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Influence of organic coal-water fuel composition on the characteristics of sustainable droplet ignition

Dmitrii O. Glushkov, Dmitrii P. Shabardin, Pavel A. Strizhak *, Ksenia Yu. Vershinina

National Research Tomsk Polytechnic University, 30 Lenin Avenue, Tomsk 634050, Russia

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ABSTRACT

This paper presents an experimental study of the ignition conditions and characteristics of the single droplets of organic coal-water fuels. The study examines suspension compositions based on low-grade coals, typical (with various characteristics of combustion) coal processing wastes (filter cakes obtained after the filtration of crushed coal), waste oils, water–oil emulsions. In the experiments, the mass fraction of the main components of organic coal-water fuel varies within the following ranges: 40–60% coal dust or filter cakes, 0–20% flammable liquid, 40–60% water. For recording the main parameters of ignition, we use high-speed video cameras, cross-correlation complexes, and a quartz cylindrical channel. To process the experimental results, specialized software systems Tema Automotive and Actual Flow are applied. We find the times of the ignition delay and complete combustion of organic coal-water fuel droplets with the sizes (radius) of 0.5–1.5 mm. The temperature and rate of air flow vary between 500 and 900 K and 0.5–5 m/s (to enable the use of research results in different fuel technologies). Further, we identify the boundary conditions of the sustainable ignition of organic coal-water fuel droplets with various compositions (by component concentrations). Also, the study establishes the scale of the effect of organic coal-water fuel component composition on these conditions.

1. Introduction

Coal-water slurry has demonstrated the possibility for the significant optimization of the operation of many power plants, units, and assemblies. The raw material base for producing coal-water slurry is big enough, but still significantly limited. In particular, it is possible to specify no more than 20 suspensions different by component compositions that have been considered in references [1–17]. The use of such relatively limited group of fuel components hinders significantly the extension of temperature ranges necessary and sufficient for coal-water slurry combustion in power plants, as well as in the transport, chemical, and petrochemical sector.

One of the most promising directions for the development of the modern technologies of coal-water slurry combustion can be considered the preparation and combustion of organic coal-water fuel compositions. They are liquid composition or suspension fuels based on a large group of coal and oil processing waste. Preliminary analysis of statistical data on the volumes and reserves of low-grade waste in the world [18–22] shows that the most promising components of organic coal-water fuel can be considered: coal dust, technological or waste water, coal processing waste (filter cakes), waste oils, and various flammable liquids. Annually, these components of organic coal-water fuel are produced and stored as industrial waste worldwide in large quantities. For example, the reserves of low-grade coal and coal slurry are more than 100 million tons only in the Siberian region of the Russian Federation [22]. The volumes of used engine, turbine and transformer oils are several hundred tons annually in Siberia [22]. The reserves of the other possible original components of organic coal-water fuel are estimated by tens and even hundreds of tons in almost each of 85 regions of the Russian Federation. Similar conclusions can be also drawn to such countries as China, Japan, India, USA, and Germany.

The large amounts of raw materials for producing organic coal-water fuel determine, first of all, the relevance of the development of the technologies for the efficient combustion of such fuels. The processes of the combustion of coal-water suspensions are characterized by improved environmental and economic performance in comparison with solid fuel in a pulverized state [23–28]. The reason for this may be the low temperature activation of the fuel reaction surface at the ignition stage; the growth of the specific reaction surface in the main zone of combustion and its intensification due to the reaction of carbon with steam, which flows parallel to the main oxidation reaction. Therefore, it is of interest to study necessary and sufficient conditions for the initiation of the sustainable combustion of organic coal-water fuel [29–33] with the most typical component compositions. Moreover, it is important to examine the magnitude of the effect of each of these components.

Such studies can be performed experimentally applying the approach described in reports [11,12]. In particular, in the experiments [11,12], the authors used a setup, in which a coal-water slurry droplet was hung on a ceramic needle and was inserted into a chamber with a

* Corresponding author.
E-mail address: pavelspa@tpu.ru (P.A. Strizhak).

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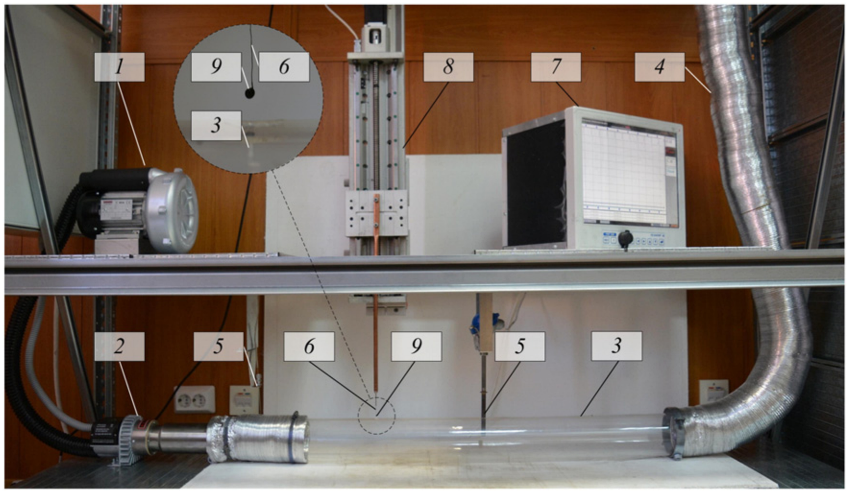

