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COMPUTATIONAL FLUID DYNAMICS. INFLUENCE OF ATMOSPHERIC STRATIFICATION ON DISCHARGE OF HAZARDOUS GASES THROUGH A STACK TO THE ATMOSPHERE

Keywords: discharge through a stack; hazardous gas; numerical modeling; meteorological conditions.

Numerical modeling of discharge of ethylene through a vent stack under various atmospheric stabilities is carried out. Indicative common factors of propagation of ethylene with the account of meteorological conditions are determined. A conclusion is made regarding a necessity of conducting a thorough analysis of discharges of this kind.

Ключевые слова: сброс со свечи; опасный газ; численное моделирование; метеоусловия.

Проведено численное моделирование сброса этилена со свечи при различных атмосферных устойчивостях. Определены характерные закономерности распространение этилена с учетом метеоусловий. Сделан вывод о проведение всестороннего анализа подобных сбросов

In cases of emptying the equipment during repair shutdowns or emergencies, it is necessary to free the equipment from circulating gases using vent stacks (vertical pipes for discharging wastes). Discharges of hazardous gases from a stack must be safe: the formed air-gas clouds should not reach the residential areas and industrial sites filled with processing equipment. However, in practice under certain meteorological conditions a distribution of dangerous concentration of the air-gas mixtures can take place directly within industrial sites and residential areas [1].

For determining the influence of the atmospheric conditions on discharge of ethylene, numerical modeling with the use of a model and a method described in articles [2-5] was carried out. The same types of discharges of ethylene at various atmospheric stratification conditions (stable, neutral and unstable) were calculated. Calculations were conducted at a subcritical speed of efflux of ethylene with the following set parameters at the stack's tip: gauge pressure is 0.1 MPa s, temperature is 315 K. The stack had the following dimensions: height is 10 m, diameter is 0.1 m. Wind speed at the height of 10 m was taken as equal to 1 m/s, roughness of the underlying terrain was considered as equal to 0.01 m, and its temperature was 303.15 K. In the calculations, the Monin-Obukhov length scale for stable, neutral and unstable stratifications was 309.5 m, 0 m and -108.1 m, respectively. The structured grid with cells refined near the ground, the mouth and the source's barrel was used. For saving computational time and reducing demands for computing resources, a symmetric problem with a symmetry axis coinciding with the discharge axis from the stack was considered, i.e. calculation of only a half of the working domain was actually made. Results of calculations are given in Fig. 1. Values of concentration at various heights from a terrestrial surface (in vol. %) on the axis of ordinates for convenience of presenting the information (the considered range of values is very broad) were shown using the logarithmic scale.

Results of calculations have brought us to an interesting conclusion that near the stack (at distances from the stack up to 100 m), values of concentration at unstable and neutral stratifications of the atmosphere are even greater than those present at the stable stratification case. It can be explained by the fact that ethylene is a light gas capable of intensively mixing up with air under conditions of increased turbulization of the atmosphere (values of turbulent characteristics at the unstable atmosphere exceed the ones at the stable atmosphere). Owing to this, already at an early stage of discharge, rather large amounts of ethylene reach the terrestrial surface. In case of stable stratification (inversion), gas leans to the terrestrial surface smoothly; only at certain distances from the stack (> 100 m) values of concentration become much greater than those during discharges under the influence of other types of atmospheric stratification. It should be noted that even at the subcritical efflux of the gas from the stack, similar discharges of ethylene are not safe, since already at the distance 12.5 m from the stack, concentration of ethylene starts exceeding considerably the maximum admissible concentration value.

