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Effect of macroscopic porosity onto the ignition of the waste-derived fuel droplets

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ABSTRACT

We have observed the influence of an artificial macroscopic surface modification onto the ignition of droplets of the waste-derived coal water slurry with petrochemicals. Fuel composition was based on filter cake of bituminous gas-coal with inclusion of small amount of the waste oil fuel. The sizes and other parameters of the fuel droplets were chosen very close to used in typical power units. The fuel droplet surface was pierced making conical pores whose depth was more than half of the droplet radius. Changes of the ignition delay time were analysed together with features of the combustion of volatiles in vicinity of introduced macroscopic pores. The advanced mathematical model was used to clarify the contribution of the droplet surface modulation in different effects that present during the fuel ignition. It was shown that ignition delay time is decreased by up to 20% with growth of number of pores and particularly with growth of the specific surface of the droplet (by 10–20% and more). The maximal combustion temperature at the droplet center was slightly decreased after the introduction of the macro-pores. The recommendations for modification of the industrial power units to optimized ignition regime were presented.

1. Introduction

Last decades people try to switch from usage of the traditional fossil fuels to different alternative ways. The wind and solar energetics are highly promoted forks of the power engineering progress but there is one more very attractive way - the usage of accumulated and newly produced industrial wastes as fuels. It allows from one hand dealing with usual coal- and oil-based components and from other hand the effective combustion of all these stuff, giving the possibility for utilization of mountains and lakes of wastes.

The growing interest of industrial and scientific community to coal-water slurry fuel (CWS) technologies is caused by three main reasons. The first one and the most clear for everybody is ecological [1,2]. The usage of the coal-water slurries with small amount of liquid combustible wastes instead of traditional fuels allows great decrease of the air pollution by the sulfur and nitrogen oxides. Production of the greenhouse gases could be decreased by 20–30% relatively to case of the usual coal fuels. It appears because the hot steam provides enough much of hydrogen ions for effective decomposition of volatile components of coal to carbon monoxide [3]. The second reason is economical. The low-grade coals, coal-processing wastes, waste oil-products, sludges, etc. can be a component of the coal-water slurries with waste petrochemicals (CWSP). It allows better thermal efficiency relatively to CWS due to presence of oil-based components with high calorific value. The year per year production of such potential fuel components is in scale of hundred million tons, and it costs very few [4–6]. The third problem is technological: the usage of the CWS and CWSP allows increasing of the fire safety of storage and usage of the fuel composition due to the presence of big amount of water inside it [7]. The risky stages of drying and milling of the coal are excluded from the fuel production process at all.

The experience related to the usage of the CWS and CWSP [8–10] that was accumulated during last 20–30 years shows certain set of problematic points. One of the main problems is a stable ignition of the quasi-liquid composite fuels with high content of water (up to 60%). Typically, the combustion chamber should be pre-heated before start with CWSP fuel using enough big amount of expensive traditional fuels. The way of usage of the slurry fuels without the pre-heating is of interest for scientists. The

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predictable and stable ignition is always at focus of most of fuel-related investigations [11–13].

It is clear from the thermodynamics that acceleration of the fuel heating could be done for the expense of more intensive heat exchange between ambient atmosphere and fuel droplets. The evident ways are growth of temperature of the incoming oxidant (air) flow, growth of the specific surface area of the fuel droplet, creation of complicated droplet shapes etc. Some of these approaches are presented in Refs. [14,15]. Analysis of energetic and economical results of the well-known approaches of intensification of the fuel ignition [16–18] enables to make conclusion that increase of the CWSP droplet surface complexity making an artificial pores could be enough effective and very cheap solution for ignition optimization.

The goal of this work is development of the simple and cheap way of physical (mechanical) processing of the fuel droplets to make it maximally suitable for industrial usage. In particular, we were aimed to decrease the ignition delay time keeping the overall thermal efficiency and power regime without strong changes. Influence of the surface deformation onto the ignition delay time together with the combustion of volatiles induced by this feature are the subject of our investigation.

2. Fuel components and preparation of the CWSP

The main component of the used fuel composition was the filter cake of gas-coal. This is typical processing waste of widespread and cheap coal type which appears during the coal-enrichment by floatation. We have used the filter cake from one of the coal-enrichment factories of Kuzbass region (Russia). Coal is washed there by water with surfactants and further it is separated for fractions by screens. Water used for coal washing is filtered by the stripe filters and coal particles are deposited making the wet filter cake. Typical coal particle size is near 100 μm. Table 1 shows the physical and chemical properties of the used filter cake.