Fig. 1. Fragment of an experimental setup: *1* — blower; *2* — air heater; *3* — glass cylinder; *4* — ductwork; *5, 6* — thermocouples; *7* — temperature recorder; *8* — coordinate mechanism; *9* — organic coal-water fuel droplet.

heated air flow. The droplet was heated up to the conditions ensuring sustainable ignition. An observation window of quartz glass was made in the camera for the high-speed recording of the processes that occur during heating and ignition of the fuel droplet. One can mark several major limitations of the experimental facility [11,12]. At first, it is possible to maintain the oxidizer (air) temperature only within a limited variation range – about 1000 K. Secondly, there is no possibility of controlled varying the velocity of an oxidizer flow. Third, a thin pointed tip was used as a device to hold the coal-water fuel droplet [11,12], which did not allow to place on its end the droplets with a diameter greater than 1 mm (test experiments revealed that large droplets would break away from the tip under the influence of aerodynamic forces). Therefore, it is advisable to develop an experimental setup taking into account the limitations identified, in order to examine the ignition characteristics of typical organic coal-water fuels and analyze the impact of the component composition on the characteristics of this process.

The aim of this work is to study experimentally the effect of the component composition of organic coal-water fuel on the ignition characteristics of a droplet in an oxidizer flow.

2. Experimental methods

Fig. 1 illustrates a fragment of the appearance of the experimental setup developed in the present study. The main tools for the registration and generation of single droplets are similar to that used in the experiments described in references [34–36].

To prepare an organic coal-water fuel droplet, we used typical coal processing waste (filter cakes) (Tables 1–3) from concentrating factories. As a result of technological process, coal rock is washed with water using surfactants. Further, coal is separated into fractions on screens. Water used for washing coal rock is fed into special containers, where the deposition of carbon particles occurs. A coal-water suspension is pumped out and passed through belt press filters for water extraction. The moist residue (a mixture of water and coal) is filter cake. The average particle size of coal dust in filter cakes is not more than 100 μm. Also, for the preparation of organic coal-water fuel, we used pulverized coal (Tables 1, 2) with a particle size of about 100 μm. As the liquid fuel components (Table 4) of organic coal-water fuel, we added waste oils: engine, turbine, transformer oil, or a water–oil emulsion. To enhance the stability (to reduce the effect of stratification) of fuel compositions in organic coal-water fuel, we used a plasticizer "Neolas" (Table 5).

We prepared organic coal-water fuel using a homogenizer IKA T18. In the first stage, we prepared an oil–water emulsion. The components were put in a glass (volume 0.25 l) with a homogenizer after preliminary weighing with an analytical balance ViBRA HT 84RCE. The duration of mixing the emulsion components was 3 min. Then, filter cake or coal dust was added to the emulsion. The duration of mixing the suspension was 10 min. These compositions in the amount of about 0.25 l were put into sealed glass containers to ensure the long-term preservation of stable composition without the bundle of components. On average, this value was not less than 15 days.

Using a rotational viscometer EAK-1 M (at the temperature of 300 K), we have determined the characteristic values of the effective viscosity of resulting fuel compositions. It has been found that this parameter is 0.18–0.21 Pa s.

In the second stage, we have investigated the ignition and combustion of organic coal-water fuel droplets (Fig. 1) during low-temperature heating (less than traditionally accepted in the furnace devices of power plants) [37–39] and at maximum oxidizer temperatures (up to 1200 K). A blower *1* (power is 0.25 kW, gas flow rate is not more than

Table 1
The results of the technical analysis of coals and filter cakes.

Sample	W^a, %	A^d, %	V^{daf}, %	Q^a_s, MJ/kg
Brown coal No. 1, the "Talovskoye" deposit of the Tomsk region, Russia	10.15	22.84	61.47	17.30
Brown coal No. 2, the "Borodinskiy" section of the Krasnoyarsk region, Russia	14.11	4.12	47.63	22.91
Brown coal No. 3, the "Balakhtinskiy" section of the Krasnoyarsk region, Russia	15.52	3.85	46.62	23.36
Flame coal, the "Listvyanskoye" deposit of the Novosibirsk region, Russia	10.09	8.52	40.19	24.82
Filter cake (dry) based on bituminous coal, the enrichment factory "Severnaya" of the Kemerovo region, Russia	–	26.46	23.08	24.83
Bituminous coal, the "Severnoye" deposit of the Kemerovo region, Russia	2.05	14.65	27.03	29.76
Filter cake (dry) based on low-caking coal, the enrichment factory "Chernigovskaya-Koksovaya" of the Kemerovo region, Russia	–	50.89	30.16	15.23
Low-caking coal, the "Chernigovets" section of the Kemerovo region, Russia	2.76	21.68	27.40	26.23
Filter cake (dry) based on nonbaking coal, the enrichment factory "Kaltanskaya-Energeticheskaya" of the Kemerovo region, Russia	–	21.20	16.09	26.92
Nonbaking coal, the "Kaltanskiy" section of the Kemerovo region, Russia	2.89	18.07	15.07	27.65