Pulverized coal torch combustion in a furnace

E Y Gorelikov, I V Litvinov, A S Styuf, S I Shtork
Institute of Thermophysics SB RAS, Novosibirsk, Russia

Corresponding author: gorelikoey@gmail.com

Abstract. Aerodynamics of flame combustion of a pulverized coal was studied experimentally using a laboratory setup with a thermal power of 25 kW. The axial and tangential velocity profiles were measured with the co- and counter-swirl of the first and second degrees of the burner. Averaged velocity profiles were measured by a two-component LDA system. The temperature was also measured on the walls and axis of sections of the pulverized coal burner. The temperature distributions were obtained at different coal dust flow rates as well as at co- and counter-swirl. The results obtained allow us to conclude about the efficiency of flow mixing at pulverized coal combustion.

1. Introduction

The decisive role in organization of the combustion process belongs to the burners: reliability of ignition, character of mixture formation, and aerodynamics of active combustion zone in the furnace of a boiler unit depend on burner design, location and operation. These factors in turn determine the rate and completeness of fuel combustion, as well as the amount of harmful emissions into the atmosphere. The design of burners must ensure efficient fuel combustion, that is, a complete absence of chemical and mechanical underburning at moderate coefficient of air excess in the furnace, stability of burning in all operating regimes, wide range of regulation without reducing efficiency, simplicity of manufacturing, installation and repair, as well as safety and durability.

The technologies of flame combustion in dust burners in comparison with combustion on the grid bars or moving grates have a number of advantages. They are the utmost simplicity of heat generator and minimal number of moving parts, high intensity of combustion process, wide range of regulation and long service life. However, this method requires special pretreatment of fuel and has high specific energy consumption for fans and coal mills. At the same time, the flame combustion of pulverized coal with an average particle diameter of about hundred microns remains the most popular method for thermal energy production. In engineering, the vortex burners are the widespread devices. With this method of combustion, most fuel is not on the grid, but it rotates in the vortex flow of blast air. The centrifugal force arising in this case presses the fuel particles to the internal hot surface of the furnace, contributing to their more complete combustion and preventing the removal of unburned particles from the furnace. The flame of vortex burners is more turbulent. In addition, jet swirling improves the ignition of air-fuel mixture. With an increase in the swirl parameter, the angle of jet opening increases and its boundaries expand, the amount of gases, recirculating towards the flame mouth, increases. At the same time, the flame range decreases. This method of combustion increases the combustion efficiency and decreases concentration of harmful emissions. In the process of burning of a high-temperature, the aerodynamic parameters responsible for the oxidant supply to the surface of burning particle are the determining factors. Thus, aerodynamics of a pulverized coal flame is closely related to the kinetics of reactions taking place in it.

In publications on experimental study of coal fuel combustion, two stages are distinguished: release and burning of volatiles and coke residue burning. It is shown that the time of devolatization is directly related to the time of particle heating. To increase the reaction rate, it is necessary to use fuel with highly reactive properties, which can be obtained by applying mechanical activation [1]. Great of experience in the field of studying the efficient use of mechanically activated fuel at power plants has been accumulated at the Institute of Thermophysics of the Siberian Branch of the Russian Academy of Sciences.
With the development of modern non-contact methods of flow diagnostics, topical and popular studies on the flame combustion of coal, aimed at aerodynamic methods of combustion stabilization, appear in the literature [2]. The study of flame aerodynamics in a pulverized microburner by a non-contact technique using a laser-Doppler anemometer provides information on the flow structure by varying the ratio of stoichiometry, the method of coal grinding, and possibility of an aerodynamic method of flame stabilizing by changing the ratio of secondary air supply and swirl conditions (co- and counter-swirl) in a pulverized coal microburner [3,4]. One of the main tools for improving the existing and developing new technologies for burning solid fuels is mathematical modeling, but to develop the mathematical models describing the processes that occur at combustion of pulverized solid fuels and verifying them, it is necessary to obtain reliable experimental results at laboratory setups where it is possible to carry out the full detailed measurements.

2. Experimental setup

To study the processes of pulverized coal combustion in a swirling flow, an experimental setup with a thermal power of 25 kW an automated data acquisition system was constructed.

The experimental setup is shown in Figure 1. The furnace volume consists of 7 muffled sections with an internal diameter of 100 mm and length of 150 mm. The walls of the muffle are made of a refractory mixture “Mertel” with plasticizing additives. In the center of each section there is a circular channel for installing a quartz viewing glass, which provides an optical access to the furnace volume. The pulverized coal and gas burner is made with two stages. The first stage is a tangential mixing chamber, where a protective ignition device is mounted axially. A mixture of propane and air was fed into the primary tangential swirler with two tangential inlets of primary air [3]. Pre-ground coal with a characteristic grain size of 40-60 micrometers was loaded into a screw feeder. The pulverized coal was supplied from the bunker to the air line of a snail swirler; the flow rate of pulverized coal dust was controlled by a scale with a measurement error of 1 gram. With the help of accompanying air, the coal spray was transported to the burner. The air flow to the tangential and snail swirler was fed using the constriction devices and pressure drop meters. This measurement method gives an error of no more than 4%. The pulverized mixture was swirled by a snail swirler and set on fire by a pilot flame obtained by burning the gas mixture from the first stage. The choice of geometry is caused by the simplicity of geometry of the tangential and snail swirlers, and this is often used when burning various types of fuel, including solid ones [4]. In each section, as well as in the snail swirler, the mobile K-type thermocouples were mounted on the walls to change the temperature. Data from thermocouples was collected by an eight-channel temperature meter with a built-in RS-485 interface for the exchange with a personal computer. The temperature
measurement error was 1°C. All measuring devices of this setup are integrated into single software that allows us to obtained experimental data in a single data file with a reference to the time of experiment.

