Features and problems of environmental pollution from decentralized heating systems (on the example of Chita)

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Abstract. This article is devoted to the study of the environmental load of decentralized energy facilities using the example of furnace heating in Chita. Existing residential and non-residential buildings heated with household stoves and low-power boilers increase the environmental burden on the environment. There are tendencies to switch to long-burning boilers. An analytical assessment of the change in the amount of emissions of the main pollutants when changing the operating modes of boilers is presented. Mechanisms for solving problems are proposed.

1. Introduction

Ambient air quality has a direct impact on human health. In 2018, Chita entered the list of cities with the dirtiest air. In 2019, a significant excess of the MPC of harmful emissions was also recorded, including for phenol, dust and suspended solids, benzo(a)pyrene, the vast majority of emissions of which are accounted for by numerous energy enterprises - Chita CHP-1 and Chita CHP-2, and also a number of boiler houses, also fueled by coal [1]. Despite the proven harm of carcinogenic benzo(a)pyrene, other emissions in the air also cause significant damage to human health, including: carbon monoxide, nitrogen dioxide, sulfur oxide, heavy metals, formaldehyde, dioxin, fine particles, ash, phenol, the emissions of which, in turn, are incorrectly attributed only to energy facilities. In addition to the obvious contribution of CHP and boiler houses, as well as numerous road transport, there is a problem of stove heating that is rarely considered in scientific research.

In the winter of 2019-2020, cases of high and extremely high air pollution were recorded in Chita and the Zabaikalsk, an excess of MPCs for phenol, dust and suspended solids was noted, dense smog with a characteristic odor, and reduced visibility were observed [2]. The geographical location of the city in a lowland (foundation pit) and calm weather contributes to the stagnation of smoke and combustion products and the formation of dense smog.

Despite the existing program for the closure and modernization of boiler houses in the city of Chita and the ambitious plans of the KarboFEC company to equip the Zabaikalsk with thermo-robot boilers in particular [3], and the Clean Air project within the framework of the Ecology national project in general [4], at present, in the Zabaikalsk, a rather alarming situation has developed in terms of the incidence of respiratory organs.

In 2018, an increase in the incidence of oncological diseases was noted in the Zabaikalsk. In the Aginsky district, an increase was noted by 1.76 times, in Chita - by 1.21, in Petrovsk-Zabaikalsk by 1.24, in Ulyotovsky, Shelopuginsky and Shilkinsky - by 1.1. At the same time, according to the
analytics of the regional Rosprotrebnadzor, in the list of oncology incidence in the period from 2011 to 2015, the first place was taken by cancer of the trachea, bronchi and lung [5].

2. Materials and methods

The problem of furnace heating emissions from the private sector is currently insufficiently considered in the scientific literature.

Wood burning stoves and low power coal boilers are widespread in the private sector of the city. Burning wood releases the following chemical compounds into the air: carbon monoxide, nitrogen dioxide, sulfur oxide, heavy metals, formaldehyde, ash, phenol, and fine particles. At the same time, in addition to wood, coal fuel is often used in heating stoves, however, unlike energy facilities, chimneys of private residential buildings are not equipped with ash collectors, and emissions from domestic heating stoves are not standardized and are not measured.

The problem of incineration of household waste (including plastic, highly toxic during combustion) in household heating furnaces is a separate issue. So, residents of Chita have repeatedly reported about the incineration of household waste at the bases on Lazo Street, but no significant measures were taken on this problem.

It is difficult to estimate the volume of housing in Chita heated with stove heating, and it can be called sufficient to be one of the causes of air pollution in Chita [6], while the option voiced by the head of the city E. Yarilov to minimize furnace heating emissions is gasification - does not seem very likely in the current economic conditions.

At the same time, the federal government deprived the region of 860 million rubles, previously assumed for the implementation of the "Clean Air" program within the framework of the national project "Ecology", which in fact led to the suspension of all work under the program [7].

In addition, at present, there is a growing demand for boiler plants that ensure the duration of combustion. Their feature is work with a reduced excess air ratio. Combustion with a low excess air ratio is longer in time, however, it increases the amount of harmful emissions.

