Noise Propagation in Urban Area from Chimneys of Thermal Power Plants

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Annotation. Large energy facilities are noise sources of the adjacent to them urban buildings. In case of noise propagation from pipes, the assessment of the noise mode of the urban building area is a complex scientific-practical problem of building physics. The solution of the problem is carried out consistently in two stages. At first, the noise distribution in channels from ventilator to the mouth of the pipe is determined. Proposed calculation model takes into account sizes and shape of channel and pipe, noise insulation properties of the walls and the mirrored-diffuse nature of the sound reflection from the fences. For metal ducts, 95% of reflected sound energy is mirrored, and other 5% of it is diffusely. The distribution of emitted by pipe sound energy within urban building is found at the next stage. A new method is suggested for solution of this problem. It is based on received analytical dependence of the sound energy directivity factor from the mouth of pipe and integration of its diffraction. To implement the method a computer program is developed. The program makes it possible to assess the propagation of noise inside ducts and in an open space from the mouth of the pipe to various sites of buildings. To realize the method, an example of calculation of noise emitted by the chimney of a steam boiler of a thermal power plant in Moscow is given. The example shows the potential of suggested calculation model and its computer realization for the noise mode assessment of the adjacent to energy facilities urban buildings.

Keywords: noise, noise of chimneys, calculation of noise in urban area

1 Introduction

The ecological situation of present-day megalopolises, including Moscow, substantially depends on permanently operating energy facilities. Primarily they are the thermal power plants. One of the most negative factors that arise during their operation is the noise of the adjacent area. The main sources of noise at these facilities are chimneys. The height of the pipes is 100-180 m. Therefore, the noise emitted by them can penetrate far into the building.

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It can spread beyond the enterprises on the distance of 800 - 1600 m [1, 2, 3]. At the same time, noise levels exceed permissible values significantly.

Noise enters the chimneys from smoke exhausters. Through the channels, it spreads into the pipe and then to mouth of the pipe. From the mouth the noise is emitted into the space surrounding the pipe. For this reason, during development of actions to limit noise emission by chimneys, two problems have to be solved. The first problem is an assessment of the noise propagation from the smoke exhauster to the mouth. And the second one determines the sound pressure levels in the building when noise is emitted from the mouth.

The sound power of the smoke exhausters is determined at the factory stands when they work in the maximum efficiency mode [4]. At the same time, there is no reliable data on the propagation of sound energy from the smoke exhauster in the channel and pipe in the mode of its work. Therefore, we carried out research in the increase channels when exemplary noise sources worked in them [5]. They provided an opportunity to determine the process of propagation of sound energy in channels, and also to establish the nature of sound reflection from channel surfaces. Research have shown that sound reflection has a mirror-diffuse nature. In this case, one part of the sound energy is reflected mirrored, and the other part of it is scattered according to Lambert’s law [5]. The number of dissipated energies depends on the characteristics of the channel walls. It found that inside the channels and pipes the part of the diffused reflected energy does not exceed 5% of all reflected energy.

The presence of the specular and scattered components of the reflected energy leads to the formation of specular and scattered sound fields in the channel [5]. In this case, it was proposed to use the ray tracking method to determine the mirror component of noise, and the numerical energy method is convenient for the scattered component [6]. During its development, the concept of a quasidiffuse sound field was used, in which there are recessions of the reflected sound energy, but the conditions for the isotropy of coming of reflected energy to the calculated point [7]. A similar approach to the calculation of scattered energy is also used in foreign practice. In works [8–14] a diffuse model for calculation of scattered sound was proposed, based on the Brownian concept of the motion of phonons of reflected energy in a closed volume of a room [15, 16]. The methodology of calculation of sound fields in rooms with mirrored- scattered reflection of sound is considered in detail in [17, 18]. Based on it, research of the influence of the sound reflection nature on the distribution of sound energy in closed volumes have been carried out. It found, that in channels with 95% of mirrored reflection, the calculation error when using of the mirrored model of sound reflection does not exceed 1.0 - 1.5 dB. It is acceptable in practical calculations.

2 Methods

The sound power levels of the energy emitted by the mouth of the chimney can be determined according to the expression

$$L_{wm} = L_w - \Delta L_{wcan} - \Delta L_{wduct}, \tag{1}$$

where L_w – passport sound power levels of the smoke exhauster; $\Delta L_{wcan}, \Delta L_{wduct}$ - recession of sound power in the channel and in the chimney respectively.

Preparatory research have shown that when calculations of sound pressure levels in the channel from the smoke exhauster to the chimney and in the pipe from the channel inlet to the pipe mouth, it is possible to use the ray tracking method [19].

