Prospects for using combined low-power fluidized bed installations for heat supply of departmental and municipal facilities

A V Bondarev*, S V Sarkisov, S V Aleksandrov, S B Pashkin and V A Vakunenkov

Military Institute (engineering) of the Military Academy logistics support named after Army General A. V. Hrulev, 22 Zakharyevskaya, St. Petersburg, 196121, Russian Federation

* E-mail: Bondarev.aspb@mail.ru

Abstract. The article presents the scheme and principle of operation of a combined fluidized bed unit with re-utilization of heat from exhaust gases of a diesel generator and indicates the requirements for the functioning and operation of these types of installations. It presents theoretical and experimental graphs of the required volumes of air replacement with diesel exhaust gases in nominal and fractional modes, fuel economy, transients of changes in the fluidized bed temperature from time to time when various disturbing effects are applied.

1. Introduction
Nowadays, one of the options for modernizing the heat and power supply systems of small settlements is the use of installations for combined generation of heat and electricity.

A significant part of the objects of departmental and municipal formations located in the Far North, Siberia and the Far East do not have centralized heat supply systems. The remoteness of these objects predetermines the need for their autonomy. At the same time, in order to improve technical, economic and environmental indicators, it is necessary to provide for the possibility of operating these installations on various types of fuel that are available in these regions in excess, such as coal, peat, and wood waste [1-2].

2. Materials and methods
One of the most promising areas of heat and power supply to the considered objects is the joint operation of diesel-electric installations with low-power fluidized bed boilers, acting as heat recovery boilers.

Many studies have been conducted in this area of joint generation of heat and electric energy with re-utilization of heat by exhaust gases of a diesel generator in fluidized bed boilers [3-5].

The greatest attention should be paid to the study of the operating modes of a high-temperature fluidized bed boiler KVP-1.74 VTKS, with a capacity of 1.5 Gcal/hour, using various types of coal (from brown to anthracite), peat, and wood waste together with a diesel generator set with a capacity of up to 100 kW as the initial fuel. This installation provides for the supply of diesel exhaust gases to the boiler furnace chamber with a temperature of 400-450 °C and a high oxygen content [6].
The developed technological solutions make it possible to realize a number of advantages of the high-temperature fluidized bed technology, which increases their technical, economic and environmental performance. These include:

- Low sensitivity of the operation of boilers with VTKS furnaces to a heterogeneous fractional composition and heat and moisture composition.
- High reliability of operation of a narrow inclined grate due to its effective cooling by primary blast and heat extraction by submerged heating surfaces.
- Ignition of furnaces without the use of auxiliary fuel and ignition burners, eliminating the need to maintain gas or fuel oil facilities.
- Regulation of load changes from 40...120%.
- Maintaining the “fluidized bed” without adding special inert materials (sand, chamotte chips, etc.).

The device, the principle of operation of this power plant is confirmed by patents for inventions and utility models. [7-9].

3. Results and discussion

Figure 1 below shows a diagram that includes a diesel generator 1, a boiler unit 2 with a high-temperature fluidized bed furnace 4, with a movable grate 7 inclined to the horizon, heating surfaces 9, blast zones of primary 5 and secondary air 6, fuel feeder 8, fuel bunker 19, blow-off ejector 10. High-pressure fan 15 is connected to the gas inlet pipe 11, the exhaust manifold 3 of the diesel generator is connected to the exhaust gas bypass gas duct to the atmosphere 13 with a noise muffler 14. On the discharge line 12 of the blast fan, on the exhaust manifold and on the exhaust gas bypass to the atmosphere, devices for regulating the flow of media 16, 17, 18 are installed. The water is heated by pump 20 through pipeline 21.

To exclude the modes of back pressure in the air duct of the first blast zone 22, a constriction device made in the form of a truncated cone 23 is installed. The exhaust manifold of the diesel generator is connected to the air duct of this blast zone at the point of formation of the air pocket.

![Diagram of joint operation of a diesel generator with a high-temperature fluidized bed boiler.](image)

To create a high-temperature fluidized bed, air is supplied to the gas inlet by a blast fan, where it mixes with the exhaust gases of a diesel generator and enters the primary and secondary blast zones.
The introduced heat and oxygen of the gas-air mixture ensures rapid heating and fuel economy while maintaining the same thermal power of the unit as during operation without re-utilization of heat.

One of the essential features of the joint operation of a diesel engine and a solid fuel boiler with a VTKS is a strict restrictive requirement to maintain the hydrodynamic regime of the fluidized bed, so the addition of diesel generator exhaust gases to the combustion device can significantly disrupt the hydrodynamics of combustion processes and lead to a shutdown of the installation. Another requirement is limitation on the minimum value of the excess air coefficient in the boiler furnace.

As an experiment, the static and dynamic modes of operation of the high-temperature fluidized bed boiler "KVP-1.74-VTKS" with the supply of exhaust gases of the AD-60 / T-400-1P diesel engine, 60 kW, into the primary air pipeline were considered [9].

For this type of boilers, the actual combustion air consumption at nominal load is 3000 m$^3$/h with a combustion air excess ratio of 1.5. The exhaust gas consumption rate of the presented diesel generator at rated load is 960 m$^3$/h.