It is possible to assess the danger of a transition in the private sector to long-burning boilers analytically, using the methodology for determining emissions of pollutants into the atmosphere when burning fuel in low-power boilers [8]. The methodology is intended to determine emissions of pollutants into the atmospheric air with flue gases from boiler units with a steam capacity of up to 30 t/h and hot water boilers with a capacity of up to 35 MW (30 giga calories/h) based on the data of periodic measurements of their concentrations in flue gases or by calculation when burning solid, liquid and gaseous fuels.

Nitrogen oxides (NOx), carbon monoxide (CO) and benzo(a)pyrene (C20H12) are of the greatest interest in estimating emissions, since for them the intensity of the formation processes correlates with a change in the fuel combustion mode. The emission of sulfur oxide (SO2) is mainly due to the chemical composition of the fuel and the processes of binding of oxide to fly ash, and therefore, within the framework of the method, it is impossible to assess the effect of combustion modes in the boiler on SO2 emissions without additional experimental studies.

The excess air coefficient in the furnace is taken as a parameter characterizing the combustion mode.

The calculation of NOx in terms of NO2 emitted into the atmosphere with flue gases from boilers with solid fuel layer combustion is carried out according to the formula (1):

$$M_{NOx} = B_p \cdot Q_i^f \cdot 0.35 \cdot 10^{-3} \cdot \alpha_T \cdot \left(1 + 5.46 \cdot \frac{100 - R_6}{100}\right) \cdot \sqrt[4]{Q_i^f \cdot q_r \cdot \beta_r \cdot k}$$

where: $B_p$ - estimated fuel consumption, kg/s; $Q_i^f$ - lowest heat of combustion of fuel, MJ/kg; $\alpha_T$ - coefficient of excess air in the furnace; $R_6$ - characteristic of coal particle size distribution, %; $q_r$ - thermal stress of the combustion mirror, MW/m2; $\beta_r$ - dimensionless coefficient taking into account the recirculation of flue gases; $k$ - is the conversion factor.
According to the formula, NO\textsubscript{x} emissions are directly proportional to the combustion air excess ratio.

In the absence of instrumental measurement data, CO emissions can be estimated by the ratio (2):

\[ M_{CO} = 10^{-3} \cdot B_0 \cdot q_3 \cdot R_1 \cdot Q_i \]  \hspace{1cm} (2)

where: \( q_3 \) - heat loss due to chemical incompleteness of fuel combustion, \%; \( R_1 \) - coefficient that takes into account the share of heat loss due to chemical incompleteness of fuel combustion due to the presence of carbon monoxide in the products of incomplete combustion.

A feature of the CO calculation is an implicit dependence on the excess air ratio in the furnace. With standard estimated calculations, CO emission will not depend on \( \alpha_T \) since losses \( q_3 \) practically do not change within the normal combustion mode with excess air greater than 1.1. However, long-burning boilers operate in modes of oxygen deficiency, in such conditions, an exponential increase in losses \( q_3 \) occurs [9]. Accounting for underburning will indirectly assess the impact of excess air on CO emissions.

The \( \text{C}_2\text{H}_12 \) emission calculation is estimated by the ratio (3):

\[ M_{\text{C}_2\text{H}_12} = 10^{-3} \cdot \left( \frac{A \cdot Q_i^{1.2}}{\exp(2.5 \cdot \alpha_T)} + \frac{R_2}{t_n} \right) \cdot \left( \frac{D_n}{D_f} \right)^{1.2} \cdot \left( 1 - \eta_z \right) \cdot \frac{\alpha_T}{1/A} \cdot V_{cr} \cdot B_0 \cdot k \]  \hspace{1cm} (3)

where: \( A \) - coefficient characterizing the type of grate and the type of fuel; \( R_2 \) - coefficient characterizing the temperature level of the screens; \( t_n \) - saturation temperature of water at the outlet from the boiler, °C; \( D_n / D_f \) - ratio of nominal to actual boiler load; \( \eta_z \) - degree of gas purification in the ash collector for ash, \%; \( V_{cr} \) - the volume of dry flue gases formed during complete combustion of 1 kg of fuel, with an excess air ratio of 1.4, m\textsuperscript{3}/kg.