Sound pressure levels in the channel will be determined by the formula

$$L_{can} = 10\lg\left[\left(\varepsilon_{dir} + \varepsilon_{ref}\right)c / I_0\right], \tag{2}$$

where ε_{dir}, ε_{ref} – the energy densities of direct and reflected sound respectively; c – the speed of sound in air; I_0 – the sound intensity at the threshold of audibility.

Sound pressure levels in the pipe are determined by the formula

$$L_{duct} = 10\lg\left(\varepsilon_{ref}\, c / I_0\right). \tag{3}$$

To calculate the sound pressure levels L_{can} и L_{duct}, a computer program has been developed. It takes into account the features of mirrored reflection of sound in a channel and in a pipe with a round-cross section. There is determination of the sound power levels of the pipe, based on the received values of sound pressure levels at the mouth of the pipe. The transition from the calculated sound pressure levels to sound power is implemented according to the formula

$$L_w = L + 10\lg(A/2), \tag{4}$$

where A – the cross-sectional area of the pipe; L – the sound pressure level at the mouth of the pipe.

The calculation of sound in a channel with the ray tracking method is straightforward. In a cylindrical pipe the movement of rays occurs along helical line (Figure 1).

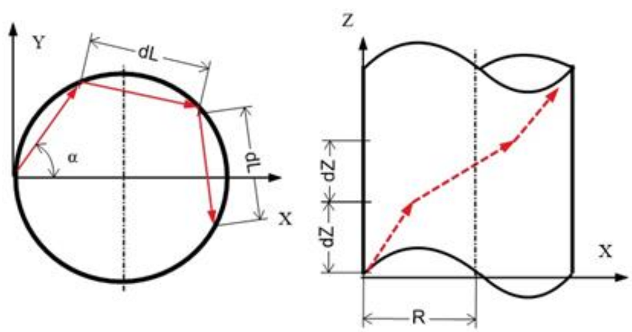

Fig. 1. - Trajectories of the movement of ray in the pipe

With guides of the cosine of the ray $cos\theta_x$, $cos\theta_y$, $cos\theta_z$ with the axes X, Y, Z, the trajectory of the movement can be calculated. The angle between its projection onto the XOY plane and the X axis is

$$\alpha = \arctan\left(\frac{\cos\theta_y}{\cos\theta_x}\right), \tag{5}$$

and the projection length will be

$$dL = 2R \cdot \cos\alpha, \tag{6}$$

where R = 3.5 m is the radius of the pipe.

With each act of reflection, the ray rises to a height

$$dZ = dL/\cos\theta_z\,. \tag{7}$$

With a known value of dZ, it is possible to calculate the number of acts of reflection of the ray when it rises by a specified distance to the calculated point.

The mouth of the pipe as a noise source refers to point sources. Its acoustic characteristics are determined by three parameters such as the acoustic power, the spatial angle of emission and the directivity factor [20]. In this case, the sound pressure level is determined by the expression

$$L = L_w + 10\lg(\frac{F}{\Omega r^2}), \quad (8)$$

where L_w – the sound power level of the pipe; $\Omega = 4\pi$ - the spatial angle of energy emission from the pipe; F - the directivity factor of sound energy emission.

Thus, in the calculation of sound pressure levels on the territory of building, it is necessary to have data on the directivity factor of emission in the pipe. It is impossible to receive them by direct measurements. Research were carried out on a model of a pipe in a damped chamber of the NIISF. The received data are in good agreement with the data in [21] and [22]. In article [20], analytical expressions are proposed for determination of the directivity factor for a pipe in the form

$$F = \begin{cases} 2.88\cos 0.5\theta \text{ при } \theta = 20^{\circ} \\ 1.44\cos 0.5\theta \text{ при } 20^{\circ} < \theta < 180^{\circ}, \end{cases} \quad (9)$$

where θ - the angle between the axis of the cone and the direction to the calculated point.

3 Results and Discussion

To assess capabilities of the proposed methods, noise levels were calculated in the territory adjacent to the chimney of the CHP-20 in Moscow. The calculation was performed during the smoke exhauster DN 21.5 × 2 operation. The cross-section of the channel is 1.5 × 2.4 m. The length of the channel from the smoke exhauster to the pipe is 10 m. The height of the pipe to its mouth is 120 m. The diameter of the pipe is 7 m.

