmful substances throughout the building [3].

Quantitatively, the release of a chemical substance depends on the degree of decompression of the system, its volume and pressure in it, the speed of forming the command to close the shut-off organs and its execution. The emergency discharge treatment device must have properties that are adequate specified accident factors for equipment that does not have internal self-protection properties.

The prediction scale of contamination with harmful substances in accidents in absence effective means of their neutralization is carried out in accordance with the methodology [4].

Since accidental releases are probabilistic, the structure of the treatment equipment and its operating conditions must differ from the structure and conditions for cleaning only process waste.

It should be noted, treatment equipment must be able to neutralize large mass emissions in a short period of time.

It should be noted, the operation equipment should be based on the principle waiting for work, that is, in the automated mode, moment of entry into operation should be determined when dangerous concentrations of harmful substances occur in the room.

Performance exhaust emergency ventilation and time of its incorporation are determined by the conditions of achieving indoor concentration of harmful substances is not higher than 0.1, the lower concentration limit flame propagation in explosive gas mixtures and to ensure the dispersion of emissions, surface concentrations are not higher than the set-tion of normative values, and for non-explosive mixtures – only the second condition.

To clean up significant mass emissions of a substance, it is necessary use high-speed methods of cleaning them or devices with a significant capacity. These methods can be thermal, thermocatalytic, or ozone. An ad-sorption column with a developed sorption surface can be referred to a capacious cleaning equipment.

The operation standby mode can be performed by software switching on and off equipment by commands from the gas detector. This mode will minimize operating costs compared to capital costs, and in this case it is acceptable to assume that the given costs consist only of capital costs.

In case of accidental release harmful substances, the damage to environment may exceed long-term damage caused by technological emissions, so the significant capital cost of creating an emergency emission prevention facility may be significantly lower than the damage being eliminated. To determine area of rational ecological and economic parameters of the treatment equipment, it is necessary to determine the dependence required costs for its creation achieve the required degree cleaning emissions $\eta$ and the dependence between the amount of damage prevented $P_R$ from the value $\eta$. The area enclosed between the graphical representation of these dependencies defines the desired zone. In emergency situations, the resulting concentration of a harmful substance $C_n$ room is very large and at a low degree purification surface concentration in the air can be extremely dangerous and damage sustained is very considerable, so you need to know minimum value of the abatement efficiencies of $\eta$.

An emergency release has a short-term impact on the environment, so the maximum one-time surface concentration of a harmful substance in the working area can be taken as the calculated concentration $MPC_{wa}$, it is acceptable to take it as a calculated value $C_{wa}^{max} = MPC_{wa}$, $C_{max} = ПДК_{р,з}$ before setting the standard value in the future. In this case, you should:

$$\eta = \frac{8 \cdot MPC_{wa} \cdot H^{1/4}}{A \cdot z \cdot C_n \cdot D \cdot n}.$$  \hspace{1cm} (5)

It is known [5] that all economic relations are based on approximations, and not on fundamental laws, so the dependencies that characterize the cost relations are not very accurate. Taking into
account the work [6, 7, 8], the dependencies of the relative required costs are established \( \frac{U_{cs}}{U_{cs_{\text{max}}}} \) and the relative damage prevented \( \frac{Y_k}{Y_{\text{max}}} \) depending on the degree of efficiency \( \eta \) cleaning device [9]. Value \( Y_{\text{max}} \) expresses the maximum permissible elimination of environmental damage, in which the quality of the environment meets the regulatory indicators and is determined by the methodology [10]. Value \( U_{cs_{\text{max}}} \) expresses the limit of the reduced cost to achieve \( Y_{\text{max}} \), determined by using the calculation of the overall weight characteristics of the treatment plant. A significant growth gradient of the damage being repaired occurs in the area of moderate efficiency of the cleaning equipment, and a small growth gradient occurs in the area of its high values. This type of change can be expressed by a power function

\[
\frac{Y_k}{Y_{\text{max}}} \approx \eta^{0.5}.
\]  

(6)

The value of the indicator of this power function expresses the differences in the gradients of damage in the area of small and large values of \( \eta \), since at high air pollution negative processes in nature occur quickly, and at low its influence is weakened and the change in the prevented damage is less. For accidental releases at high initial concentrations \( C_n \) depending on (5) and large air flow rates of emergency ventilation, the lower limit is \( \eta_k \) it can have a high value, where a change in the degree index in the range of 20 ... 25% changes the limit value by 4...6 %, so the inaccuracy of the dependence (6) is acceptable.

