Influence of replacement of steam power plant on combined cycle gas equipment on the sanitary protection zone by noise factor

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Abstract. Improving the safety of energy equipment of thermal power plants (TPPs) is an important task. The safety of power equipment is affected by physical influences, the most important of which is noise. Noise is one of the factors determining the size of the sanitary protection zone of thermal power plants. Article analyses the influence of TPP equipment structure on the size of sanitary protection zone (SPZ) by noise factor when replacing the equipment of traditional steam power plants with the equipment of steam and gas plants. Combined cycle gas plants (CCGT) are the most innovative technology in heat and power industry. Currently, most of exhausted steam turbine units (STU) replaced by CCGT. CCGTs are more economical and at the same time have better environmental performance, which consists in both less emission of pollutants and less noise exposure. STU supplied in standard configuration, as their efficiency slightly depends on external conditions. On contrary, the efficiency of CCGT significantly depends on climatic conditions. This dependence necessitates the implementation of individual projects, which allows at design stage of CCGT equipment to provide measures to reduce noise. Main CCGT’s noise sources are air inlet and gas outlet. At design stage, provide reducing sound pressure levels to regulatory values on border of SPZ. Data of calculations showing that increasing of STU power leads to an increase the size of the SPZ. Comparison with the results of calculations on semiempirical model and using computer of SPZ sizes at different type and structure of STU is given. Transition to supercritical steam parameters causes a jump in noise levels. Considered stepwise withdrawal of equipment and its replacement by CCGT. Described a decrease in noise levels at SPZ border. This allows performing equipment modernization in cities in conditions of developed residential building also with increase of plant capacity. Influence of climatic conditions on width of sanitary protection zones described. Shown that during the year boundaries of SPZ change at the same structure of equipment. The most correct is to specify interval in which boundaries of SPZ are located. These results allow selecting noise reduction measures more accurate.

1. Introduction

Improving the safety of energy equipment of thermal power plants (TPPs) is an important task. The safety of power equipment is affected by physical influences, the most important of which is noise. In general, thermal power plants (TPP) have two types of dangerous effects on people who define the boundaries of the sanitary protection zone (SPZ): chemical and physical.

The chemical effect is associated with the use of organic fuels at thermal power plants, the combustion of which leads to the formation of compounds of different hazard classes. Flue gases are removed...
through the chimney, which contributes to the dispersion of pollutants in the ground layer of atmospheric air. The lowest concentration of pollutants is observed directly under the pipe. In the future, as it dissipates, the concentrations increase and reach a maximum, after which they again decrease to zero. The profile of concentrations of pollutants from the considered thermal power plant in the ground layer depends on the height of the chimney and the state of the atmosphere. Under normal operating conditions equipment, excess concentrations in the surface layer should not be observed even in the zone of maximum concentrations. That is achieved by calculating and correctly selecting the height of the chimney.

Noise is the most significant factor of the physical impact of thermal power plants on the environment. The operation of almost all the main and auxiliary equipment of the TPP is associated with noise emission. A large number of articles are devoted to this issue [1-4]. In comparison with the chemical impact on the nearby TPP territory, the physical impact has a qualitatively different character – the highest sound levels and sound pressure levels (SPL) are observed near the noise-emitting equipment, and as you move away from it, noise attenuation occurs due to the divergence and absorption of sound waves by the environment. A sanitary protection zone is established for all industrial objects [5]. SPZ helps to reduce dangerous effects on people to the values set by sanitary standards. At the same time, restrictions are imposing on lands located within the boundaries of the SPZ. For example, it is forbidden to build residential buildings, kindergartens, hospitals, and other facilities with normalized indicators of the environment quality.

The factors described above lead to the fact that the thermal power plant acoustic impact is the determining boundary of the SPZ. The usual picture of the ratio of the calculated SPZ boundaries by the chemical and physical impact factor is shown in Fig. 1.

The article considers the issue of establishing the boundaries of the SPZ of thermal power stations by the noise factor. Below calculated data on the size of the SPZ of TPP depending on the composition of generating equipment and climate factors is shown.

