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Methods for determining the effective height of the pipe taking into account the dispersion of emissions in the production facilities working area

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Introduction. In order to determine the height of the rise of the polluted substances above the source of the pollution, it is important to know the exact distribution of the gas plume.

Problem Statement. The determination of the dust concentration in the working area of asphalt concrete plants should take into account the assessment of the concentration of harmful substances in the working area of the asphalt concrete plant. The study is the analysis of methods for determining the effective height of the pipe, taking into account the dispersion of emissions in the working area.

Theoretical Part. The paper considers the dependences of the estimation of the initial rise of the gas jet, proposed by Berland, Holland, Briggs, and the specialists of the Tennessee Valley. The value of the initial rise of the impurity jet depends on the moment of the amount of gas movement, the thermal power of the wind speed carrying the jet, and the conditions of thermophoresis. The paper presents the comparative graphs of the calculation of the level of the initial rise of the gas jet at different rates of gas exit from the pipe and constant wind speed.

Conclusion. The method of taking into account the initial rise of the heated gas jet gives us better convergence in the calculations of the maximum surface concentrations of harmful substances and in the estimation of distances to them.

Key words: pollutants, concentration, emission, gas movement, height of the pipe, working area, rise of the jet.

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Introduction. Most analytical methods used to calculate the concentrations of harmful substances in emissions from pipes in the working area of production facilities involve the use of a virtual or equivalent source. The study was conducted to determine the virtual point of the beginning of gas dispersion [1-2]. The height of the virtual source is obtained by adding the initial rise of the impurity term Δh, due to the rise of the jet, to the actual height of the pipe h. The phenomenon of the exhaust of a gaseous jet from the pipe into the atmosphere of the working area is mainly determined by three sets of parameters. These include the pipe characteristics, meteorological conditions, and physical and chemical properties of the emission. There are a large number of formulas for determining Δh. Most of them contain arguments determined by the moment of the amount of movement and the thermal lifting force, that is, the first argument is related to the vertical moment of the amount of movement of gases emitted from the pipe, and the second is determined by the difference between the temperature of the gases at the outlet of the pipe and the ambient temperature [3, 4].

Carpenter and others studied the rise of the jet from the pipes of power plants and concluded that the formula proposed by Briggs is preferable for estimating the rise of the jet from the pipes of local power plants [5].

Problem Statement. The emissions coming from the flue and ventilation pipes and openings to the working area have an initial rate of rise and are often overheated relative to the surrounding air. With a light wind, it can be seen that the smoke first spreads almost vertically upwards and then begins to spread horizontally only at some level. Therefore, it is proposed to take into account the initial rise of the impurity ΔH and consider some conditional source located at a higher level (He =H+ДH), usually called the effective height [6, 7].

Theoretical Part. The height of the rise of pollutants above the source of pollution is determined by formula [8]:

$$H_c = H_Г + \Delta h,$$

where $H_Г$ — the effective height (total) of the gas plume rise, m; Δh — the initial rise of the jet (gas), m.

In the transformed form, this formula, based on empirical data, has the form [8]:

$$\Delta h = \frac{114 \times C \times F^{1/3}}{u}, \qquad (1)$$

where $F = \frac{g \times V_s \times d^2 \times (T_s - T_a)}{4 \times T_a}$, m^4/s^3; g — gravity acceleration, m/s^2; V_s — gas velocity at the outlet of the pipe, m/s; d — diameter of the outlet of the pipe, m; T_s — gas temperature at the outlet of the pipe, ^0K; T_a — atmospheric air temperature, ^0K; $C = 1{,}58 - 41{,}4 \times \frac{\Delta\theta}{\Delta z}$ — dimensionless coefficient; $\frac{\Delta\theta}{\Delta z}$ — potential temperature gradient, $^0K/m$; u — wind speed at the outlet level, m/s. The constant 114 has a dimension of $m^{2/3}$.

The experimental data analysis shows that the rotation of the jet in the conditions of asphalt concrete plants is carried out at altitudes 10 times less than it is determined by the calculation according to formula (1). Therefore, the constant in the Tennessee Valley formula is overestimated by one order, so in further calculations the value of the constant will be taken as 11,4 $m^{2/3}$.

The linear correlation between C and $\frac{\Delta\theta}{\Delta z}$ is observed in the range $\frac{\Delta\theta}{\Delta z}$ from 0.001 to 0.013 ^{0} K/m.