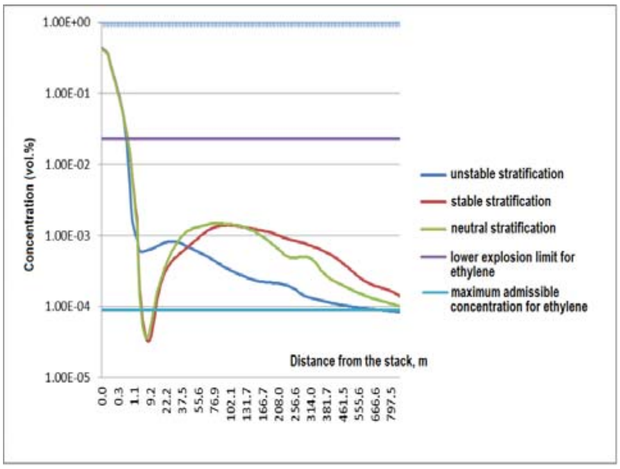

Fig. 1 – Dependence of concentration on atmospheric stratification away from the stack (height above the ground, over which the concentrations are determined, is 10 m)

For a further estimation of influence of atmospheric stabilities on distribution of a hazardous gas, we will consider Fig. 2, in which the values of concentration at the height of 2 m are considered, i.e. the height corresponding to a working zone. One can see that behavior of distribution of a gas at the height of 2 m at a distance of 6 m from the point of release practically repeats the above-considered structure of behavior at the height of 10 m. Discrepancies in the structures of behavior right next to the stack are related only to the height under consideration and, therefore, in the first case considering the height greater than the stack's location, the values of concentration exceeding the lower explosion limit for ethylene will prevail. In the second case, concentrations next to the stack have much smaller values. However, because in case of gas propagation at unstable atmospheric stratification, the processes of turbulent diffusion prevail, concentration of ethylene up to the height of 850 m will indeed exceed the maximum admissible concentration. This can explain quite low values of concentration, lower than the maximum admissible concentration, at the location of roughly 30 m from the point of release at stable and neutral conditions of the atmosphere. In addition, it can easily explain behavior of a hazardous gas "creeping" above the terrestrial surface under the conditions of stable and neutral stratification. Thus, at the distance of 160 m from the stack, at stable stratification the values of concentration will increase in comparison with the values corresponding to neutral stratification. However, because of "feeding" the mixture with some new portions of air in an air-gas cloud, the concentration at a certain distance starts decreasing. It is important to note that the maximum values of concentration under the influence of instability appear at a shorter distance from the stack compared to the situation with neutral stratification. In turn, the maximum values of concentration in case of neutral stratification appear at a shorter distance from the stack compared to the situation with stable stratification. At that, in case of stable stratification, the values of concentration exceed values encountered under the remaining conditions of the atmosphere before the complete dispersion of a hazardous gas in environment occurs. Thus, it is possible to draw a conclusion that under unstable stratification the highest value of concentration occurs near the stack, under stable stratification – at a great distance from the stack, and under neutral stratification – at distances in between the distances of the first two scenarios. Besides, distances, at which the concentrations in case of unstable and neutral stratifications are high, decrease in line with an increase in the considered height from the terrestrial surface.

One can also draw a conclusion that the greater the height, at which the concentrations are considered, is, the closer to the stack the corresponding maximum concentration becomes for any atmospheric stratification.

Therefore, for improving the safety of operation and designs of the stacks, the comprehensive analysis of propagation of ethylene released from a stack must be carried out together with studying the influence of atmospheric stability on this process.

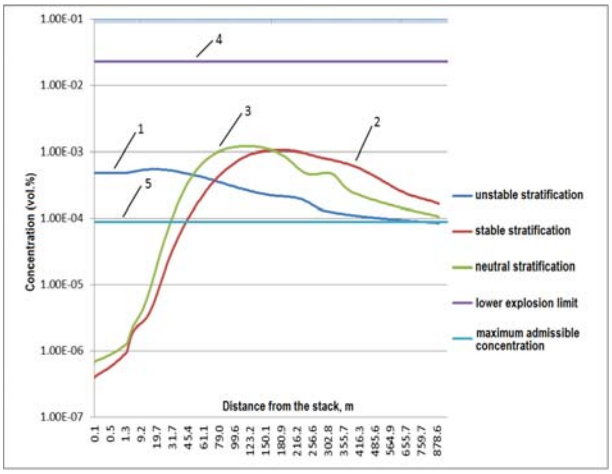

Fig. 2 – Dependence of concentration on atmospheric stratification away from the stack (u=1 m/s; z_0=0.01 m; h=10 m; d=0.1 m; P_{gauge}=0.1 MPa; T=315 K; h_{ground}=2 m).

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