2. Sanitary protection zones of TPP
The works [6-10] are devoted to calculations of sanitary protection zones. Consider this issue from the point of view of the type of equipment and the prospects for its replacement with more advanced equipment.

First, we consider the boundaries of the SPZ for thermal power plants with traditional steam-powered equipment and combined-cycle plants (CCGT) equipment. Most of the steam turbine plants that have exhausted their resources in Russia are being replaced by CCGT units. CCGT have a higher efficiency for the production of heat and electric energy than conventional steam-powered equipment. This leads to fuel economy and reduction of pollutant emissions with the same equipment capacity. A distinctive feature of CCGT in comparison with steam turbine units is a significant dependence on the climatic conditions of the area in which the unit operates. This dependence leads to the need to carry out individual projects of power plants. At the same time, at the design stage, issues are solved not only of technical and economic indicators of the equipment, but also environmental, in particular, noise reduction. At the design stage taking into account the location of residential buildings or other standardized objects near the generation equipment. After this noise levels are calculated and measures are developing to reduce it. Thus, the CCGT equipment before the delivery provides implementation of sanitary requirements by physical factors. The main sources of CCGT noise are the air intake device and the gas path behind the gas turbine.

In Russia, industrial facilities producing electric and thermal energy during the combustion of mineral fuels have the following sizes of SPZ depending on the class [5].

The experience of the Russian unification of steam turbine installations has led to the fact that the largest number of them produced by the same plant for objects located in different climatic conditions is delivered in a typical configuration. For this reason, it is possible to consider the dependence of the noise level on the total power of the thermal power plant. The following semi-empirical formula can be used to estimate the size of SPZ boundaries [10]:

$$r_{SPZ} = K_1 K_2 \sqrt{N_e},$$  \hfill (1)

where $N_e$ – total electric power of the TPP, MW; $K_1$ – coefficient of the equipment types and features of the noise propagation from it; $K_2$ – operating mode coefficient [10].

The most correct way to determine the SPZ boundaries of the TPP is to calculate according to the formulas of ISO 9613-2: 1996 [11]. In this case, the individual sound power levels of each unit of equipment, noise propagation conditions, climatic and terrain features are taken into account. Such complex calculations are performed in specialized software products. The calculation is carried out according the formula:

$$L = L_W + D_c - A,$$  \hfill (2)

where $L_w$ is the octave-band sound power level, in decibels, produced by the point sound source relative to a reference sound power of 1 picowatt (1 pW); $D_c$ is the directivity correction, in decibels, that describes the extent by which the equivalent continuous sound pressure level from the point sound source deviates in a specified direction from the level of an omnidirectional point sound source producing sound power level $L_w$; $A$ is the octave-band attenuation, in decibels, that occurs during propagation from the point sound source to the receiver.

An octave-band attenuation calculating by the formula:

$$A = A_{div} + A_{atm} + A_{gr} + A_{bar} + A_{misc},$$  \hfill (3)

where $A_{div}$ is the attenuation due to the geometrical divergence (due to the energy divergence upon emission into free space); $A_{atm}$ is the attenuation due to atmospheric absorption; $A_{gr}$ is the attenuation due to the ground effect; $A_{bar}$ is the attenuation due to a barrier; $A_{misc}$ is the attenuation due to miscellaneous other effects.

The calculations performed [12] for steam power equipment made it possible to do the following conclusions:
• When turning on the same type of equipment, there is an increase in sound levels at the receiver points. The size increase in the SPZ boundaries is proportional to the root of the TPP's electrical capacity.
• Using supercritical steam parameters causes a leap in sound levels at the receiver points. The leap is explained by the use of axial traction machines on high-power units, which are a significantly more intense source of noise in comparison with radial machines. The formula (1) can be used to describe the SPZ.
• The spread of sound level values in the receiver points is determined by the different orientation of noise sources and the barrier effect of buildings and facilities on the path of sound waves propagation.