The calculation of noise inside the channel and pipe was implemented for 45 calculated points in the octave frequency band with an average geometric frequency of 250 Hz. The sound absorption coefficient of the walls of the channel and pipe at this frequency is 0.05. The nature of the reflection of sound from the channel and pipe surfaces is mirrored. The calculation scheme is shown in Figure 2. The calculation results are presented in Figures 3, 4 and table 1.

To test the software package and to assess the accuracy of the used methods, a parallel calculation of the change in sound power and sound pressure levels along the axis of the channel and pipe was performed according to the methodology of normative document Design rules 271.1325800.2016 [22], [23]. The comparison results for changes in sound power in the channel and pipe are given in Figure 3. It can be seen that the discrepancies do not exceed 3.0 dB. They are related to the fact that the Set of rules [22] adopted a greater decrease in cornering noise than it is determined in the calculation. In developing a new edition of the Set of rules [22], it is necessary to clarify these data. The proposed methodology also clarifies data on the decrease in sound power in the direct sections of rectangular and circular ducts for various purposes.

Using a computer program, the sound pressure levels in the territory adjacent to the pipe were calculated. In the calculation it was assumed, that sound energy spreads in space with $\Omega = 4\pi$ and with the directivity factor determined by expression (9). The pipe coordinates are: $X = 320$ m, $Y = 116$ m. The sound power level of the pipe is 119.8 dB (see table 1). The calculation results are presented on the plan of the territory of the CHP under the action of one noise source - a chimney (see Figure 4).

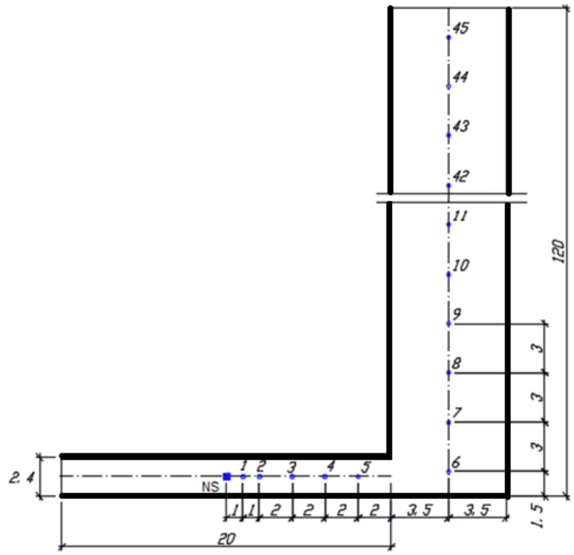

Fig. 2. – Scheme for the calculation of sound energy in the channel and pipe: NS - noise source; 1- 45 - numbers of calculated points

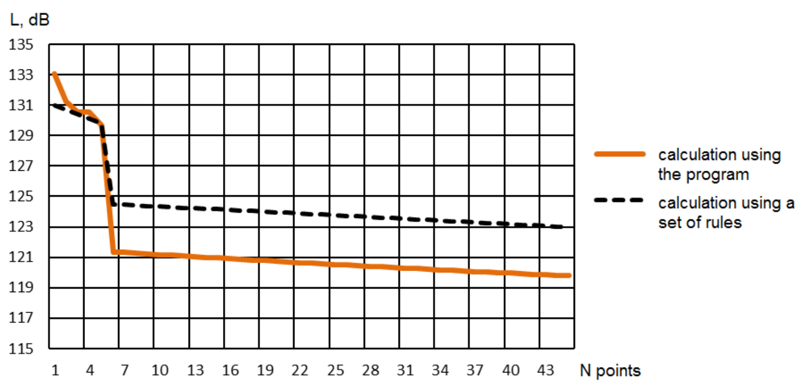

Fig. 3. – Schedule of changes in the sound power levels of the smoke exhauster along the axis of the channel and the chimney

Table 1 - Calculated sound power levels in the channel and pipe sections according to the software package and the set of rules.

Parameter	Sound pressure levels, dB, at design points								
	1	2	3	4	5	6	…	44	45
Distance from the smoke exhauster, m	1	2	4	6	8	13.5	…	127	130
Sound pressure levels, dB	130,5	128,7	128,0	128,0	127,1	108,5	…	106,98	106,95
Sound power levels, dB	133,1	131,2	130,6	130,5	129,7	121,3	…	119,82	119,79

Numbers of calculated points, their coordinates and sound pressure levels are shown on noise maps. Also, figure 4 shows that the noise map is symmetric under the chimney. Figure 5 shows that the main noise emission of the pipe is directed upward.

