Research and operating experience of long-burning boilers in the North-East of Russia

Egor Slobodchikov

1Institute of Engineering & Technology, M. K. Ammosov North-Eastern Federal University 677000, 58, Belinskogo Street

E-mail: egor-sakha@mail.ru

Abstract: In Yakutia, there is a tendency to build individual houses in rural areas. Due to the complex geographical location, economic problems and transport and logistics difficulties, it is not possible to connect many settlements to centralized sources of energy supply. Therefore, the demand for efficient autonomous sources of thermal generation due to the use of local solid fuels has recently increased. Practice shows that heat generators of imported and national manufacturers are not adapted to work at low outdoor temperatures. In the climatic conditions of the North-East of Russia, one of the important tasks is to increase the reliability and efficiency of heat generation sources; this is a necessary condition for ensuring comfortable working and living conditions for a person.

1. Introduction

The utilities of Yakutia are formed by heat generation facilities, heat carrier transportation and infrastructure facilities. In almost all districts and cities of the republic, there is a high level of deterioration of heating networks, which does not allow for the adequate performance of heat supply systems. The average wear rate reached 56.9% [1, 2]. Also, according to the Ministry of Housing and Utilities and Energy of the Republic of Sakha (Yakutia), the level of provision of the rural population with centralized sources of energy supply (gas, central heating, electric heating) is only 51.1 %; the average number of residential buildings in rural areas that are not provided with central energy sources of heat is 41427 units. A characteristic feature of the territories is:

- low population density, chaotic development of micro districts, which does not allow to cover all with the radius of effective heating of centralized sources of heat generation;
- transport and logistics inaccessibility of settlements, lack of year-round contact with major cities;
- high costs for the extraction and transportation of boiler fuel (coal, fuel wood);
- lack of comprehensive housing and communal utility services to the population (there are no or impossible implementation of programs of heat supply, gasification, electric heating, etc.);
- high cost of generating heat energy from centralized sources.

In connection with the above factors, there is a tendency to build individual houses in the Arctic and subarctic zones of the North-East of Russia with the use of autonomous heat generators on solid (local) fuel. In the republic, various types of lower burning boiler units (Zota, Uragan, Teplodar, Kiturami) and upper burning (Liepsnele, Stropuva, Candle) ones, as well as brick and homemade heaters of water and convection type, are actively operated in the districts and settlements. Heat generating units are the main component of the heat generation system. Their efficiency determines the cost of production and the profitability of heat supply to consumers of utilities [3]. The heat
generating unit is the main element of the heating and hot water supply system of buildings. High-quality, uninterrupted and fail-safe operation of the entire system depends on the elaboration and pilot testing of design solutions with the peculiarities of the climate and the environment [4, 5, 6].

The climatic features of Yakutia require increased reliability to the efficiency and functioning of engineering systems. One of the characteristic features of the climate of Yakutia is a large annual temperature range, which ranges from 50-127 °C. The temperature of the coldest five-day outdoor air ranges from -50°C to -65 °C, and in other regions of Russia from -25 °C to -41 °C, which is a difference of more than 20 °C. One of the characteristic features of the climate of Yakutia is a large annual temperature range. For a more visual representation of the severity of the climate, Figure 1 shows the values of the DDHP for typical cities in Russia and Europe, as well as localities in Yakutia.

![Figure 1. Degree-day of heating period for various cities in Russia and Europe.](image)

As can be seen from the figure, the values of the DDHP for cities in most of Russia significantly exceed the values of the DDHP for European cities, while the severity of the values for the Republic of Sakha (Yakutia) exceeds the values of Russian cities significantly, and European cities by 2-3 times and is 8000-12000. The considerable duration of the heating period, the presence of permafrost, poorly developed energy infrastructure, and the lack of logistics between settlements, that are mostly sparsely populated, create special difficulties for the construction and human life support in the North [7, 8, 9].