The formula allows you to calculate the effective value of the rise of the jet over the pipe at a certain distance in the wind direction. The position of the maximum rise of the jet can be significantly shifted away from the pipe in the wind direction. As a result, the dispersion of pollutants in the jet at small distances from the pipe will occur at a height that is less than the effective height H. The results of the method for estimating the effective rise of the jet, depending on the distance x from the pipe, give the dependence Δh in the function x for three conditions of atmospheric stability [9, 10]. For the indifferent stability of the atmosphere ($-0.17 < \frac{\Delta\theta}{\Delta z} < 0.16$,where $\frac{\Delta\theta}{\Delta z}$ is expressed in $^0K/100$ m) and a distance of up to 3 000 m [8] the height of the jet rise is calculated by the formula:

$$\Delta h = \frac{2{,}5 \times x^{0{,}56} \times F^{1/3}}{u}, \qquad (2)$$

where x — the distance from the pipe, m.

For high sources, the use of formulas that use Δh in conjunction with x will slightly change the concentration profile. However, such calculations are no longer so reliable when estimating scattering for relatively low sources [11, 12]. Emissions from low-level sources can lead to ground-level concentrations that exceed the permissible level. In addition to the special formulas, taking into account the stability of the atmosphere, a general expression was proposed for the value of the effective rise of the jet [8]:

$$\Delta h = \frac{173 \times F^{1/3}}{u} \times exp\left(0.64 \times \frac{\Delta\theta}{\Delta z}\right), \qquad (3)$$

As in the case of formula (1), the analysis of formula (3) and the results of the calculation allowed us to conclude that the coefficient 173 is overstated by one order. In the calculations it will be taken as 17.3.

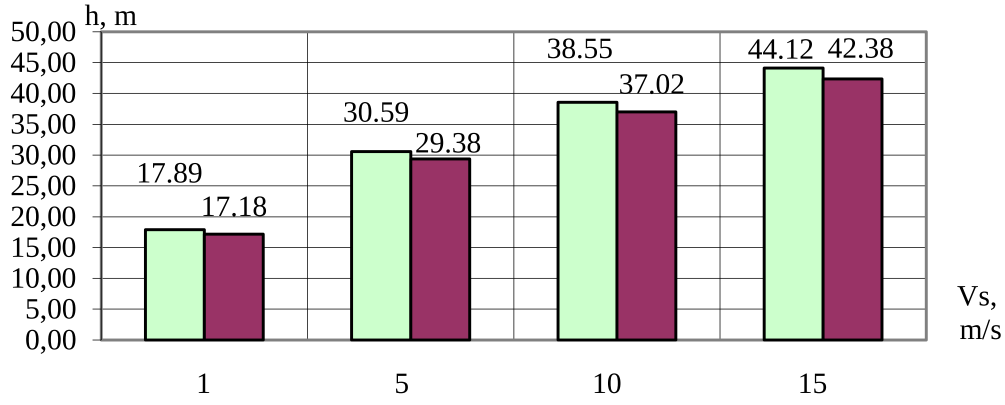

Fig. 1. Comparison graph for calculating the level of the initial rise of the gas jet according to formulas (1) and (3) at different gas exit speeds from the pipe and a constant wind speed (u=1 m/s)

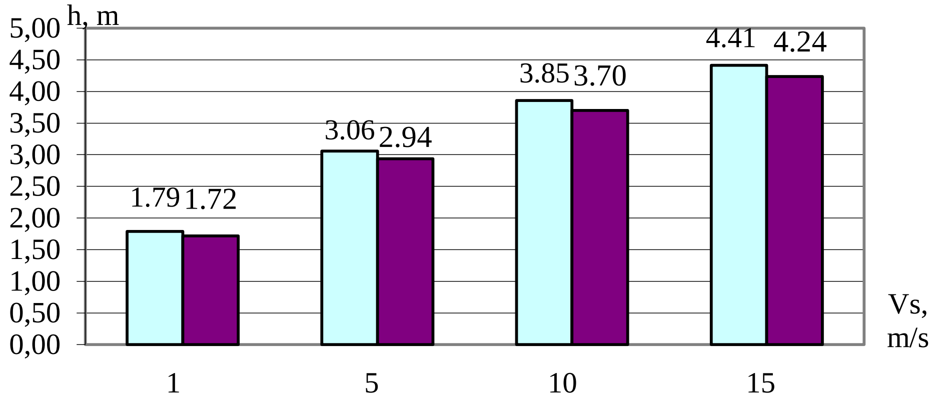

Fig. 2. Comparison graph for calculating the level of the initial rise of the gas jet according to formulas (1) and (3) at different gas exit speeds from the pipe and a constant wind speed (u=10 m/s)

The paper compares the results of calculations using formulas (1) and (3) (Fig. 1 and 2). At the same time, a good convergence of the obtained results was established (the discrepancy of the results does not exceed 5 %). Therefore, in further calculations, we will use only formula (1).