When the exhaust gases of the diesel generator are supplied to the combustion unit in full volume (900 m$^3$/h) the air speed in the primary air duct increases to a maximum of 16,2 m/s, and the air speed in the first blast zone also increases from 6,2 m/s to 8,9 m/s. Particles of solid fuel are carried away from the volume of the combustion unit and are deposited in the ash collector, which leads to a sharp increase in heat losses with entrainment. Thus, in order to maintain normal fluidized bed hydrodynamics and a stable fuel combustion mode, it is necessary to reduce the primary air consumption by the amount of the diesel generator exhaust gas supply to the boiler furnace.

The second essential condition for the joint operation of the diesel engine and the fluidized bed boiler is the requirement for the minimum value of the excess air ratio in the boiler furnace. At values below 1.15-1.2, the heat loss from chemical mechanical incompleteness of combustion increases sharply, which significantly affects the degree of burnup of the initial fuel.

So, the oxygen consumption in the mixture $V_{o_2}^m$ can be determined by formulas (1-3).

$$V_{o_2}^m = (1 - r) * K_{o_2,air} * V_{o_2}^d + r * K_{o_2,gas} * V_{o_2}^d$$

$$V_{o_2}^t = V_0 * K_{o_2,air}$$

where $V_{o_2}^d$ - the actual oxygen consumption in the mixture for combustion of 1 kg of fuel, m$^3$/kg

$K_{o_2,air}$ - the proportion of oxygen content in the air, (we take 0,21);

$K_{o_2,gas}$ - the proportion of oxygen content in diesel exhaust gases (0,1-0,12);

$V_{o_2}^t$ - theoretical oxygen consumption in air for combustion of 1 kg of fuel, m$^3$ / kg;

$V_0$ - theoretical air consumption per 1 kg of fuel, m$^3$ / kg;

$r$ - degree of exhaust gas recirculation:

$$r = \frac{V_{rec,gas}}{V_{cm}}$$

$V_{rec,gas}$ - diesel exhaust gas consumption;

$V_{cm}$ - consumption of a mixture of exhaust gases and air.

For this type of installation, multivariate calculations were performed to determine the air mixture coefficient $\alpha_k^{cm}$ in the KVP-1.74 VTKS boiler with a mixture of diesel generator exhaust gases in the blast air at the nominal and fractional boiler loads at different values of the proportion of the exhaust gases diesel in the gas mixture from 0 to 35%. The calculated dependences of the excess air coefficient on the volume of replacement by the exhaust gases of the diesel generator are obtained, shown in figure 2.

Based on the analysis of the graph, it can be concluded that in order to maintain the air mixture coefficient at the level of 1.25 at the rated load, the maximum possible volume of supplied exhaust gases should not exceed 1700 m$^3$/h. With a decrease in the load on the boiler, the maximum volume of exhaust
gases supplied to the furnace is reduced to 1000 m³/h with a load on the boiler unit to 1.15 mW, respectively.

![Figure 2. Calculated dependences of the excess air coefficient on the volume of replacement by the exhaust gases of a diesel generator.](image)

Experimental data also confirmed that with an increase in the volume of exhaust gases supplied to the boiler furnace, the excess air ratio decreases (figure 3), so with the maximum possible volume of exhaust gases of 960 m³/h obtained during operation of the AD-60-T/400-1P, the excess air ratio decreased to 1.35, while stable fluidization and slag-free combustion of coal were observed.

![Figure 3. Comparison graphs of the calculated and experimental values of the excess air consumption from the volume of the diesel generator exhaust gases supplied to the boiler at a boiler load of 100%.](image)

When using coal with a calorific value of 21859 kJ/kg during the experiment, the carbon content in the slag decreased by more than two times compared with combustion in clean air and amounted to 2.26% and 7.46% when sampling from the ash collector bunker and slag-ash removal conveyor. At the same time, the maximum fuel economy was 5.0%, and the efficiency increased to 84%.
Figures 4. Comparison graphs of calculated and experimental values of fuel economy vs. the volume of replacement of diesel generator exhaust gases at a boiler load of 100%.

Figures 5 show the experimental values of the change in the parameters of transient processes with an increase in the load of the installation from 80% to 100%.

Thus, with a change in fuel consumption, the position of the valves on the air mixture supply pipelines changes. The temperature of the layer at the initial moment has a slight delay, which is caused by the heating of the fuel and the removal of moisture from it [10][11]. The transient mode of temperature change is aperiodic, followed by the boiler reaching a new steady state [12].
4. Conclusion
The conducted research with the use of new technological solutions on this installation showed:

- stability of operation of the power plant of the AD60-T400 diesel generator and a low-power high-temperature fluidized bed boiler with a capacity of 1.5 Gcal/hour when various disturbing influences are applied by changing the fuel consumption and air mixture;
- stability of the power plant in a wide range of loads from 50 to 120% without slagging the grating;
- optimal installation modes for static and dynamic modes with exhaust gas bypass were at the values of the excess air mixture coefficient in the range of 1.3-1.6;
- saving of boiler fuel for one boiler with the use of recycling of exhaust gases is about 4%;
- reduction of harmful emissions into the atmosphere, in particular at maximum loads, the formation of nitrogen oxides NOx decreased by 20-25% due to in-furnace methods of their suppression;
- improvement of indicators of transient processes in comparison with similar installations without recirculation of exhaust gases of the diesel generator into the boiler furnace.
- the possibility of short-term operation of the unit in the mode of full recirculation of exhaust gases, without the supply of primary air, in the event of emergency situations.

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