The liquid combustible component of the CWSP was chosen taking in account its availability together with thermal properties. We have added approximately 10 wt% of the waste oil-fuel to our fuel composition. It allows enough good viscosity of the slurry together with essentially better ignition properties and calorific value relatively to pure coal-water slurry.

The plasticizer was added to the fuel composition to increase its segmental stability. We have chosen the Neolas plasticizer due to its low price together with high efficiency as wetting agent [19]. It allows keeping the slurry in ready to use state for more than a week that was proven by durable observation of the sample lamination with time (as described at [16]).

The slurry preparation was done by mechanical homogenization of liquid component mixture (the needed amounts of water and combustible liquid) with following addition of the wet filter cake like in Ref. [16]. The final relative weight content of the solid coal part was near 50%, water ~40%, liquid combustible component ~10%, plasticizer 0.5–1%.

Table 1
Physical and chemical properties of the used filter cake.

Physical properties	
Weight of solid part at initial wet state, %	46.9
Combustion heat at the wet state, MJ/kg	10.4
Combustion heat at the dry state, MJ/kg	22.16
Yield of volatiles at the dry state, %	43.11
The ash content, from wet state, %	33.82
Chemical elements content	
Carbon weight fraction, %	75.12
Oxygen weight fraction, %	20
Hydrogen weight fraction, %	4.64
Sulfur weight fraction, %	0.23
Nitrogen weight fraction, %	0.02

3. The CWSP ignition at different conditions

The CWSP droplets with characteristic size R_d ~ 0.75 mm that is very close to typical for industrial boilers were produced by electronic batcher Finnpipette Novus (using the Finntip Wide with 1.8 mm nozzle for better flowing of the viscose fuel composition). This device allows making hundreds of droplet samples after one re-filling (100–1000 μl) of the tip with typical variation of the droplet size less than 15% around chosen value. The droplet was placed at the junction of the thermocouple which could be introduced into the heat-resistant glass pipe with hot oxidant (air) flow (Fig. 1). The temperature of the incoming air in the glass pipe (in front of the CWSP droplet) was controlled by quick response type-K thermocouple (the working range is up to ~1500 K, thickness is 0.1 mm, response time is ~1 s). The type-B thermocouple (the working range is up to 2100 K, thickness is 0.1 mm, response time ~1 s) was used as holder of the fuel droplet to control the temperature changes inside the droplet during the combustion process as it was done in Refs. [10,17]. The droplet holder movements were implemented by motorised translation stage that allows very good reproducibility of the time-related measurements. The temperature and velocity of the flow around the droplet can be changed by adjustments of the flow-heater (Leister LE 5000 HT with flexible electronic control of temperature and flow rate) in range 870–1200 K and 0.5–5 m/s correspondingly. The high-speed video camera (Phantom V411) with macro optics was used for measurements of ignition and combustion characteristic times of the CWSP portion [17,18].

The ignition delay time was defined as time difference between moment of heterogeneous ignition (that was obtained from analysis of brightness of the droplet image, like at [19]) and moment of passing of the droplet through the wall of the glass pipe. The frame-rate of the camera was chosen at 1000 fps that allows millisecond level precision for time measurements. Camera allows the HD resolution of an image (1280 × 800 px) at this frame-rate.

This setup allows the simultaneous measurements of thermal

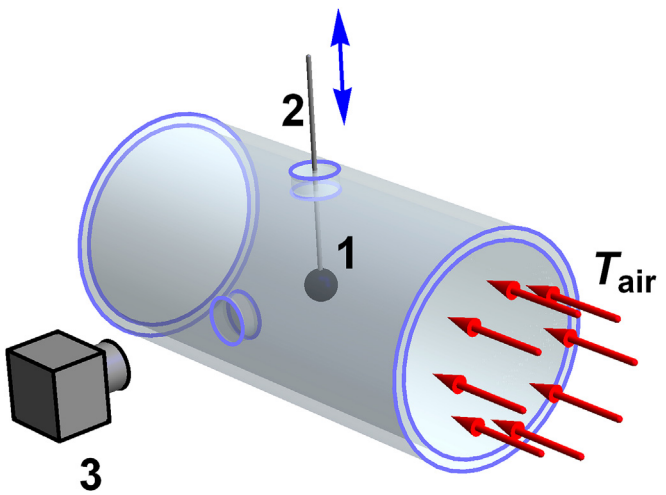

Fig. 1. Scheme of the experimental setup. The fuel droplet (1), could be introduced into the heat-resistant glass pipe by holder (2). The high-speed video camera (3) is used for ignition observation. The hot oxidant (air) flow is shown by red arrows. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

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