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Research Paper

The ignition parameters of the coal-water slurry droplets at the different methods of injection into the hot oxidant flow

Ksenia Yu. Vershinina, Roman I. Egorov, Pavel A. Strizhak *

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

HIGHLIGHTS

- Soaring droplet ignition was compared with one of droplets fixed by holder.
- Soaring droplet has smaller ignition delay time than droplet fixed by holder.
- Holder impact is significant at fuel heating, its evaporation, and volatile yield.
- Heat conductive holders accelerate ignition and make combustion longer.

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ABSTRACT

Two different experimental approaches were realized for investigations of integral characteristics of single droplet ignition of coal-water slurry containing petrochemicals (CWSP) inside the hot flow of the gas oxidant. At first, the droplet was fixed inside the flow by special holder and the second way is free injection of the soaring droplet into the volume of combustion chamber. Research reports an experimental estimation of influence of material holder on ignition characteristics for typical CWSP. This is important, since many researchers use various holders (the ceramic rod, thermocouple junction, metal wire) when inserting droplets of coal-water slurry (CWS) and CWSP into the combustion chamber. There were three types of the droplet holders: the junction of the high-speed thermocouple, metallic wire and the ceramic rod. The basic components of the CWSP were filter-cake (the coal processing waste), the used turbine oil, the plasticizer (wetting agent) and water. Initial droplet radius was 0.5–1 mm, and the temperature and the oxidant flow velocity were 400–1000 K and 0.5–5 m/s correspondingly. The ignition delays and the combustion times for the fuel droplets together with minimal temperatures of the stable ignition (with further combustion) were defined. Comparison of parameters of the flying droplet ignition with corresponding values for droplets that were fixed by holder was done. Soaring droplets have smaller ignition delay times (for 7–25%) relative to the case of droplet fixed inside the oxidant flow by holder (when the all rest parameters are similar). Influence of the holder material onto the values of times of ignition delay and combustion become essentially weaker with oxidant temperature growth. The obtained numerical results show the limitations and advances of the two approaches for laboratory investigations of the CWSP ignition and combustion.

1. Introduction

Coal-water slurry (CWS) is the composite slurry fuel that has two main components – coal (or wastes of coal processing) and water. The perspective kind of the composite liquid fuel is coal-water slurry containing petrochemicals (CWSP) with main components such as water, coal (or coal processing wastes) and flammable liquid. The usage of the CWS and the CWSP at energetics gives the real possibility to utilize effectively (from both ecological and economical points of view) the huge amounts of the coal - and oil-processing residues, chemical and other similar industrial wastes [1–5].

Some of the coal-enrichment wastes have potential of low-grade fuel because it has combustible component – coal particles (the size is usually less than 100 mkm). It makes sense to use wastes as a flammable liquid at CWSP mixtures too. For example, it could be different types of used engine oils, water-oil mixtures, oil sludge, etc. Thus, unclaimed wastes of different industrial processes could be a component of the resource base for preparation of the CWSP.

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

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Nomenclature

A^d	ash, %	T_g	oxidizer temperature, K
C^{daf}	fraction of carbon, %	T_m	minimum oxidizer temperatures for sustainable ignition, K
H^{daf}	fraction of hydrogen, %	V_g	oxidizer velocity, m/s
m_d	initial weight of droplet, g	V^{daf}	volatile, %
N^{daf}	fraction of nitrogen, %	W^a	humidity, %
O^{daf}	fraction of oxygen, %	τ_d	ignition delay time, s
Q_s^a	heat of combustion, MJ/kg	τ_c	combustion time, s
R_d	droplet radius, mm		
S^{daf}	fraction of sulfur, %		
T_d	temperature inside droplet, K		

The CWSP and CWS can be a good replacement of more expensive residual heavy oil and gas fuel. Therefore the high level of independence of the electrical generating companies from fuel providers could be realized. Besides, the CWSP and CWS are more fire safe [6–9] and more ecological (the air pollution by sulfur and nitrogen oxides at the CWS usage is quite low [10–13]) relative to traditional coal dust fuels. Taking into account, that list of the possible fuel components is very reachable, the properties of different types of coal wastes could be very different. Therefore it is almost impossible to satisfy the energetic, ecological and economic requirements by optimal way for different CWS or CWSP compositions simultaneously and the definition of the unified burning conditions is really difficult.

