Development of a method for flameless combustion of finely dispersed carbon-containing waste

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Abstract: The high demand for waste incineration in the Russian Federation, due to the large size garbage landfills. The article analyzes the existing and promising methods for burning municipal solid waste. Describes the above studies on the creation of a furnace for the flameless combustion of coal-containing waste. The results of experiments on combustion of solid materials with a low carbon content are presented. The analysis of the applications of this type of furnace. This technology allows you to burn not only household waste, but also the waste of some industrial enterprises. Using such technology it would be economically justified by alignment with the conventional process of burning municipal solid waste.

Research on the creation of new flameless methods of burning various materials has been going on for several years. This article presents the results of research on the creation of a new type of furnace for the incineration of municipal solid waste. The purpose of this research is to create a new method for burning solid materials with a low carbon content.

The main objectives of the research: construction of an experimental furnace for the incineration of municipal solid waste and the development of its operating modes. The possibilities of using the resultant heat from waste incineration. Creating a mobile unit for use in remote areas.

One promising area is the incineration of municipal solid waste. According to statistics in Russia is generated about 60 million tons of garbage a year. If, on average, burning 1 ton of municipal solid waste produces about 700 kWh of electricity and about 900 kWh of heat. On the thermal energy market, as a result of the incineration of these 60 million tons of waste, about 42 million MWh or about 54 MWh of heat can be obtained from electricity. World statistics show that thermal processing of waste can reach more than 70%, as in Japan. At the same time, a number of European countries, such as Austria, Germany, Belgium and the Netherlands keep the level of thermal processing at about 50% [1, 2]. And in the USA only 15%, in Russia the figures are lower (see Figure 1). One of the problems of incineration of municipal solid waste in the Russian Federation is the large scattering of the created landfills and the low population density. Therefore, a lot of attention in the market is paid to mobile waste incineration plants. In Russia there are more than a dozen companies offer mobile units for incineration, while manufacturers are mainly in the European part of Russia and combustion technology is the standard, which could lead to environmental effects [3]. The proposed type of furnace will create a mobile set and customize the particular type of fuel and waste.
In Russia, almost completely, which is thrown in the garbage containers, is sent to landfills and dumps. According to statistics, less than 2% of waste is incinerated, and only about 4% is recycled. The Accounts Chamber of the Russian Federation has estimated that the area of landfills in Russia four million hectares. This size of the territory is quite comparable to the size of some countries, for example, Switzerland (4.12 million hectares) or the Netherlands (4.15 million hectares). The area of Slovenia (2 million hectares) and Israel (2.2 million hectares) is 2 times smaller than the landfills of Russia [4, 5].

There is practically no waste processing industry in Russia. This factor is a very negative aspect, because cities and towns are heavily littered. There are 1,000 landfills and 15,000 official landfills officially registered in the country. 17,000 waste disposal sites are unauthorized. It has already been noted that in the course of a number of inspections, 13,000 unauthorized waste disposal sites were identified [6].

![Management of municipal waste in Europe and the Russian Federation](image)

*Figure 1. Management of municipal waste in Europe and the Russian Federation. Light green is the volume of composting organic waste, green is recycling, orange is thermal processing, black is burial.*

The authorities believe that only representatives of private business can help in solving the problem, since it is necessary to invest 65 million dollars to build one full-fledged waste recycling plant. Only for the destruction of unauthorized waste disposal sites (13,000) will require the construction of factories for 845 billion rubles [7]. Therefore, the creation of mobile units that will allow the disposal of the landfill and the transfer of equipment to another site is a very urgent and economically justified task of this study.

There are known methods for producing silicon dioxide and thermal energy from silicon-containing plant waste and an installation for the combustion of fine materials [8]. The invention relates to the field of energy-technological processing of fine materials, mainly to the disposal of silicon-containing plant waste. The result is silica of varying purities. It can be used to generate thermal energy by burning crushed solid fuels or combustible waste, which are used, for example, for heating, hot water supply, technological needs, as well as for generating electricity. The method includes oxidative roasting in a continuous mode of a previously prepared feedstock while moving a dense layer in the combustion zone with control of the combustion temperature. By changing the flow rate of water or steam supplied to the combustion zone and the utilization of the heat of the waste gases.

An analogue of the proposed solution is the possibility of energy-technological processing of finely dispersed materials and regulation of the combustion temperature.

