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The Research of Coal-Water Slurry Fuel Ignition and Artificial Composite Liquid Fuel Droplets in Academic Context

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Abstract

There are new types of composite fuels, such as coal-water slurry fuel and artificial composite liquid fuel that can be used to exploit the limited energy sources more effectively. Such composite fuels consist of coal fine particles and water (or liquid industrial waste). This paper presents the experimental study of the ignition of coal-water slurry fuel and artificial composite liquid fuel droplets during convective heating carried out at the National Research Tomsk Polytechnic University. The ignition delay time of the fuels has been determined when the heat source temperature varied from 350 to 600 °C. The analysis reported here has revealed droplet ignition mechanisms for four different fuel compositions.

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Keywords: Coal-water slurry fuel; artificial composite liquid fuel; droplet; convective heating; ignition.

1. Introduction

Traditionally, thermal power plants use solid (coal), liquid (fuel oil) or gaseous (natural gas) fuels as energy sources (Lior, 2008; Sarkar, et al., 2010; Takeshita & Yamaji, 2014; Mukhutdinov, 2007). However, there are such substances as low-grade coal, unclaimed petroleum products, byproducts from biodiesel production, and other solid or liquid combustible wastes which are not yet used as energy sources. They are stored in special storage facilities or discharged into the environment; this leads to environmental pollution (Jung, et al., 2014; Tonini, et al., 2013; Liu

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G., et al., 2012). This approach is inefficient in terms of using extracted minerals as energy sources and recycling industrial wastes.

The problem of increasing power generation efficiency in thermal power plants has been a subject of considerable interest during recent years (Delitsyn & Vlasov, 2010; Bukhonov & Morozov, 2003; Belošević, et al., 2015). Besides these researchers, there is a group of scientists consisting of professor P.A. Strizhak, research engineer D.O. Glushkov, graduate student K.Yu. Vershinina and others, who work at the Department of Heat and Power Process Automation of the Institute of Power Engineering at the National Research Tomsk Polytechnic University. The research group works within the educational direction "Thermal Engineering and Heat Engineering" during the 2014/2015 academic year. Scientific results obtained during this period of time were tested in academic disciplines "Modern problems of power engineering", "Heat engineering and heat technologies", "Experimental studies of heat and mass transfer and gas dynamic processes".

According to some researchers, one of the possible solutions of the problem of increasing power generation efficiency in thermal power plants is to use the new types of energy sources, such as coal-water slurry fuel (Cheng, et al., 2010; Phuoc, et al., 2014; Khodakov, et al., 2006) and artificial composite liquid fuel. The composition of coal-water fuel includes two components: coal or lignite fine particles and water or liquid industrial waste (industrial water). Furthermore, various combustible liquid wastes may be added to artificial composite liquid fuel in addition to the components typical for coal-water slurry fuel.

There are the following advantages of using these composite fuels: the rational use of limited liquid and gaseous fuels, the utilization of combustible solid and liquid waste, the improvement of the environment (less emissions of sulfur, nitrogen oxides, carbon monoxide), the improvement of boiler efficiency, the reduction of energy costs in a fuel preparation system (compared to coal-fired boilers).

The aim of this paper is to investigate experimentally the ignition mechanisms of coal-water slurry fuel and artificial composite liquid fuel droplets by heating air flow. Experiments were conducted to develop the basic elements of the ignition theory of the essentially heterogeneous droplets of organic coal-water slurry fuels.

Nomenclature

t_{ign}	ignition delay time, s
T_a	air temperature, ^oC

2. Experimental setup and methods

Fig. 1 shows an experimental setup for studying the laws of physical and chemical processes that occur during the heating of a fuel droplet by air flow.

The operating principle of the setup was as follows: a remote control 3 implemented the operating modes of a high-pressure blower 2 and an air heater 3. The parameters of air flow in a hollow glass cylinder 5 varied: the velocity varied from 2 to 6 m/s, the temperature varied from 350 to 600 °C. A chromel-alumel thermocouple 7 and a multichannel registrar RMT 59M 8 were installed to monitor and record the airflow temperature. When the temperature has been stabilized, a droplet was inserted into the cylinder 5 by means of a positioning mechanism 6. A high-speed video camera "Phantom Miro" M310 4 recorded the processes studied in this paper. The analysis was performed with the help of a computer 9 and software "Tema Automotive".

Fig. 1. Experimental setup: *1* – heating system remote control; *2* – high-pressure blower; *3* – air heater; *4* – high-speed video camera; *5* – hollow glass cylinder; *6* – positioning mechanism for droplet supply; *7* – thermocouple; *8* – multichannel registrar; *9* – computer.