The scientists from China, India, Japan, USA, Russia, Poland, etc. deal with development of technologies of the CWS combustion during the last decades. Processes of ignition of the CWS are investigated well enough. The influence of different factors such as fuel content, components ratio, the fuel preparation method, external conditions onto the ignition and combustion of the CWS was investigated in [13–20]. In contrary to this, the investigations of the CWSP are much rare. Consequently, features of the CWSP are much less reviewed in publications. Optimal conditions for effective combustion of the CWS and CWSP are strongly different [15–18] and further investigations in this area are evidently needed.

The wide introduction of the CWSP into the industrial energetics implies the preliminary laboratory investigations. The well-known experimental technique of the investigations of heating, evaporation, ignition and combustion processes of the CWSP droplets is introduction of the droplet into the hot oxidant flow by certain holder. This approach was used, for example, in [21–31]. Usually, the droplet holders were metal wires, ceramic rods, and junctions of the small thermocouples with quick response. The thermal leakage through the holder (or heat inflow) can essentially change the ignition delay time and total combustion time when the droplet size is small (typically it is less than 2 mm). It is the principal limitation of this experimental technique. However, the effect of the holder material onto the combustion parameters of the CWS or CWSP was out of consideration before the present time. For example, in [21–31] the droplet holders were the junctions of PtRh-thermocouples (with diameters from 0.01 mm to 0.25 mm), quartz threads, nichrome wires and ceramic rods. By the way, the similar approaches are used for investigations of different bio-fuels and other related subjects too [32]. Therefore, it is clear that comparison of the results obtained using different types of holders is problematic.

The experimental investigations of ignition of the CWSP droplets containing wastes of the coal processing, water, waste turbine oil, waste motor and transformer oil are presented in [29–31]. Even more interesting was "low-temperature" ignition regime [33] when the oxidant temperature is less 1000 K. The CWSP droplet in [29–31] was introduced into the hot air flow by one of three types of holders (the ceramic rod, thermocouple junction, metal wire). This approach allows detailed investigations of the ignition and combustion of the CWSP (using the high-speed video recording and temperature measurement system with quick-response together with tools for flow velocity measurements and particle size control). The attempt of experimental definition of the CWSP droplet ignition in the oxidant flow without holder was done in [34]. The single fuel droplet was freely soaring in the oxidant flow. Comparing the theoretical [33] and experimental [29–31,34] values of the integral ignition parameters of the CWS (such as the ignition delay time, temperature fields), we can assume that the ceramic threads, metal wires (even very thin) or thermocouple junction can lead to changes of the heat and mass transfer processes in the connected fuel composition droplet. Comparison of the ignition parameters of the CWSP droplets for the different types of holders is interesting together with the results for soaring droplets.

The aim of this work was namely comparison of the ignition parameters of the coal-water slurries with petrochemicals using different approaches of its introduction into the hot oxidant flow.

The motivation of this investigation is based on the necessity of definition of the conditions set when the processes going inside the industrial combustion chambers are exactly reproduced in the laboratory conditions. One of the key features of this analysis is definition of the influence of holder material onto the ignition delay times and total combustion time of the CWSP droplets.

2. Experimental setup and procedure

At our experiments the CWSP components were the filter cake of bituminous coal (the waste of the bituminous coal enrichment by floatation) with mass ratio of the solid part ~53.5% (additionally ~41% of the cake mass is water) and used turbine oil (5%). The additional component of the slurry is plasticizer (wetting agent) "Neolas" with mass ratio of 0.5%. The plasticizer was introduced into the fuel to maintain its structural stability (to eliminate the fuel lamination for separate phases during the measurement time). The fuel components were placed into the working volume (0.25 l) of the homogenizer MPW-324 for 10 min after the weight control by analytical balance ViBRA HT 84RCE respectively of needed concentration. The final fuel mixture was placed into the hermetic cavity. The droplet generation was done by electronic batcher Finnpipette Novus. Control of the droplets weight was done by mentioned analytic balance.

The presence of the plasticizer is needed to protect the coal-water slurry from lamination when appropriate for industrial usage time. Typical plasticizers have following positive and negative sides: