Gasification of powdered coal in filtration regime with a superadiabatic heating

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Abstract. A new method is proposed for gasification of a powdered coal in filtration regime with superadiabatic heating. The fuel is supplied suspended with the flow of oxidant gas, whereas the gas flow filters through a porous bed of large particles making a heat recovery medium. Owing to the heat exchange between countercurrent solid and gas flows part of the heat is recuperated and transferred from the products to the reaction zone. The heat accumulation in a relatively narrow combustion zone can result in the temperature within the combustion front substantially higher than the adiabatic temperature calculated for the initial temperature of the reactants being that ambient and the heat of the reaction is evenly distributed over the products.

1. Introduction
Processes of the filtration combustion with the accumulation of released heat is an interesting object for the studies in chemical physics and, on the other hand, is attractive for practical use. A large number of studies on non-isothermal self-sustaining processes in the counter flow regime are aimed at optimizing various stages of industrial production, such as in situ coal gasification [1], self-propagating high-temperature synthesis [2], power and syngas production [3-7], hydrogen production [8-9], etc. Filtration combustion is the fuel oxidation process with a gaseous oxidant passing through fuel or a layer of inert material [10-15].

Gasifier of a dense layer, operating in a filtration combustion mode with superadiabatic heating, allow processing high-ash and high-moisture fuels with high environmental purity and high process efficiency [16, 17]. A disadvantage of gasifier of this type is their relatively low productivity. There are several ways to increase productivity. One way is to increase the flow rate of the oxidant, but this method has a limitation associated with the disturbance of a dense layer of the charge at high oxidant flow rates (formation of a fluidized bed) [18]. Another way is to increase the reaction surface of the fuel by reducing its particle size.

The aim of the work is to study the regularities of gasification of a highly dispersed solid fuel in a gaseous oxidizer stream during filtration of the mixture through an inert charge. This approach is new and its application can combine the advantages of gasification of solid fuels in the filtration mode and increase the productivity of a single reactor.
2. Experimental set-up
The first stage of the research is devoted to the development of a method for supplying fine-dispersed fuel to a dense bed reactor, so the purpose of the work was not to gasify the fuel, but to completely burn it to CO\textsubscript{2} in a filtration mode. Laboratory studies were carried out in a quartz vertical quasi-continuous reactor, with an internal diameter of 66 mm and a length of 500 mm (Fig. 1). The wall thickness of the reactor was 3 mm. To reduce lateral radiative heat losses, the outer wall of the reactor was shielded by a heat-reflecting screen. The volume of the reactor was filled with an inert material. The porosity of the backfill was 0.6. Porcelain rings Raschig with a characteristic size of $5 \times 10$ mm were used as an inert material. The melting point of the porcelain rings was ~1400°C. Wood birch charcoal was used as fuel. Wood birch charcoal is a model of ashless fuel that does not contain a volatile organic part.

![Figure 1. Scheme of the experimental setup of quasicontinuous action.](image)

The gaseous oxidant was fed into the reactor through two nozzles, a primary and an additional. A stream of additional gaseous oxidant was used to transport fuel to the reactor through a nozzle. Adjustment of fuel supply from the bunker was carried out with the help of a drum-type dispenser, the use of which allows for a uniform controlled supply, in contrast to the dispenser in the works [19, 20]. Highly dispersed fuel from the bunker through the feeder fitting was fed into the dispenser volume, from where, with the help of a sector valve, it was sent via a discharge nozzle into the additional air flow. The mass flow rate of fuel was controlled by the speed of the sector shutter.

3. Experimental methods
The feed fuel was crushed to a size of less than 160 μm and dispersed on the sieves by fractions. Figure 2 shows a photograph of samples of crushed fuel obtained by scanning electron microscopy using a microscope Zeiss LEO SUPRA 25.
Initiation of the combustion process was carried out by first loading the ignition mixture into the reactor (a mixture of charcoal with Raschig rings), heated to 800°C. Over the ignition mixture, an inert material at room temperature was charged to the reactor up to the top end. After this, the supply of the gasifying agent to the reactor was begun. Transportation of pulverized fuel to the reactor volume was carried out by an additional air flow through the side inlet in the reactor. Then, combustion of already pulverized fuel took place, while the high-temperature combustion wave propagated along an inert charge in the direction of the gas flow. The combustion process was carried out in a quasi-continuous regime; for this purpose, during the experiment, the cooled inert was discharged by a rotating grate from the reactor and the fresh portions of the inert were refilled into the reactor. In this mode of operation, the pulverized fuel was supplied to a section of the reactor heated to above 700°C. The unloading-loading of the inert was performed to stabilize the high-temperature region in one position inside the reactor.