3. Results and discussion

We performed experimental studies for four fuel compositions: the composition No. 1 – coal-water slurry fuel (50% of coal, 48% of water, 2% of plasticizers), the composition No. 2 – coal-water slurry fuel (50% of coal, 50% of water), the composition of No. 3 – coal-water slurry fuel (50% of lignite, 50% of water), the composition No. 4 – artificial composite liquid fuel (50% of lignite, 40% of water, 10% of oil). The analysis of videograms (Fig. 2–5) established the difference between ignition mechanisms for various compositions. It can be seen in Fig. 2 that the size and shape of the droplet do not change significantly during the induction period. At the moment of ignition (t=7.764 s), an exothermic process is initiated inside the droplet (a visible dark border line between the droplet and air). This result can be explained by the fact that plasticizers affect the characteristics of high-temperature moisture evaporation by forming a thin film on the droplet surface. During the heating of the fuel droplet, the temperature of coal ignition is reached. After some time, the ignition is initiated inside the fuel droplet and then the flame spreads throughout the droplet (Fig. 2).

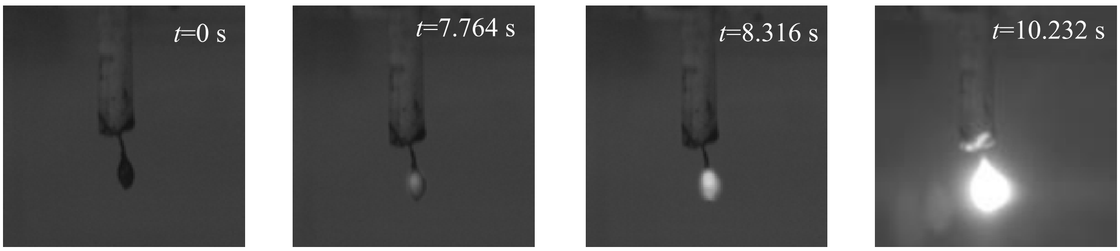

Fig. 2. The ignition of a coal-water slurry fuel droplet, the composition No. 1, T_a=550 ºC.

The ignition mechanism of coal-water slurry fuel (the composition No. 2) without plasticizers is different from that observed in the case of composition No. 1 ignition. The heating of the fuel droplet is accompanied by the intense evaporation of moisture. This affects significantly the droplet size and shape (Fig. 3). Thermal stresses inside the fuel droplet lead to its destruction and the inflammation of particles entrained by heating air flow. The ignition delay times of the composition No. 2 are shorter, on average, by 20-30% compared to the same characteristics for the composition No. 1. This is due to more intense moisture evaporation.

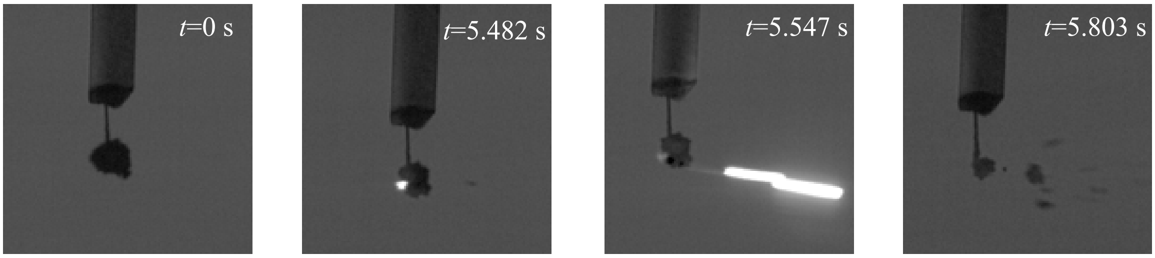

Fig. 3. The ignition of a coal-water slurry fuel droplet, the composition No. 2, T_a=570 °C.

The ignition mechanisms of the compositions No. 3 and No. 4 (Fig. 4, 5) are identical, in contrast to the ignition of the compositions No. 1 and No. 2. The ignition zone was observed on the fuel droplet side which faced incoming heating air flow (Fig. 4, 5). This area was characterized by more intense moisture evaporation and the heating of coal particles up to the temperature of their ignition. When the exothermic reaction had proceeded faster, the ignition zone increased; thus, the combustion zone spread over the entire surface of the droplet (Fig. 4, 5).

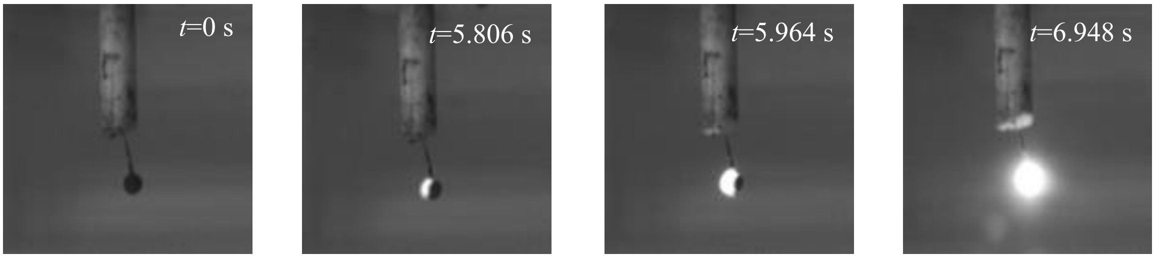

Fig. 4. The ignition of a coal-water slurry fuel droplet, the composition No. 3, T_a=570 °C.