The proposed technical solution can be implemented using relatively large and complex installations. A chimney is required, which makes them unsuitable for heating small spaces. Presence of screw devices leads to entrainment of fine particles in the atmosphere.

Closest to the proposed method of burning solid fuel is the known flameless method of burning solid fuel, including horizontal stacking of solid fuel in a dense layer, its ignition and combustion. Solid fuel
is placed on the grate, and fuel briquettes are used as solid fuel [9]. This invention can be used for autonomous, environmentally friendly, economical heating and can increase the period between fuel loads up to 11 hours.

Coincides with the proposed technology for the flameless combustion of solid fuel and the possibility of burning pulverized fuel.

The disadvantages of this method, this is an additional operation of preparing briquettes from pulverized fuel and it is not suitable for burning fuel with a low carbon content. There is no possibility of adjusting the heat output during fuel combustion.

The solution obtained as a result of the research relates to the field of combustion of solid fuels containing carbon-containing materials. The technology can be used for waste processing, autonomous, environmentally friendly and economical heating of residential and utility rooms, greenhouses and hotbeds, country houses, cabins, tents and railway cars. The flameless method of burning solid fuel involves stacking solid fuel on a grate. Ignition is carried out by the upper layers of the fuel, instead of the grate, a porous heat-resistant partition is used, through which the gaseous combustion products are forcibly removed, and carbon-containing raw materials with a content of at least 10% carbon are used as solid fuel. The process is shown in Figure 2. The development of this method of burning solid fuels, will apply the obtained energy for heating of premises, including residential, sleeping rooms. As a result, new technical results were obtained, consisting in a decrease in heat losses with gaseous combustion products, as well as with chemical underburning of fuel carbon. Possibility of burning fine fuel with a high content of non-combustible materials. The final finished product based on this technology will be installations for various types of consumers [10].

The technical results are achieved by the fact that in the flameless method of burning solid fuel, including the laying of solid fuel on a base, its ignition and combustion, coal-containing raw materials with a content of at least 10% carbon are used as solid fuel. A porous heat-resistant partition is used as a basis, while fuel combustion is carried out by forcibly removing gaseous combustion products through a porous heat-resistant partition.

These technical results are achieved by the fact that in the method of solid fuel combustion, including the placement of solid fuel, its ignition and combustion, the solid fuel is laid in a horizontal layer on a porous heat-resistant partition through which the gaseous combustion products are removed. The furnace diagram is shown in Figure 3.

A distinctive feature of the proposed method of burning solid fuel is that the solid fuel is placed on a porous heat-resistant partition through which the gaseous combustion products are forcibly removed. The source of oxygen required for the combustion process is air which is fed from the top layer of burnt fuel. Unlike conventional methods incineration combustion zone thus moves downward. Filtration of gases through the particulate material provides a high heat exchange efficiency between the gaseous and solid phase. As a result, the supplied air heats up quickly, cooling the ash (non-combustible materials), and the combustion products effectively release heat, heating the fuel before the combustion process. Heat losses with combustion products are reduced, which allows maintaining a stable combustion process of fuel with a high content of non-combustible components.
Figure 2. The process of flameless combustion of carbon-containing waste.

Figure 3. Schematic of a flameless combustion furnace.

When lumpy fuel and briquettes are burned, the lumps are burned for a long time and the combustion products (carbon dioxide) move relative to the heated carbon-containing material, which leads to an increased content of carbon monoxide in the combustion products:

\[ \text{CO}_2 + \text{C} = 2\text{CO}. \]
Water vapor contained in combustion products leads to a similar effect:
\[ \text{H}_2\text{O} + \text{C} = \text{CO} + \text{H}_2. \]

In the developed scheme, the probability of these reactions decreases due to efficient heat exchange and rapid cooling of carbon dioxide and water vapor. In addition, carbon particles contained in finely dispersed fuel burn out without having time to react with the formation of carbon monoxide [11, 12, 13].

The proposed technical solution is implemented in vertical combustion chambers, in which a porous heat-resistant partition plays the role of a grate, on top of which a pulverized carbon-containing fuel is poured. A vacuum is created from the bottom of the partition in the combustion chamber, stimulating the flow of air supplied to the upper part of the chamber. The air passes through the ash, heats up and enters the combustion zone. The fuel layer is ignited from the upper side of the layer and burns without flame with oxidation of carbon in the combustion zone, which, in turn, moves towards the baffle as the carbon burns out. Combustion gases are filtered through finely dispersed fuel.