3. Results
In the experiment, the flow rate of propane-butane mixture was fixed and it was 15 l/min. The flow rate was controlled using a 034-39-ST rotameter of Aalborg company for the propane-butane mixture. The standard error of this rotameter is 2% of the upper scale. The air flow rate for the first stage was 21.5 - 22 m³/h, and for a given flow rate of propane-butane mixture, this corresponds to $\alpha = 1.2$. The flow of pulverized coal ranged from 3 to 8 kg/h and the air flow rate for the second stage varied from 15 to 40 m³/h respectively. A change in the flow rate of pulverized coal is achieved by changing the frequency of motor rotation using a frequency converter.

![Figure 2. Temperature vs. time at combustion of mechanically activated brown coal on the axis of combustion chamber (a) co-swirl (b) and counter-swirl.](image)

As it can be seen from Figure 2, the experiment can be divided into four main stages. I - supply of air and propane-butane to a tangential swirler, followed by ignition of the pilot flame. II - increase in the flow rate of propane-butane up to 15 l/min and heating the snail swirler and combustion chamber. III- supply of secondary air with pulverized coal. IV- cessation of fuel supply.

In the experiment, the maximal temperature on the chamber axis at supply of mechanically activated coal fuel was 1278°C.

![Figure 3 Temperatures on the chamber axis at (a) co-swirl and (b) counter-swirl with different flow rate of coal fuel.](image)

The maximal temperatures on the axis of combustion chamber at co-swirl of the first and second stages are shown in Fig. 3. The presence of a temperature plateau from section 2 to section 5 indicates the presence of a propane-butane jet, which diffusely burns in the center of combustion chamber. With an increase in the flow rate of the dust-air mixture, the flame temperature decreases due to the influx of a large volume of cold air. When counter-swirl, the temperature on the axis of the chamber reaches high
values, which indicates the burning of a mixture of coal dust and propane-butane. This effect is achieved due to better mixing of flows from the first and second stages of the swirling device due to the destruction of the vortex core formed by the first stage of the swirling device.

The velocity in the pulverized coal flame was measured using a two-component laser Doppler anemometer LAD 06-i. At each measuring point, statistics equal to 2 thousand Doppler flashes was collected.

Due to measurements in the furnace volume, distributions of axial and tangential velocities were obtained in each muffle section in the regime of co-swirl of two chamber stages (co-directional), and also at counter-swirl. The axial velocity distributions of particles of a pulverized coal flame, non-dimensionalized to the average flow velocity $U_0 = 4.2$ m/s, are presented in Fig. 4a. It is seen that at the beginning of the chamber a central jet of the propane-butane mixture is formed, which is fed through the end cover of the tangential swirler (first stage). The effect of a gas jet almost completely disappears over the length of combustion chamber $z \approx 750$ mm. When considering the counter-swirl, the axial velocity profile becomes uniform at the exit of the snail swirler.

![Figure 4a](image1.png)

**Figure 4a.** Profiles of axial (a) and tangential (b) velocities at co- and counter-swirl.

Figure 4b shows distribution of the tangential velocity of particles of pulverized coal flame. It is seen how the change in orientation of the snail swirler changed the direction of entire flame swirl. In the case of co-swirl of stages along the chamber center, an axisymmetric vortex structure with the vortex core size of about 0.4R arises, and this is consistent with visualization of this regime. The pulverized coal flame occupies the space around the gas flame, which burns diffusively in the center of the furnace chamber, falling into the area of potential flow.

In the case of counter-swirl, it can be seen that the swirl changes sign, while there is no pronounced vortex core from the gas flame, since the pulverized coal mixture of the second stage is completely mixed with the flow leaving the first stage; at that, distributions of tangential velocity are more even.

Temperature measurements showed that in the center of the second stage swirler, where the pulverized coal fuel ignited, the temperature on the chamber axis reached 1000°C in both cases, which is sufficient for ignition of the mixture of pulverized coal fuel. At co-swirl, the maximal temperature on the muffle wall was reached in the 4th section, and at counter-swirl, the maximal temperature on the muffle wall was shifted to the 7th section.

4. **Resume**

The spatial distributions of axial and tangential components of the velocity of pulverized coal flame were measured in a 25-kW combustion chamber. Brown coal with an average particle size of 60 μm was used as a solid fuel and tracers of a Doppler signal. The change in combustion aerodynamics was varied by changing orientation of the second-stage swirler (co- and counter-swirl relative to the first stage of the chamber). It is shown that under the conditions of counter-swirl, the flow is evenly distributed across the combustion chamber width, the supply of pulverized fuel to the second stage is completely mixed with the “hot” flow leaving the first stage, and this has a positive effect on flame stability and combustion of pulverized fuel in this regime.

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