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Sawdust as ignition intensifier of coal water slurries containing petrochemicals

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ABSTRACT

The low reactivity of coal processing wastes (filter cakes), petroleum derivatives, oil sludge, oil-water emulsions, coal-water suspensions, as well as used fuel and industrial oils is the main barrier to their common use as main fuel on thermal power stations and a boiler plants. It leads to high energy consumption for heating the combustion chambers and subsequent firing. In this work, we suggest using sawdust as an additive to intensify the heating and ignition of coal water slurries containing petrochemicals (CWSP) prepared from coal and oil wastes. We show that adding even 10% sawdust lowers the threshold temperature of sustainable ignition by as much as 70–80 K. The more volatiles are in coal processing wastes, the more noticeable the contribution of sawdust to the intensity of CWSP ignition. The role of sawdust as an ignition intensifier is found to increase significantly with the rising CWSP droplet size and air temperature. Replacing the coal component (e.g., filter cake) of the CWSP composition by sawdust of the same mass leads to a negligible change in the calorific value of the fuel. At the same time, the anthropogenic emissions of nitrogen and sulfur oxides are reduced considerably.

1. Introduction

1.1. Advantages of slurry fuels based on different grades of coal

The main purpose of introducing the technologies of coal-water slurry (CWS) and coal-water slurry containing petrochemicals (CWSP) is to reduce the environmental load of fossil fuel power stations on the global population [1]. Laboratory experiments have established [1] that using CWS and CWSP instead of conventional pulverized coal provides almost zero emission of sulfur and nitrogen oxides. These are widely thought to be the most hazardous part of flue gases. According to feasibility studies, CWS and CWSP technologies have high potential [1], since they use less combustible matter in a fuel composition (almost a half of it is water).

In the seventies and eighties of the 20th century, CWS technologies received much attention as a realistic alternative to petrochemicals [2,3]. Currently, slurry fuels are getting a new lease of life. This time, however, the world community largely perceives the CWS and CWSP technologies [4,5] as a more environmentally friendly rival of traditional technologies involving high-temperature coal dust combustion.

Although the use of renewable energy is on the rise, conventional fossil fuels are still playing the dominant role. Coal is one of the main and readily available power resources. In 2014, for example, about 40% of electric power in the world was generated by coal combustion [6]. Such a significant contribution of environmentally hazardous coal to the world power industry cannot be minimized in the coming decades. However, we can search for and develop alternative approaches to using the coal resource. From this perspective, the environmental aspect of using CWS and CWSP is of considerable interest.

The combustion of high-moisture fuels generates significantly fewer toxic products (nitrogen and sulfur oxides) and fly ash as compared to traditional coal dust combustion [5,7]. Using liquid slurry fuels reduces the temperatures in combustion chambers due to moisture evaporation. This promotes a decrease in both harmful emissions and the heat release rate of heating surfaces. CWS and CWSP technologies also provide an effective approach to the recovery of wastes and by-products of coal and oil processing industries. This problem is a global concern. It is complicated by the limited areas appropriate for waste storage and even more by the environmental hazard of these wastes [8–10].

Sweden, USA, Canada, Japan, Germany, China, and some other countries used to have several CWS production factories in the

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Nomenclature

A^d	ash (%)
C^{daf}, H^{daf}, N^{daf}, O^{daf}, S_t^d	fraction of carbon, hydrogen, nitrogen, oxygen and sulfur in the sample converted to a dry ash-free state (%)
Q_1	combustion heat of CWSP (90% wet filter cake of coking coal, 10% used turbine oil) (MJ/kg)
Q_2	combustion heat of CWSP with sawdust (85% wet filter cake of coking coal, 10% used turbine oil, 5% sawdust) (MJ/kg)
Qas	heat of combustion (MJ/kg)
Q_{fc}	combustion heat of wet filter cake (MJ/kg)
Q_{fc}	combustion heat of used turbine oil (MJ/kg)
Q_s	combustion heat of sawdust (MJ/kg)
R_d	initial CWSP droplet radius (mm)
T_d	temperature in the center of a CWSP droplet (K)
T_d^{max}	maximum temperature in the center of a CWSP droplet during heating (K)
T_g	air temperature (K)
T_g^{min}	minimum air temperature sufficient for sustainable CWSP ignition (K)
V^{daf}	yield of volatiles of filter cake to a dry ash-free state (%)
V_g	air flow velocity (K)
W^a	humidity of analytical sample of filter cake in an air-dry state (%)
φ_{fc}	relative mass fraction of wet filter cake (%)
φ_{to}	relative mass fraction of used turbine oil (%)
φ_s	relative mass fraction of pine sawdust (%)
τ	time (s)
τ_c	time of complete CWSP droplet burnout (s)
τ_d	ignition time delay of CWSP droplet (s)