3. Results

Using the above dependences, the calculation of a low-power boiler at 90% of the load with a thermal stress of the combustion mirror of \( \approx 0.500 \text{ MW/m}^2 \), burning 0.62 kg/s of fuel with a net calorific value of 13.44 MJ / kg, was carried out. The calculation was carried out in a wide range of changes in the excess air ratio. The calculation results are shown in figure 1.

![Figure 1](image)

**Figure 1.** Change in the amount of pollutants in the flue gases from the boiler at different values of the excess air ratio in the furnace.
For correct visualization of the dynamics of changes in various substances, the $M_{C_{20}H_{12}}$ emission in Figure 1 is presented with a factor of $10^5$.

Analyzing the emissions of harmful substances at different air excess ratios and based on the calculations made, the following can be noted:

If the excess air ratio of 1.2 is taken as the normal operating mode, then when the excess air ratio decreases to 1, nitrogen oxide emissions decrease by 16%, CO emissions increase by 400%, benzo(a)pyrene emissions increase by 10%.

When the excess air ratio drops to 0.9, nitrogen oxide emissions decrease by 25%, CO emissions increase by 900%, and benzo(a)pyrene emissions increase by 16%.

Considering the hazard classes of substances, it can be concluded that reducing the excess air in the boiler furnace increases the environmental load on the atmosphere, even despite the reduction in NO$_x$ emissions.

It is worth noting that in long-burning boilers from responsible manufacturers, a system is organized for the afterburning of fuel pyrolysis products, which solves the problem of CO emissions. Working with such boilers requires increased attention to the combustion and afterburning processes, which is not always done in domestic conditions.

The problem associated with an increase in the emission of benzo(a)pyrene is currently difficult to solve and requires additional study [10-12]. For small boilers, there is no effective solution to suppress benzo(a)pyrene.

In practice, there are modernizations of standard boilers for long-burning boilers without post-combustion, and the operation of standard boilers with a low excess of air. The main goal pursued by people with such modernizations is to reduce the number of fuel fillings. The environmental factor is ignored.

4. Discussion
To solve such a large-scale problem, several solutions can be proposed.

First, the use of cleaner fuels. For example, in the Krasnoyarsk Territory, there is experience in the manufacture of smokeless coal (smokeless briquettes) by SUEK. This type of fuel is positioned by the manufacturer as environmentally friendly: fuel is pressed under high pressure and high temperature, which allows removing harmful substances immediately during production. Smokeless briquettes burn without waste, due to which coal dust is not poured through the grate into the ash pan and does not fly out into the chimney [13]. At the same time, the calorific content of smokeless briquettes reaches 6000 - 7000 giga calories/kg.

Secondly, the introduction of administrative responsibility for the incineration of highly toxic waste in household stoves and low-power boilers, intensive work of the supervisory authorities to identify the facts of such emissions; development of a program to support and subsidize the purchase of smokeless fuel for low-income groups of the population.

Third, the development of new models of low-power energy-saving boilers (for example, with heat storage) and the introduction of energy-saving measures.

It is possible to combine the duration of the boiler operation on one fuel tab and prevent an increase in harmful emissions by quickly burning fuel under optimal conditions with the accumulation of heat in accumulators with its further use. In this connection, the technology of boilers with heat storage seems to be the most promising for use for these purposes.

5. Conclusion
The problem of furnace heating emissions from the private sector currently requires attention and detailed study.

There is a tendency to switch to boilers that burn in an environment with a low oxygen content, which negatively affects the environmental situation in the residential area.

Analytical calculations show an increase in the emission of the most dangerous substance - benzo(a)pyrene when switching to combustion with a small excess of air in the furnace.
Of particular interest is the direction of development of new models of low-power energy-saving boilers with heat accumulation, which can combine the advantages of long-burning boilers and boilers operating with an optimal excess of air.

Unfortunately, these measures are quite costly and are hardly feasible without centralized funding. This topic presupposes a great research potential not only for power engineers and ecologists, but also for economists, because, as Academician M.A. Styrkovich said, “Energy is physics plus economics”.

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