Environmental Problems of Solid Fuel Combustion in House Furnaces and Small Boilers and Ways their Solution

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Abstract. This work is devoted to the determination of the volume and composition of emissions into the atmosphere during the combustion of solid fuels (coal, wood) in house furnaces and small boilers with capacity till 1 Gcal/h. The relevance of this work is stipulated by the fact that a large number of small boiler operate in Russia, especially in rural and decentralized areas of energy supply. In addition, each city has many private residences heated by wood and coal-burning house furnaces. The large coal reserves, as well as its low cost, make it a priority fuel, especially in the eastern regions of the country. When coal and wood are burnt in small heat sources, the resulting emissions enter directly into the atmosphere surface layer, where human activity is carried out. Thus, using the example of Irkutsk Oblast, it has been demonstrated that the burning of high-ash Cheremkhovsky coal in house furnaces produces the estimated amount of emissions that is 4.4 times higher than that produced by small boilers. Such amount of emissions is due to the low efficiency of coal combustion. As a result, conducting environmental assessments of the impact of small boilers and house furnaces on the environment help formulate the main environmental problems and determine the range of issues that need to be solved.

1. Introduction

The Russian Federation has extensive zones of decentralized heat supply due to the economic inexpediency of creating district heating systems in the areas with low density of thermal loads. First of all, this applies to rural areas and urban areas with low-rise buildings. The housing development programs in Russia have been changed to accelerate construction of individual low-rise houses and at the same time we can now observe an overall increase in the well-being of the population. All this implies the preservation and, probably, the upscale of decentralized heat supply. Such trends take place in developed foreign countries, for example, Canada, Scandinavian countries, etc.

The main types of heat sources for decentralized heat supply are boiler stations with boilers of small unit capacity (up to 1 Gcal /h) with layer combustion of solid fuel (coal, wood) and manual loading. For example, in Irkutsk Oblast the number of such boiler stations is close to 75% of the total number of operating boiler stations. Basically, it is coal boiler stations, and only about 15% of them operate on wood fuel. It is worth noting that 24-27% of Russian population lives in rural areas and exploits house stoves for individual heat supply. At the same time, such heat sources are characterized by low energy and environmental efficiency, as well as by a high cost of produced thermal energy.

Small boilers and house furnaces are the main sources of pollution of the atmosphere surface layer. Therefore, the problem of radical improvement of the energy, environmental and economic efficiency
of decentralized heat supply remains highly relevant. To address this issue, it is necessary to develop modern highly efficient and environmentally friendly heat sources.

The research in the field of low-power heat supply systems shows that, despite the emergence of new more modern technologies that increase the efficiency of heat production and provide better environmental indicators, they are not implemented into real heat supply systems due to the fact that they require significant investments. In this regard, the upgrade of such boiler stations is rarely performed. This happens, in particular, because of the lack of systematic technological research in this area. Official statistics do not contain data on the impact of numerous small boiler stations and home furnaces on the air basin. The only available information is the data on large sources of pollutant emission into environment [1].

At present, impact assessments are carried out on the basis of existing and approved at the state level methods for calculating pollutant emissions into the atmosphere by boiler plants with a capacity of less than 20 Gcal/h [2, 3]. These methods determine the amount and component composition of emissions (solid particles, sulfur oxides and nitrogen oxides). The amount of emissions depends on the quantity and qualitative composition of the fuel burned in the boiler, the incineration conditions and the purification equipment operation.

The aim of the present paper is environmental assessment of the contribution made by small emission sources into the air basin, as well as the development of guidelines and environmental measures to reduce the impact of such energy sources. This research was carried out using Irkutsk Oblast as a case study.

2. Assessment of the contribution made by small boilers into the atmosphere of Irkutsk Oblast

Irkutsk Oblast has 1108 big and small boiler stations. 621 of them are coal-fired stations (56% of the total number); 284 are electric boiler stations (26%); 157 are wood-fired stations (14%); 42 stations operate on liquid fuel (4%). There are 465 coal-fired and 151 wood-fired heat sources with boilers up to 1 Gcal/h in Irkutsk Oblast. The majority of them are the boiler stations that make emissions through the stacks of up to 60 m high into the atmosphere surface layer. Of course, such emissions do not enter into long-range transport and have a direct impact on the population living in the territory. The assessment of the impact of heat supply sources on the atmosphere is carried out depending on the volume of fuel burned. According to the data of forms of Rosstat 4-TER. "Fuel consumption by fuel in the Irkutsk region in 2016", the volume of coal consumption in the boiler stations of Irkutsk Oblast in 2016 amounted to 2 million 61 thousand tons, wood fuel to 156.7 thousand tons, fuel oil and oil to 158 thousand tons.