The simplest estimates of Δh are based on the use of some results of the theory of jet propagation in a stationary medium and finding empirical connections between Δh and these factors [13-15].

Further calculations of Δh at different velocities of the jet stream showed the validity of the constant estimate. Table 1 presents the results of calculating the initial rise of a gas jet on the dependencies proposed by Berlanda (2), Holland (3), Briggs (4) and specialists of the Tennessee Valley (1).

The speed of the gas flow from the pipe (W_0=1–15 m/s) and the speed of the air flow that carries away the jet U=1–10 m/s varied in the calculation.

Table 1

Initial rise of the gas jet

U, m/s	W$_0$, m/s	Berland	Holland	Briggs	Tennessee Valley
		$\Delta h = \frac{3{,}58 \times R_0 \times W_0}{U}$m	$\Delta h = \frac{3 \times R_0 \times W_0}{U}$ $+4 \times 10^{-5} \times \frac{Q_t}{U}$m	$\Delta h = 2{,}6 \times \left(\frac{F}{U^3}\right)^{\frac{1}{3}}$ $F_t = \frac{g \times R_0^2 \times W_0 \times \Delta T}{T_a}$m	$\Delta h = \frac{11{,}4 \times C \times F^{\frac{1}{3}}}{u}$m
1	1	3.58	3.384	3.85	17.89
1	5	17.9	15.384	6.59	30.59
1	10	35.8	30.384	8.31	38.54
1	15	53.7	45.384	9.5	44.12
5	1	0.716	0.6768	0.77	3.57
5	5	3.58	3.0768	1.31	6.12
5	10	7.16	6.0768	1.66	7.71
5	15	10.74	9.0768	1.90	8.83
10	1	0.358	0.3384	0.38	1.79
10	5	1.79	1.5384	0.65	3.06
10	10	3.58	3.0384	0.83	3.85
10	15	5.37	4.5384	0.95	4.41
15	1	3.58	3.384	3.85	1.19
15	5	17.9	15.384	6.59	2.04
15	10	35.8	30.384	8.31	2.57
15	15	53.7	45.384	9.51	2.94

$$\Delta h = \frac{3{,}58 \times R_0 \times W_0}{u}, \quad (4)$$

where R$_0$ — the inner radius of the pipe, m; U — the wind speed on the pipe section, m/s; W$_0$ — the speed of the gas flow flowing out of the pipe, m/s;

$$\Delta h = \frac{3 \times R_0 \times W_0 + 4 \times 10^{-5} \times Q_t}{u}, \quad (5)$$

where Q — the thermal power of the source, cal/s;

$$\Delta h = 2{,}6 \times \left(\frac{F_t}{u^3}\right)^{1/3}, \quad (6)$$

where $F_t = \frac{g \times W_0 \times R_0^2 \times \Delta T}{T_a}$

g — the acceleration of gravity, m/s^2; ΔT — the difference between the temperature of the outgoing gas and the ambient air temperature ^{0}C; T$_a$ — the ambient air temperature, ^{0}C.

Conclusion. In this paper, we study four computational models for estimating the height of the jet rise. The authors have refined the estimate of the amount of jet rise above the geometric height of the pipe, depending on various factors: jet momentum, temperature drop. When determining the effective height of the pipe, taking into account the dispersion of emissions in the working area of production, this technique has received a more reliable calculation when assessing the dispersion of harmful substances, which is confirmed by experiments at different speeds of the jet stream.

The validity of this estimate is confirmed by the constants proposed by Berland, Holland, Briggs, and experts from the Tennessee Valley.

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Contribution of the authors:

V. Ya. Manokhin — scientific supervision, formulation of the main concept, goals and objectives of the study; I. A. Ivanova — calculations, preparation and presentation the text of the article, work with literature; E. I. Golovina — analysis of the research results, conclusions, correction of the conclusions.