1980s [2]. Multiple industrial tests that were run back then showed high potential of coal slurries in terms of not only their combustion properties but also transportation, production, and storage [2]. These tests used slurries based on high-rank pulverized coals rich in carbon. As for slurries based on coal flotation and petroleum wastes, researchers started to explore their main ignition and combustion properties a relatively short time ago (see some results in Refs. [11,12]). Unfortunately, there is no sound experimental database with the main ignition and combustion parameters of waste-derived fuels with varying types and properties of the main components as well as using different additives.

The active usage of CWSPs in the energy sector of many states has some economic advantages as well. The cost of moist coal processing wastes and used oils is minimal, mostly consisting of transportation costs. Therefore, it makes economic sense to produce slurries on their basis. Not only wastes, but also local low-rank coals can serve as components of slurry fuels, because these are readily available at a low price in every region. However, the use of coal flotation wastes (filter cakes) is of greater economic interest, because no significant expenses are needed for their use when producing CWSPs. In particular, the initial particle-size distribution of a filter cake is on average 80–150 μm [13,14]. This makes it possible to skip the stage of drying and quite an energy-consuming stage of solid fuel component grinding. It is noteworthy that using a filter cake or any other moist coal processing wastes minimizes the risk of fire outbreaks during transportation, storage and unloading, because the fuel is not a fire-hazardous dried coal dust.

The energy performance indicators of using coal processing wastes instead of coal do not seem beneficial at first sight. Due to a large proportion of moisture in CWSPs, stable combustion requires more time and energy. However, as shown in Refs. [11,12], the ignition and combustion properties and factors may be varied in a wide range by adding petroleum components to a coal-water slurry or moist filter cake. These can be, for example, used motor and industrial oils, fuel oil, and oil-water emulsions. Such an approach can significantly increase the combustion heat and reduce the ignition delay time of CWSPs by adding even as little as 5–7% to 10–15% of an oil product. Another important point is that the anthropogenic emissions from the combustion of CWSPs based on coal and oil processing wastes do not exceed those from coal dust combustion [15]. The effect of other additives including plant-based ones on the ignition and combustion of high-potential CWSPs is a question that requires further investigation.

The slurry fuels under discussion clearly have good environmental, economic and energy prospects, but their feasibility largely depends on the prices of fossil fuels, the global environmental and energy strategy, as well as the depth of research into liquid composite fuels based on coal and oil processing wastes.

1.2. High-potential CWSP components

Over the recent years, experts have extensively discussed the production of CWS and CWSP not only from low-quality coals but also from low-rank coal and processing wastes (in particular, filter cakes produced during coal washing). The volume of these wastes is growing by tens of millions of tons each year [16,17] and the technologies for their deep conversion have not been developed yet. The main barriers to using them in the heat power industry are as follows: no reliable experimental database on combustion processes; high energy consumption required for stable ignition (the temperatures need to be above 1000 K); no adequate models to forecast the optimal ignition conditions and attributes of this process.

Due to the growing interest in filter cakes, especially in China, Russia, India, Pakistan, and other countries, the attributes of their combustion have been a popular object of research and publication over the last 3–5 years (e.g., [4]). The filter cakes have fewer carbon and volatile components than coals [11]. Therefore, it takes significantly longer for filter cakes to ignite (for most filter cake types, the ignition delay times are several times longer than those of coals). It is thus a relevant task to search for ways to intensify the ignition of CWS and CWSP based on filter cakes. Studies [11,12] suggest used oils, oil sludge, resins and other liquid fuel components as intensifying additives to coal-water slurries containing petrochemicals. The key problem, however, of using these to intensify the CWSP ignition process is the growing concentration of anthropogenic emissions into the atmosphere (NO_x, SO_x, CO_2). The additives should be chosen from wastes with minimum environmental load. One of such options is sawdust. The volume of its associated production is 50–60 million tons a year [18]. Therefore, it is of interest to evaluate how small concentrations of sawdust affect the ignition delay of CWSPs based on widespread filter cakes.

The following substances hold much promise as CWSP components: oil refinery wastes (oil sludge and sediments formed when cleaning oil pipelines and tanks) [5]; liquid wastes of coke and by-product process, namely heavy coal-tar products, polymers after absorption oil regeneration [4,19], kerosene [20], and other flammable liquids. Organic solvents like 2-propanol, benzene, xylene, n-