These calculations were made for the steam power plant, which is the most typical for Russian conditions. Step-by-step input of power units is studied here. When the number of units is changing from 1 to 6 considered equipment operating on the subcritical parameters of superheated steam, with an electric power of 100 MW per unit. When turning on the power units from 7 to 10, considered equipment operating on supercritical parameters of superheated steam with an equivalent electrical power of 300 MW per unit. To reduce the border of the sanitary protection zone, the following measures can be used [10, 16, 17].

Let's compare obtained results with the results for thermal power plants with CCGT equipment. Acoustic model of a thermal power plant with the installation of a single unit of CCGT equipment is shown in Fig. 2.

![Figure 2](image)

*Figure 2.* Scheme of CHP’s buildings and noise sources: 1 – boiler and turbine workshop buildings, chimneys and air intake of the blower fan; 2 – cooling towers; 3, 4 – gas distribution stations; 5 – indoor switchgear; 6 – diesel fuel pumping; 7 – fuel oil pumping; 8 – CCP buildings, chimney, roof fans, transformers, integrated air cleaning device, booster compressor station, dry fan cooling tower; 9 – gas pipelines.

Let's consider changing the size of SPZ when turning on 4 identical CCGT units by stages. The results of the calculation at the same receiver points (R-1 – R-4) are shown in Fig. 3. At points R-3 and R-4, there is a slight increase in sound levels when new CCGT units are turned on. At point R-2, the sound
levels remain unchanged when new blocks are turned on. This is because the main source of noise of the new equipment – the gas control point – is barriered by the CCGT building relatively the R-2 point. Roof fans located on roofs of different levels are also barriered by the CCGT building. At R-1, on the contrary, there is a decrease in sound levels. This result is explained by the orientation of the CCGT unit relatively the R-1 point. The building of the CCGT unit significantly screens the main noise sources of steam power equipment relatively the R-1 point.

![Graph showing change in sound level at receiver points when changing the number of power units.](image)

**Figure 3.** Change in sound level at receiver points when changing the number of power units.

For qualitative analysis, calculations of sound levels were performed at points separate from the STU equipment and the CCGT equipment. The results are shown in Table 1. At points R-2, R-3 and R-4, the dominant source of noise is the STU equipment. Only at point R-1 the main contribution to the sound level is from the CCGT equipment.

**Table 1.** Sound levels at receiver points separately from the STU and CCGT equipment

| Receiver point | 7 power units | 8 power units | 9 power units | 10 power units |
|---------------|--------------|--------------|--------------|---------------|
|               | STU          | CCGT         | STU          | CCGT          |
| R-1           | 50,4         | 51,4         | 49,6         | 51,8          |
| R-2           | 60,1         | 37,8         | 60,1         | 38,5          |
| R-3           | 42,1         | 36,3         | 42,1         | 37,5          |
| R-4           | 52,0         | 48,4         | 52,0         | 48,5          |

Figure 4 shows a comparison of SPZ boundaries for three variants of equipment structure: before the expansion of the TPP with CCGT units, with 1 CCGT units and with 4 CCGT units. Also, Fig. 4 shows the approximate boundary of the regulatory sanitary protection zone. The comparison shows that increasing the TPP capacity three times from 600 to 1800 MW does not lead to a qualitative change in the SPZ boundary, which for all cases approximately has the same distance from the station boundaries. The visible change in the SPZ boundary is not due to changes in the power of the TPP, but
to the appearance of buildings CCGT units, which are obstacles for noise sources. Thus, the use of combined-cycle technologies allows increasing the capacity of thermal power plants practically without restrictions in the conditions of existing residential buildings. Even though 51 noise sources were added to the model when each new unit was introduced SPZ boundaries did not change. In this case, the noise levels in the receiver points will be determined only by the relative location of the noise sources and buildings that are artificial barriers and reflection surfaces.

The results of the calculation show that for CCGT units with noise reduction measures, the estimation of the size of the SPZ boundaries using the semi-empirical formula (1) is incorrect. In this case, special software must be used to determine the boundaries of the SPZ, considering individual characteristics.