2. Materials and methods
The most important advantages of autonomous heat supply are a significant reduction in construction time, a reduction in capital costs, a reduction in heat loss and the elimination of leaks during transportation via external heating lines, the elimination of costs for the repair and operation of heating lines, the possibility of local regulation, etc. [10]. The features and general characteristics of autonomous heat supply are described in the works of G.M. Klimov, V.I. Sologaev, O.K. Mazurova, N.V. Kuznetsov, A.N. Butenko, et al. [11, 12]. Since the beginning of the 2010s, solid fuel boilers using the so-called “top” burning principle have been actively introduced in Yakutia. Currently, more than 2000 units of boilers that used this principle of the “Liepsnele, Stropuva, Candle” brands are operated in the republic. The main source of fuel for such autonomous systems is brown coal of the Kangalas coal deposit, coal of the Harbalakh and Dzhebariki-Khain deposits, and fuel wood of larch wood. The “top burning” heating boiler is a cylindrical body, which houses a fuel combustion
chamber, a fire grate, a container for loading the heat-transfer agent, a device for supplying and distributing air. Its distinctive feature is that the combustion takes place at low oxygen content, thereby increasing the heat transfer time of the fuel and giving less solid waste. The combustion process is carried out on the principle of a candle from top to bottom, the upper layers burn, and the lower ones wait for their turn without heat releasing [13, 14].

According to the results of observations, the operation of boilers is accompanied by the processes of soot formation of varying degrees and the formation of acid condensates, followed by the destruction of chimneys, spontaneous combustion of soot, the formation of micro cracks and the penetration of flue gases from the boiler into residential premises.

![Figure 2. The process of soot formation in the chamber of the boiler chimney.](image1)

![Figure 3. The process of formation of acid condensate on the boiler chimney.](image2)

These problems are related to the fuel humidity, the combustion mode, the heating system features, and other factors. The main fuel problems affecting the heating productivity of boilers are:
- the use of wet wood, due to the lack of dry trees, storage difficulties, remoteness of plots and cutting areas;
- low quality of brown coal with mineral impurities, soil particles and moisture, with loss of structure during transportation;

In order to study the operation of heat generators in Yakutsk, full-scale measurements of the operation of an autonomous solid fuel boiler of the Liepsnele Arctic brand, with a power of 20 kW, operated in low outdoor temperature conditions, were carried out. The installation diagram of the measuring instruments and equipment is shown in Figure 4.
Figure 4. Designations: 1 – solid fuel boiler brand «Liepnele Arctic», with a power of 20 kW; 2 – blower fan WPA 120; 3 – automation controller TAL RT-22; 4 – heat exchanger Teplocom GSM; 5 – circulation pump Wilo Star 25/4; 6 – power supply; 7 – 4-channel temperature meter Center 309; 8 – indoor air temperature sensor; 9 – outside temperature sensor; 10 – flow temperature sensor; 11 – return temperature sensor; 12 – boiler controller thermostat; 13, 14 – 1-channel meters EClerk–M-K; 15 – flue gas temperature sensors; 16 – flue gas sampling probe and boiler draft measurement; 17 – gas analyzer Testo 340.

To ensure the normal operation of the heat generating unit, it is necessary to supply air to the combustion furnace continuously, to ensure the necessary speed of movement of hot gases and to remove the resulting combustion products using draught-blowing devices [15, 16] Due to the above problems during the operation of boilers, many users switch to the installation of automated air supply systems for fuel combustion for the purpose of complete combustion of fuel, regardless of the quality and humidity, operating conditions, and so on. The test boiler unit contains a WPA 120 blower fan, a TAL RT-22 master controller and a thermostatic element. Fan operation monitoring is carried out by the controller, depending on the parameters of the heat-transfer agent in the supply line of the heat generator.
3. Results and discussion

As a result of the analysis of the conducted field surveys, the actual parameters of the flue gas temperature in the operating and non-operating mode of the heat generator were determined. The tests were carried out under natural climatic conditions and depending on the outdoor temperature in the range of -30 to -40 °C and characterize the autumn-winter period in the conditions of Yakutia, and above the calculated parameters of manufacturers and the central regions of Russia and Europe.

3.1. Based on experimental data, the dependence of the flue gas temperature parameters on the operation mode of the air blower fan, the duration of combustion on one fuel tab under the considered climate parameters, which is shown in Figure 5, is compiled.

As it can be seen from this graph, the change in the flue gas temperature depends directly on the operation of the air blowing fan into the fuel combustion chamber, which is triggered when the temperature of the heat-transfer agent of the supply line decreases $t_p<65$ °C. At the same time, when the flue gas temperature increases, the influence of the excess air coefficient on the heat loss intensity increases, thereby reducing the efficiency of the boiler unit. Also, the temperature values in the upper part of the chimney (at the gas outlet) differ significantly from the flue gas temperature values at the boiler outlet, reaching in some cases indicators close to the formation of condensate.