The flue gases purification is accounted for depending on the type and power of boilers in the boiler stations. It is established that no purification is performed in the boiler stations with small-capacity boilers and manual fuel supply, and the situation is same in the majority of medium-power plants (from 1 to 10 Gcal/h) with mechanized fuel supply and a furnace with a shaking bar. Boiler units with mechanized fuel supply and chain grating are structurally connected with cyclones of different types (single, battery) and have an average degree of purification from solid particles up to 80%. In large boiler stations that have boilers with a capacity of more than 10 Gcal/h, the degree of purification from solid particles is set to be 90%.

Table 1 shows the results of calculating the amount of emissions of all boiler stations in Irkutsk Oblast, depending on the degree of purification of the flue gases and the type of fuel. In general, the emission is estimated at 121.2 thousand tons per year.

Approximately 80% (or 96 thousand tons) of all boiler emissions are solid substances, and about 20% (or 25 thousand tons) are sulfur oxides. The greatest contribution to emissions is made during the operation of coal heat sources without purification (56% of the total estimated emission).

In the framework of this study, we focus on boiler stations with low-capacity boilers with no flue gases purification. There are 616 of such stations in Irkutsk Oblast. Based on the volume of fuel burned by these power facilities, we carried out a calculation of pollutant emissions into the atmosphere.
Table 1. Estimated emission of boiler stations in Irkutsk Oblast in 2016, kt.

| Degree of flue gases purification (for coal), % | Type of fuel | Total |
|----------------------------------------------|--------------|-------|
|                                              | Coal         | Wood (pellets) | Fuel oil, oil |
| 0                                            | 68.1         | 2.7             | 2.2           |
| 80                                           | 34.6         |                 |               |
| 90                                           | 13.6         |                 |               |
| Total                                        | 116.3        |                 | 121.2         |

The small boiler stations consumed 308.3 thousand tons of coal and 156.7 thousand tons of wood fuel. The total emission made by small heat sources is estimated at 41.5 thousand tons per year, table 2.

Table 2. The amount of emissions made by small boilers in Irkutsk Oblast in 2016.

| Fuel            | Emissions, kt/year |
|-----------------|--------------------|
|                 | Particulate matter | Sulfur oxides | Nitrogen oxides | Total |
| Coal            | 36.7               | 3.5           | 0.1             | 40.2 |
| Wood            | 1.2                | 0             | 0.03            | 1.25 |
| Total           | 37.9               | 3.5           | 0.13            | 41.5 |

The emissions made by the boiler stations under consideration are characterized by the predominance of particulate matter in the total emission: up to 91% for coal combustion and up to 96% for wood burning.

The bulk of pollutants comes from coal-fired boiler stations. Wood burning boilers burn 3 times less fuel (in conventional fuel), but emissions of pollutants into the atmosphere are 32 times lower, and there are no emissions of sulfur oxides.

Therefore, the contribution of small boilers in the total emission of all boiler stations in Irkutsk Oblast is estimated at 34%.

The amount of ash-and-slag wastes was determined on the basis of recommendations from [4-5] and happened to be 250 thousand tons in Irkutsk Oblast in 2016. Of this volume, the share of small boiler stations is 15.4% (or 38.5 thousand tons in year).

It should be highlighted that ash wastes from the burning of wood fuel are almost harmless and can be used in agriculture, whereas ash-and-slag wastes require a special storage place.

Estimating the amount of emissions from house furnaces is a challenging problem due to the complete lack of the environmental statistical data and information on both the volume of fuel consumed and the equipment used for its combustion. In this situation, it is suggested to use expert estimates developed by the authors of the current study.

In Irkutsk Oblast, individual heat supply in settlements with private residential buildings equipped with furnaces requires 132 kg of birch firewood, 88 kg of brown coal and 71 kg of coal per year to heat 1 m$^2$. As a rule, an individual house has an area of about 100 m$^2$, which means that the volume of fuel consumption per year is: 13.2 tons of firewood, 8.8 tons of brown coal and 7.1 tons of hard coal.

Taking into account that rural population in Irkutsk Oblast is 508,227 people with an average 3 people in a household, the number of stove-heated houses is estimated at 170,000 (according to the data of Federal Service of State Statistics in Russia). They use brown coal from the Azey斯基 mine, and hard coal from the Cheremkhovsky mine. The fuel characteristics are presented in table 3 [6-8].
Table 3. Characteristics of fuels used in stove-heated houses of Irkutsk Oblast.

| Fuel Type, label | Ash content, % | Sulphur content, % | Calorific capacity, GJ/kg |
|------------------|---------------|-------------------|--------------------------|
| Azeysky coal     | 23            | 0.4               | 16394                    |
| Chereemkhovsky coal | 31            | 1.5               | 18110                    |
| Woodfire         | 0.6           | 0                 | 10224                    |

In accordance with the recommendations for the combustion of solid fuels in a layer furnace, for the selected fuels we calculated the emissions of pollutants into the atmosphere from furnaces in private households with a house area of 100 m², table 4.