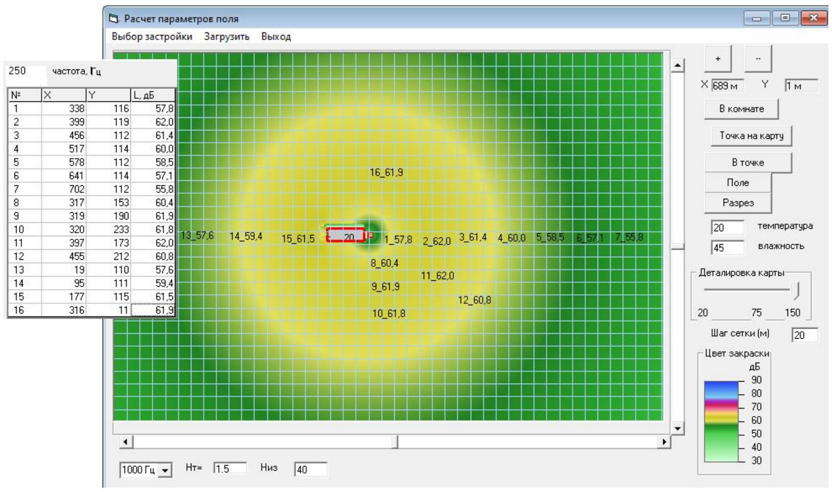

Fig. 4. – A noise map on the territory of the CHP-20 and near it, with indicating the coordinates and sound pressure levels at the calculated points

The calculations show that the distribution of sound energy in space is determined by the directivity factor. Moreover, its magnitude is influenced by the directivity factor and the change in sound energy on the trajectory r from the mouth of the pipe to the calculated point. Their action is multidirectional.

The minimum sound pressure level is received at the base of the pipe. As the distance from the pipe by the magnitude of R = 90 m increases, the sound pressure levels in the calculated points due to a slow increase in r while the directivity factor increases. After R> 90 m the sound energy decreases, because the directivity factor can no longer compensate for the decrease in sound energy due to an increase in the value r. The nature of such changes is shown in Figure 6 for a height of 1.5 m from the ground.

The considered example is given for the operating conditions of one smoke exhauster only. Similar calculations can be performed for the case of simultaneous operation of several smoke exhausters connected to the pipe.

4 Conclusions

The performed research suggests the following conclusions.

1. In the assessment of the distribution of noise in the territory surrounding the chimneys, it is necessary to solve two problems consistently, namely, to calculate the propagation of noise from the smoke exhauster to the mouth of the pipe and then calculate the sound pressure levels in the space surrounding the pipe.

2. To calculate the propagation of sound energy in a channel and a pipe, the ray tracking method should be used with adaptation to calculations in channels with rectangular and circular cross-sections.

3. The calculation of noise in the territory adjacent to the chimney should be performed considering the pipe as a point source with a directivity factor determined by expression (9).

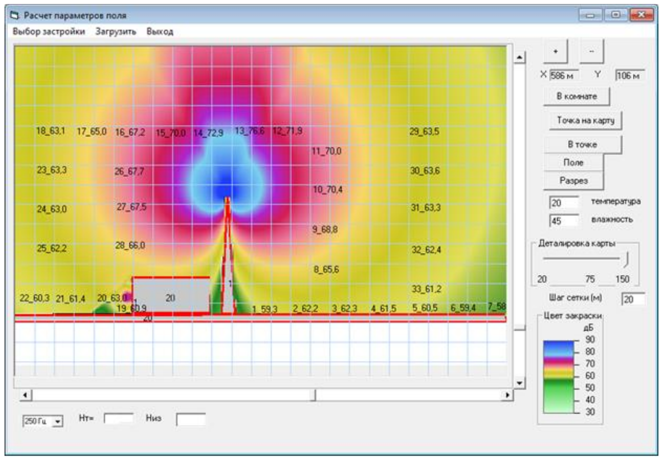

Fig. 5. - Sound card in a vertical plane passing through the chimney

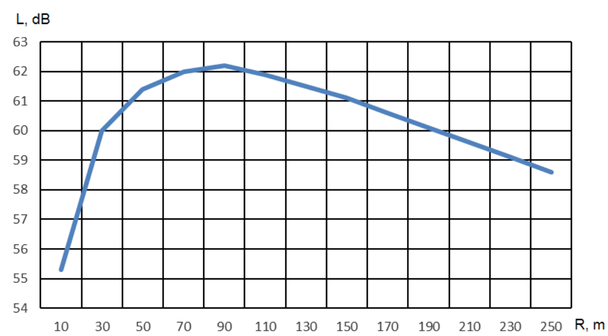

Fig. 6. - Schedule of change of sound pressure levels with distance from the chimney

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