The relative costs \( \frac{U_{cs}}{U_{cs_{\text{max}}}} \) for the creation and operation of cleaning equipment of the required efficiency \( \eta \) they are expressed as a dependency that approaches a straight line when the equipment needs low efficiency, and when the equipment needs high efficiency, the costs increase almost exponentially [11…18]. Since each method of cleaning emissions has a certain limit value of neutralization \( \eta_p \), which defines the intersection point of the desired dependency with the dependency (2), that \( \eta_p \) expresses the first boundary condition. The second restriction – value \( \eta_k \), cutting off the area of irrational environmental and economic parameters of cleaning equipment. In the calculations for choosing the best option for cleaning emissions, certain inaccuracies in the choice of the cost relationship will not have a significant impact on the final result. Based on these assumptions, the dependence is assumed

\[
\frac{U_{cs}}{U_{cs_{\text{max}}}} = \frac{0.05 \cdot \eta^2}{1-\eta} + 0.5 \cdot \eta.
\]  

(7)

In the figure, the area bounded by the dependency curves (6), (7), and vertical lines \( \eta_k, \eta_p \), defines the range of rational environmental and economic parameters of treatment equipment for emergency emissions.

Figure 1. Area of rational parameters for cleaning ventilation emissions.
4. Results
After selecting a method for cleaning emergency emissions, the structure and operating mode cleaning equipment is determined, while taking into account a number of its features due to the unpredictability moments of occurrence of an emergency situation [19-21]. These include:
- long-term presence of equipment in continuous standby mode for the occurrence of an accident;
- ability of the neutralizing agent to be in working condition at any time year and not require a heated room;
- equipment must maintain its operability for a long time and its protection systems must be provided;
- there must be locks and duplicate commands to prevent unauthorized activation of the equipment and its guaranteed activation by the command formed during the accident.

5. References
[1] Elterman V 1980 Ventilation of chemical manufactures Moscow Chemistry p 288
[2] Skrypnik A 2002 Cleaning of ventilation emissions from chemical harmful substances Voronezh VGASU
[3] Polosin I 2007 Protection of atmosphere from emissions of industrial ventilation and boiler Voronezh VGASU p 192
[4] Derepasov A 2017 Research air exchange production premises with holes in the overlappings Housing and utilities infrastructure 1-2(1) pp 18-25
[5] Polosin I 2009 Realisation of mathematical model for an estimation of efficiency of schemes of the organisation of air exchange in shops Galvanocoverings Privolzhsky scientific magazine 2(10) pp 42-47
[6] Polosin I, Yaremenko S, Chernih R, Danilov T 2011 Prediction of the prevented ecological damage to the resources of the local bodies of water if the atmospheric protection Engineering systems and constructions 2 pp 9-16
[7] Zherlykina M 2006 Improving the efficiency of the emergency ventilation of industrial premises to ensure explosion in the release of chemicals Voronezh p 166
[8] Elinsky I 1987 Ventilation and heating electroplating facilities Moscow Mashinost 92 p
[9] Grimilin A, Datsyuk T 2007 Heating and ventilation of industrial premises St. Petersburg Northwest AVOK p 399
[10] Yaremenko S, Pereslavl'tseva I, Rudneva N, Malin V 2012 Energy spectra of the pulsation velocity in free turbulent ventilation flows Engineering systems and facilities 3(8) pp 32-38
[11] Skrypnik A, Zherlykina M 2004 Computational model determining the most probable values of the ventilation emission of chemical substances during an emergency News of higher educational institutions Construction 5 pp 72-75
[12] Kolodyazhny S, Pereslavl'tseva I, Filatova O 2010 Dependence of the distribution of hazardous harmful substances in the premises ventilation rate Engineering systems and constructions 2 pp 192-196
[13] Chuikin S, Zherlykina M 2011 Ensuring environmental safety of the environment from food industry emissions The Bulletin of MGSU 7 pp 288-295
[14] Nakhod V, Fil E 2016 Providing Explosion-Fire Safety of Ventilation Systems Potential of Modern Science 4(21) pp 89-93
[15] Zayats Yu, Belyaev V 2005 Numerical model of premises ventilation during emergency emissions of harmful substances Science and Progress in Transport 9 pp 31-35
[16] Kopytina M, Kitaev D, Shchukina T, Apalkova E 2017 Diagnostics of environmental pollution and the integrated approach to the protection Ecology and industry of Russia 21 4 pp 59-63
[17] Sarmanaev S, Desjatkov B 2002 Modeling of a microclimate of inhabited and industrial buildings News of high schools Building 1-2 pp 70-78
[18] Datsyuk T, Derjugin V, Vasilev V, Ivlev Ju 2003 Analysis of results of physical and mathematical modeling at the decision of problems of industrial ventilation *News of high schools Building* 9 pp 24-31

[19] Amelin A 1972 Theoretical foundations of fogging by steam condensation *Moscow Chemistry* p 304

[20] Frank-Kamenetskii D 1967 Diffusion and heat transfer in chemical kinetics *Moscow Nauka* pp 50-60

[21] Skorikov D S, Solovev D B 2018 Consideration of an Ecosystem From the Standpoint of Theory and Practice of Managing Production Systems *IOP Conference Series: Materials Science and Engineering* 463 Part 1, Paper № 022003. [Online]. Available: https://doi.org/10.1088/1757-899X/463/2/022003