### 3. Influence of climatic conditions on the size of the SPZ

Usually, the boundaries of the SPZ by the acoustic impact factor are determined based on calculations performed for fixed climatic conditions. Temperature and humidity are selected for this area, and its changes are not considered in the calculations. In articles [13-15], it was shown that the influence of climatic conditions for certain average geometric frequencies leads to a significant change of sound pressure levels at the receiver points. This change reaches tens or hundreds of decibels. The influence of climate factors leads to the fact that the calculated border of the SPZ will change during the year. Thus, it is necessary to calculate and consider a certain interval in which the SPZ border is locating.

For the considered TPP with 4 CCGT blocks, the analysis of SPL changes for the SPZ border at 300 m was performed. A total of 122 cities in Europe were considered. The results are shown in Table 2. For the cities considered the maximum change of the atmospheric attenuation coefficient is determined by the values of average monthly temperature and humidity for each city as:

\[ \Delta \alpha = \alpha_{\text{max}} - \alpha_{\text{min}}, \]  

(4)
where $\alpha_{\text{max}}$ and $\alpha_{\text{min}}$ are the maximum and minimum values of the atmospheric attenuation coefficient during the year for a city for each octave-band frequency.

The change of SPL for frequencies 500-8000 Hz was determined by the formula:

$$\Delta L = \Delta\alpha \cdot d,$$

(5)

where $d=300$ m is the distance to SPZ boundaries.

As shown in [13] for octave bands 31.5-250 Hz, the influence of climate factors is not appropriate to consider, since it is comparable to the error of calculations and measurements.

**Table 2. Annual change in the SPL at the border of the SPZ**

| $f$, Hz | 500 | 1000 | 2000 | 4000 | 8000 |
|---------|-----|------|------|------|------|
| $\Delta L_{\text{max}}$ (city) | 0,5 (Pòdgorica) | 1,6 (Levi) | 5,4 (Levi) | 11,2 (Vitebsk) | 25,8 (Veliko Tarnovo) |
| $\Delta L_{\text{min}}$ | 0,2 (Porto) | 0,2 (Aberdeen) | 0,2 (Porto) | 1,4 (Belt Valletta) | 8,1 (Sevilla) |

Depending on the configuration of the SPZ boundary, the influence of climate factors will differ with constant values of the attenuation coefficient. In this case, the configuration affects the distance from the noise source to the calculated point, which leads to a quantitative change in the absorption of sound wave energy by atmospheric air. For example, in this case, for 4 CCGT units, the distance to the SPZ borders in the northern, eastern, southern, and western directions is 1550, 1910, 360 and 1400 m, respectively. Thus, the minimum uncertainty width of the SPZ border will be observed in the southern direction. In the north, east and west directions, the width of the border uncertainty of the SPZ will be 4.3, 5.3 and 3.9 times more, respectively.

4. **Conclusion**

1. The width of the sanitary protection zones depends on the type of equipment installed and its quantity and differs significantly for steam power equipment from combined cycle unit equipment.
2. For the same type of steam power equipment, an increase of the SPZ boundaries is observed in proportion to the root of the electric power of the TPP. Using supercritical steam parameters causes a leap in SPL at the receiver points. This is due to the use of axial machines on high-power units, which are a significantly more intense source of noise in comparison with radial machines. The formula (1) can be used to describe the SPZ.
3. The use of combined-cycle gas equipment (CCGT) to increase the capacity of thermal power plants from 600 to 1800 MW does not lead to a noticeable change in the SPZ boundary. The SPZ border for all cases is approximately the same distance from the station. Some changes in the SPZ border are due to the appearance of buildings in CCGT blocks, which are obstacles for noise sources. The use of combined-cycle technologies allows increasing the capacity of thermal power plants almost without restrictions in the current residential development. The SPZ calculation must be performed in accordance with equation (2).
4. Climate factors affect the width of the SPZ. Changing the width of the sanitary protection zone is especially important for octave bands 500-8000 Hz.
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