Chromel-Alumel thermocouples were used to measure the temperature. Thermocouples were located at a distance of 65 mm from each other, whose junctions were on the inner wall of the reactor. The thermocouple readings via the ADC were output to the computer in real time, which made it possible to monitor the position of the combustion front in one section by unloading the inert. To determine the methodological error of temperature measurement, a series of 3-5 identical experiments were carried out. The error in measuring temperature does not exceed 50°C.

During the laboratory tests of the pulverized fuel supply system, we encountered design limitations on the operating time associated with the insufficient volume of the fuel bunker. In this connection, at the first stage of the work, experiments were carried out at low flow rate of a gas oxidizer (air). The air flow was chosen at 530 m³ / (h * m²), which is 0.5 l/s in terms of the working section of the laboratory reactor.

Initially, the dependence of the mass flow rate of fuel on the rotational speed of the drum dispenser was investigated (Fig. 3). In Fig. 3 shows the dependence of the mass flow rate of fuel on the rotational speed of the drum dispenser for various coal fractions. As can be seen from the figure, the fuel mass flow rate is directly proportional to the rotational speed of the drum dispenser. Moreover, a larger fraction enters the reactor at a higher flow rate than the smaller fraction at the same value of the rotational speed. Thus by setting the speed of the dispenser, it is possible to control the fuel supply to the reactor.
4. Results and Discussion

An experimental study of air gasification of highly disperse fuel - samples of wood birch charcoal was carried out. The analysis of samples of dry birch charcoal showed the following average elemental composition (% wt.): C – 84.0, O – 12.5, H – 2.7, N – 0.3, ash – 0.5%. The humidity of the coal was 4%. The lower heat of combustion of charcoal was 28.6 MJ/kg. The experiments were carried out with a fuel fraction size of 63-100 μm.

In each experiment, the temperature readings of the thermocouples were recorded. The temperature profiles of the combustion wave for various fuel flow rate are shown in Fig. 4. The maximum temperature was at the level of the air-dust mixture input and at the next level of the thermocouples (red curve with the maximum temperature) further down the length of the reactor the temperature is much lower. In one experiment from this series, the temperature at the outlet from the reactor was monitored, for which an additional thermocouple was placed in the upper layer of the inert charge. As can be seen from the graph (Fig. 4a), the temperature at the outlet from the reactor (blue curve) did not exceed 200°C, thus, due to the inert circulation in the reactor, there was an effective heat recovery to the combustion zone.
Figure 4. Temperature profiles of the combustion wave for different fuel flow rate (temperature in °C versus time in seconds): a) – 0.08 g/s, b) – 0.094 g/s, c) – 0.105 g/s, d) – 0.12 g/s.

The small temperature jumps in the graphs at the beginning of the experiments correspond to the loading of the initiating composition, after which the supply of pulverized fuel to the reactor took place. The position of the combustion front was maintained in one place - between the introduction of the dust-air mixture and the first level of the thermocouples by performing unloading / loading of the inert from the reactor, which is the reason for the fluctuations in the temperature profiles during the experiment.

As can be seen from Fig. 4, with an increase in mass fuel consumption, an increase in the maximum temperature of the combustion front took place. Figure 5 shows the dependence of the maximum temperature of the combustion front on the mass flow rate of fuel. As can be seen from the graph, with an increase in fuel flow rate from 0.08 g/s to 0.12 g/s, the temperature increases with ~600°C to ~1100°C.

Figure 5. Dependence of the maximum temperature on the mass flow of fine-dispersed fuel.

5. Conclusion
In the course of experimental research, the method for supplying pulverized fuel was developed, which makes it possible to combine the advantages of a dense-layer reactor (with efficient heat
recovery into the combustion zone) with the advantages of pulverized coal gasifier (high productivity). As a result of experimental studies, an increase in the maximum combustion temperature was observed with an increase in the mass flow of fine-dispersed fuel.

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