3.2. The transition point of the phases in the second range (~43°C) is revealed, when the boiler unit loses its operational properties, shown in Figure 6. The process of smoldering turns into intensive burning of the upper layers of coal, increasing fuel consumption, as well as reducing the coefficient of efficiency. This indicates that at peak temperature values, an increase in the volume of exhaust gases through the chimney can be observed.
4. Summary

Based on the results of the experimental studies of the operation of long-burning (top) solid fuel boilers in the climatic conditions of the North-East of Russia, it is determined that when the outside temperatures reach below -30°C and when the temperature reaches -43°C, a transition moment is observed, when heterogeneous combustion turns into normal combustion. The efficiency indicators of the boiler unit depend on the values of the draft in the chimney. Among other things, the increase in the draft inside the boiler chamber and the chimney is associated with the occurrence of excess pressure of the outside air. At the same time, the strength of the resulting pressure directly depends on the height of the boiler chimneys and the outdoor air temperature.

The operation of the heat generator with the “top” burning principle on wood fuel in winter does not exceed 12 hours due to heat losses with outgoing gases, low heat-producing value and fuel humidity, contributes to the occurrence of condensation processes on the chimney.

There are various approaches to solving the problem of eliminating the influence of condensation. Among them, there is the use of corrosion-resistant materials, reducing the humidity of the fuel (pre-drying), increasing the thermal insulation layer of the chimney.

The heat protection of buildings and their architecture plays an important role in the operation of boiler equipment and the degree of fuel combustion [17]. In the conditions of the Far North, the actual loss of heat energy through the elements of the enclosing structures of the wooden housing stock is high, which affects the efficiency of heat supply and operation of boiler equipment. When selecting a boiler unit, its nominal heat output is taken into account at low ambient temperatures, but as studies showed, the operation of the heating device is accompanied by uneven differences, where the efficiency values differ depending on the fuel combustion mode.

Figure 6. Graph of the dependence of the natural draft in the chimney of a solid fuel boiler of long-term combustion on the outdoor air temperature.
5. References

[1] Arkhangelskaya E and Arkhangelskaya Ya 2014 Methodology for assessing the need for investment for the modernization of the engineering infrastructure of rural settlements in the Republic of Sakha III All-Russian Scientific and Practical Conference “Modern problems of construction and life support: safety, quality, energy and resource conservation” (North-Eastern Federal University named after M. K Ammosov) 432-442

[2] 2011 State Program of the Republic of Sakha (Yakutia) “Provision of high-quality housing and public utility services and development of the electric power industry for 2012-2019”: decree of the Head of the Republic of Sakha of October 970

[3] Ivanov V and Ivanova A 2019 Energy efficiency of low-power gas heat generators in the conditions of the Far North (Yakutsk: NEFU) 376

[4] Ivanov V, Ivanova A and Tikhonov V 2013 On the reliability of operation of low-power gas boilers in the conditions of the North-East of Russia Industrial and civil engineering 851-53

[5] Litskevich V 1984 Housing and climate (Moscow: Stroyizdat) 45

[6] Mikheeva A 2002 Design of buildings and development of populated areas taking into account climate and energy saving: textbook 3192

[7] SP 131.13330.2012. Construction climatology. Updated version of SNiP 23-01-1999* (Moscow: Ministry of Regional Development) 120

[8] Petrova A and Gordeev M 2013 The importance of small-scale energy in the energy supply of the Far North XVI International Interuniversity Scientific and Practical Conference of Students, Master Students, Postgraduates and Young Scientists “Construction – formation of the life environment” (Moscow: Moscow State University of Civil Engineering) 606-608

[9] Klimov M 2016 Decentralized water heating systems for individual residential buildings Educational and methodological guide for full-time and part-time students in the areas of 08.03.01 Construction and 13.03.01 Heat and Power Engineering and Heat Engineering, studying at the Nizhny Novgorod State University of Architecture and Construction (Nizhny Novgorod: NNSUAC) 58

[10] Mazurova O, Kuznetsov N and Butenko A 2011 Autonomous heat supply (Rostov-on-Don: RSCU) 143

[11] 2013 Technical data sheet and installation instructions for the boiler «Liepsnele» (Vakaro Rasa)

[12] Vaganov Maxim Yuryevich, Krasauskas Valdas Russian Patent 2013137041/06, 08.08.2013. Top burning heating apparatus

[13] Elshin A, Izhorin M, Zholudov V and Ovcharenko E 2001 Smokestacks (Moscow: Stroyizdat) 296

[14] Shishkov I, Lebedev V and Belyaev D 1976 Chimneys of power plants Energy 176

[15] Feist V 2011 Guidelines for the design of passive houses 2162-163