The proposed combustion scheme provides heating of air, fast heat transfer from flue gases and heating of underlying fuel layers. This ensures a decrease in heat loss with combustion products, which allows you to burn fuel with an increased content of non-combustible materials (to process waste).

The temperature of the combustion bed at flameless combustion does not exceed 800 °C, which gives almost no nitrogen oxides formed accompanying the combustion in furnaces with fluidized bed furnaces and layered with vigorous lower puffing air [14]. The combustion mode is determined by the vacuum value in the lower part of the combustion chamber or by adjusting the air flow rate in its upper part [15]. Low thermal conductivity retains particulate fuel a temperature sufficient for igniting a long time, that allows to adjust thermal power setting intermittent air flow, i.e. a temporary suspension of the combustion process [16, 17]. Heat removal from the combustion chamber can be organized by means of heat exchangers located on its lateral surfaces and in a porous partition.

This flameless method of burning solid fuel can be used for the following options.

The first option, when we use cyclonic dust from the gas cleaning system of silicon production, containing 10% carbon (charcoal and coal) and non-combustible components (silicon dioxide 88% and 2% other inorganic compounds). The materials are placed in the combustion chamber on a porous heat-resistant partition, the upper layer of dust is ignited and the gaseous combustion products are forcibly removed. Flameless combustion occurs until the laid layer is burned out. The temperature does not exceed 700 °C. The carbon content in the ash is 1.8%. Solid residues from incineration can be used in the production of building materials.

The second option is to use cyclonic dust from the gas cleaning system of silicon production, containing 10% carbon (charcoal and coal) and non-combustible components (silicon dioxide 88% and 2% other inorganic compounds). The material is briquetted, placed in the combustion chamber on the grate, ignition is carried out, after removal of the ignition source, the combustion dies out. The carbon content in the remaining fuel is 9.7%.

The third option is the use of cyclonic dust from the gas cleaning system of silicon production, containing 8% carbon (charcoal and coal) and non-combustible components (silicon dioxide 90% and 2% other inorganic compounds). The waste is placed in the combustion chamber on a porous heat-resistant partition, the upper layer of dust is ignited and the gaseous combustion products are forcibly removed, after removing the ignition source, the combustion dies out. Remaining fuel carbon 7.5%.

The fourth option, when using cyclonic dust from the gas cleaning system of silicon production, containing 16% carbon (charcoal and coal) and non-combustible components (silicon dioxide 82.5% and 1.5% of other inorganic compounds). The material is placed in the combustion chamber on a porous heat-resistant partition, the upper layer of dust is ignited and the gaseous combustion products are forcibly removed. After 30 minutes of forced removal of the combustion gases is stopped, burning stops within one hour of the heated bed temperature decreased to 610 °C. After the resumption of forced removal of gaseous combustion products, flameless combustion continues until the laid layer is burned out. The temperature of the heated layer did not exceed 740 °C. The carbon content in the ash is 1.6%. Solid residues from incineration can be used in the production of building materials.
The fifth option uses finely dispersed charcoal formed during its production, containing 72% carbon and 28% non-combustible inorganic compounds. The waste is placed into the combustion chamber on a porous heat-resistant partition, the upper layer of dust is ignited and the gaseous combustion products are forcedly removed. Flameless combustion occurs until the laid layer is burned out. The temperature does not exceed 780 °C. The carbon content in the ash is 0.5%. Solid residues from incineration can be used as fertilizer.

The proposed flameless combustion method allows the use of carbon-containing wastes as a fuel (options 1 and 5) with a carbon content of at least 10% (options 1 and 3). Produced briquettes with a similar composition do not independently support combustion (options 1 and 2) [10]. The developed flameless method of solid fuel combustion allows stopping the combustion process for a long period with its subsequent resumption, thereby regulating the heat release process (option 4).

The use of this method allows you to incinerate municipal solid waste. As shown by studies carried out using real household waste, the content of carbon in such material is more than 10% (see Figure 4). This allows the use of this technology for the disposal of municipal solid waste and reduces the cost of incineration.

The traditional combustion method has high costs for an additional source of energy and does not use the possibility of burning the carbon contained in the waste. A new method of waste incineration developed as a result of research will allow obtaining higher economic indicators of the operation of such a furnace. The research carried out prove the technological and economic advantages over the existing methods of incineration of municipal solid waste and can be implemented in various regions of the Russian Federation.

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