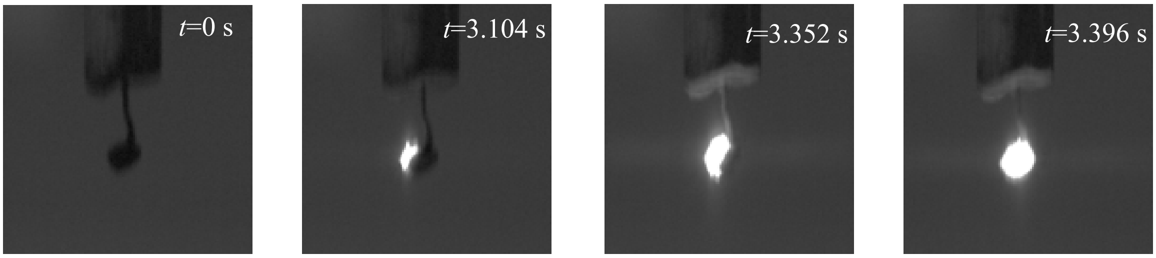

Fig. 5. The ignition of an artificial composite liquid fuel droplet, the composition No. 4, T_a=500 °C.

An artificial composite liquid fuel droplet ignited at a shorter ignition delay time than the coal-water slurry fuel droplet under identical conditions (the droplet size, shape; the airflow temperature, rate).

This feature can be explained by the presence of a flammable liquid component in artificial composite liquid fuel. The evaporation of such components and formation of combustible gas mixture (which is typical for the composition No. 4) is less inertial compared to the thermal decomposition of coal and yield of volatiles (the composition No. 3).

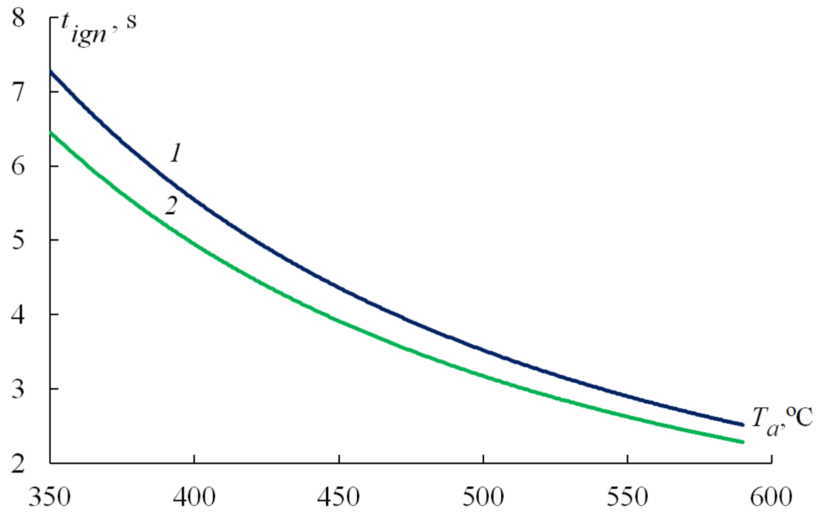

Fig. 6. The dependence of the ignition delay time of coal-water slurry fuel (*1* – the composition No. 3) and artificial composite liquid fuel (*2* – the composition No. 4) on the air temperature for droplets with the size of 0.8 mm.

Fig. 6 shows the graph of the basic integral characteristic. The basic integral characteristic describes the dependence of the ignition delay time on the heat source temperature. We have defined the basic integral characteristic for coal-water slurry fuel and artificial composite liquid fuel.

The difference between the ignition delay times of the compositions No. 3 and No. 4 did not exceed 15% at $350<T_a<500$ °C and a fixed air temperature. From the results, we draw the conclusion that it is appropriate to use artificial composite liquid fuel for boiler kindling, and coal-water slurry fuel for maintaining the nominal operation modes of a boiler torch.

4. Conclusion

The results of experimental investigations established the ignition modes for four fuel compositions: coal-water slurry fuel (50% of coal, 48% of water, 2% of plasticizers), coal-water slurry fuel (50% of coal, 50% of water), coal-water slurry fuel (50% of lignite, 50 % of water), artificial composite liquid fuel (50% of lignite, 40% of water, 10% of oil). The difference between the mechanisms lies in the intensity of heat transfer, the duration of the induction period, the position of the ignition zone, the destruction of the droplet. The experimental data can be used to develop the ignition theory for promising fuels to be used in thermal power plants.

At the same time, the implementation of investigations presented in this paper allowed participants to develop a research base. Thus, two articles were published in journals indexed by the leading database of scientific publications. We took part in three international conferences and established contacts with scientists working on similar subject, which helped us to improve research and professionally oriented communicative language competence.

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