Table 4. Emission of furnaces that heat houses with an area of 100 m².

| Type of fuel | Emission made by a single house furnace t/year | Emission made by all houses furnaces, kt/year |
|--------------|-----------------------------------------------|---------------------------------------------|
| Firewood     | 0.808                                         | 136.9                                       |
| Brown coal   | 0.885                                         | 149.9                                       |
| Hard coal    | 1.65                                           | 279.7                                       |

Assuming that in the houses of rural areas of Irkutsk Oblast 50% of the fuel is firewood, 20% is brown coal and 30% is hard coal, then 182.4 thousand tons of pollutants are additionally emitted into the atmosphere of the region. The amount of emissions produced by house furnaces is 4.4 times higher than that made by small-capacity boiler stations and 1.5 times higher than emissions made by all boiler stations. Such a large amount of emissions is associated with a low efficiency of the combustion of solid fuels caused by high chemical and mechanical heat losses.

This fact is stipulated by the low qualification of people exploiting the furnaces (most of such heating facilities are makeshift), as well as by the lack of necessary control and measurement equipment. It is important to highlight that statistical data of emission do not cover such category as small boiler stations and households that make a significant contribution to air pollution.

Therefore, we can single out the following environmental issues associated with the solid fuel burning:

- Absence of emissions from large and small boiler stations and from house furnaces of residential areas in the environmental statistics. They can add additional 30-45 % to the total emission from stationary energy sources.
- Emission from small capacity energy sources directly enters the atmosphere surface layer. Composition of emissions is dominated by particulate matter.

3. Key measures to reduce the impact of small capacity energy sources

Evaluation of the contribution made by small energy sources to the impact on the environment, as well as the identified environmental issues, help work out general directions and specific organizational, environmental, economic and technological measures [9].

Organizational measures imply improvement of the state regulation system, the formation of an effective legislative and regulatory framework. Environmental and economic measures are aimed at
stimulating the environmental activities of enterprises through economic mechanisms; technological measures are associated with improvement of production techniques and nature protection strategies.

It is important to provide a high level of labour and technological discipline at heat producing facilities, including the improvement of the system of environmental training for personnel and the strengthening of the role of social programs.

At present, it is quite popular to diversify energy sources through using renewable sources of energy and clean fuels.

It is should highlight the following directions for reduction of emission from small boilers and house furnaces:

- Preliminary preparation of fuels prior to combustion.
- Use of modern automated boilers.
- Application of technological measures to suppress the formation of harmful impurities in the combustion of fuels (design changes, regulating modes, the use of additives in the fuel path in low-capacity boiler stations).
- Transition to clean fuels such as wood pellets and natural gas.
- Use of dust collecting devices, with a degree of purification of at least 90%.

Application of any of these directions requires environmental and economic justification. Nevertheless, we can single out priority and low-cost measures among them. First of all, given that coal is the cheapest type of fuel in several regions and its reserves are significant, it is necessary to organize pre-burning coal preparation: sorting, storing, loading, unloading and protecting against wind erosion and waterlogging. Private households should be provided with quality sorted coal.

In this regard, it is necessary to develop coal preparation technologies for environmentally friendly combustion by removing harmful and polluting components from fuels. Thermal preparation of coal provides almost complete removal of nitrogen and sulfur compounds, which significantly reduces or completely eliminates the emission of oxides into the atmosphere. It also reduces slag and ash due to a minimized fuel consumption (up to 1.5 times), and increases the thermal energy production efficiency.

Organization of technological (construction and performance) activities improves fuel burn-out and reduces heat losses. The activities include timely repairs, reduction of air inflows, and introduction of additional boiler linings. Performance activities are associated with the change and regulation of the combustion process and require qualified personnel and implementation of technological regulations for the combustion of fuel.

As for private households, the owners could be motivated to use renewable energy installations through a system of economic benefits (special payments, tariffs etc.) and development and implementation of environmentally friendly technologies.

4. Conclusions
The current study resulted in the following findings:

- The assessment of the impact of burning solid fuels in small capacity boilers has revealed environmental issues, the main one of which is the emission of pollutants into the atmosphere surface layer. Using Irkutsk Oblast as an example, it has been shown that the greatest contribution to emission is made by coal-fired small boilers and can reach 34% of the total emission from all heat sources. If we take into account the contribution made by house furnaces, the emission increases 1.5 times.
- Calculation of the amount and ingredient composition of emissions from small boiler stations and house furnaces has shown that the decrease of human-caused effect on the atmosphere is a priority task that can be executed by the transition to environmentally friendly technologies which reduce emissions of particulate matter. In the total amount of emissions, particulate matter makes up to 90% and more.

- A significant amount of estimated emissions from house furnaces is associated with a poor organization of fuels combustion, especially when it comes to coal.
• From the environmental standpoint, the use of high-quality coal or firewood, both in small boilers and house furnaces, seems to be most promising. When using coals for environmentally friendly combustion in small boiler stations, the technologies of preparation and improvement of the coal quality significantly reduce the cost of energy.

5. References
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