



Maximum combustion temperature for coal-water slurry containing petrochemicals



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ABSTRACT

This study examines the temperature change of droplets of coal-water slurry containing petrochemicals (CWSP). The slurry consists of coal and oil processing waste. The temperature of oxidant in a modelled combustion chamber is varied between 600 and 1200 K. The initial size (radius) of CWSP droplets varied in the range of 0.5–3 mm. The study identifies typical temperature trends at the center and on the surface of the CWSP droplet. The temperature trends represent the following stages: (i) heating of fuel, (ii) evaporation of water and a liquid combustible component, (iii) thermal decomposition of coal and yield of volatiles, (iv) gas phase ignition of volatiles together with vapor of the combustible liquid, and (v) heterogeneous ignition of carbon and its burnout. Moreover, these trends indicate the maximum combustion temperatures of CWSP that reflect corresponding heat release. The study specifies the parameters which influence the maximum combustion temperature: fuel component composition, properties of components, droplet size, and the oxidant temperature. Finally, the study defines the minimum ignition temperatures and delay times of sustainable combustion initiation that characterize the ignition inertia. The knowledge of influence of these factors will allow one to predict the optimal conditions for the combustion of the CWSP.

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1. Introduction

Over the past ten years, fuel technologies based on coal-water slurry (CWS) and coal-water slurry containing petrochemicals (CWSP) have received a particular interest among researchers and specialists. Furthermore, the results of theoretical and experimental studies, field tests, industrial implementation and pilot operation of such technologies have shown their great benefit to humanity [1–5]. First of all, one can outline the environmental aspects of using such slurries. The CWS and CWSP cause much less emissions of sulfur and nitrogen oxides compared to solid pulverized coal. Moreover, they can contribute to large-scale recycling of coal and oil waste. The second important advantage is the economic impact of these slurries. In particular, the CWS and CWSP may expand the raw material base through the involvement of low-grade coal and various coal and oil wastes in their production. Third, in recent years, specialists have revealed that the power indices of CWS and CWSP are higher compared to conventional

pulverized coal. In particular, one can highlight low-temperature ignition of the slurries (it is possible to reduce the ignition temperature to 100–200 K), as well as reduction of fire hazard that can occur at power plants during preparation and transportation of highly reactive pulverized coal. The most promising way to make use of CWS and CWSP is their combustion in small and big power boilers. However, there are prospects of using liquid slurry fuels based on coal processing waste, low-rank coals and oil products in combustion engines (diesel fuel can be replaced by coal-water slurries) [6]. Furthermore, the conversion of coal-water slurries to obtain syngas is a popular research area [7].

Research results of the world scientific community (in particular, publications [5,8–17]) indicate that CWS and CWSP can be composed of a large group of substances. For example, the following solid combustible components can be used: coal of various grades (wood, brown, bituminous, and anthracite), coke, semi-coke, products and waste of coal processing and coal washing, tires processing waste, peat, and others. Liquid combustible components can be represented by: waste industrial and automobile oils, flammable liquids, oil sludge, oil deposits formed during cleaning of pipelines and storage tanks, polymers after saturation oil recovery, coal tar, and etc. Also, the CWS and CWSP quite often

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Nomenclature

Abbreviations

C	coking coal
CWS	coal-water slurry
CWSP	coal-water slurry containing petrochemicals
F	flame coal
G	gas coal
L	low-caking coal
N	nonbaking coal

Symbols

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 (%)
$Q_{s,v}^a$	heat of combustion (MJ/kg)
R_d	radius of droplet (mm)
T_d	temperature at the interface thermocouple junction/slurry (K)
T_d^{max}	maximum temperature at the interface thermocouple junction/slurry (K)

T_f	flash point (K)
T_g	oxidizer temperature (K)
T_g^{min}	minimum oxidizer temperature required for stable ignition of CWSP (K)
T_{ign}	temperature of ignition (K)
T_s	temperature of droplet surface measured by thermocouple (K)
T_v	temperature of droplet surface measured by thermal imager (K)
V_0	initial volume of fuel (mm ³)
V_c	volume of separated fuel layer (mm ³)
V^{daf}	yield of volatiles of filter cake to a dry ash-free state (%)
V_g	velocity of oxidizer flow (m/s)
W^a	humidity of analytical sample of filter cake in an air-dry state (%)
Y_1	stability index
ρ	density (kg/m ³)
τ	time (s)
τ_c	time of complete burnout (s)
τ_d	ignition delay time (s)
φ_l	mass fraction of water (%)
φ_w	mass fraction of combustible liquid (%)

include some additives, such as wetting agents or plasticizers that improve their segmental stability (slow down fuel lamination). Furthermore, some additional special components (for example, silicon powder, sodium humate, lignin-alkaline reagent, lignosulfonate, gelatin, aluminum powder, and etc.) may enhance or stabilize heating and combustion of CWS or CWSP.

When using CWS and CWSP, one of the main problems is lesser heat generation compared to traditional carbon fuels. This is mainly due to the fact that CWS and CWSP consist of low-grade coal or wastes from recycling. Therefore, one of the most important tasks is to define the mechanisms that may increase heat output of CWS and CWSP. Unfortunately, high material costs and complexity of monitoring the effect of one or two factors constrain such studies at operating power plants. As a consequence, it is relevant to conduct experimental research in a laboratory. This will allow us to find out how some basic parameters influence the combustion temperature of CWSP with typical component compositions.

The most common approach is considered to be the use of a low-inertia thermocouple junction or ceramic threads (rods or wires) to fix a single CWS or CWSP droplet (particle) [3,15–17]. The main advantage of this approach is the possibility to monitor the temperature of the fuel sample (droplet or particle) and the conditions of its phasic combustion. Such methods were applied in previous studies to examine pyrolysis, gasification and combustion of CWS droplets in air during radiative and convective heating. Recent reports presented the main results obtained in the experiments, where the CWS droplets were hung on a low-inertia thermocouple [3,15–18]. Reference [18] studies the cyclic combustion of coal particles of various ranks fixed on a thermocouple junction. Study [3] identifies the ignition mechanism and burnout characteristics for CWS droplets based on water and workable coals. The results described in Refs. [15–17] illustrate the impact of the component composition of CWSP based on coal processing waste and typical oil products on the inertia and minimum (limit) ignition temperatures. The heat release processes involved in CWSP droplet combustion remain unstudied, since there are no experimental data on the temperatures for sustainable ignition and subsequent

combustion of CWSP droplets. We suggest improving results [3,15–17] by performing experiments with a single droplet and on this example, to analyze the maximum combustion temperatures of CWSP. For this purpose, the following basic ignition parameters should be varied: oxidant temperature, fuel droplet size, and fuel component composition.

The studies of the last five years identified two main parameters that significantly affect the integral ignition characteristics of CWSP: minimum oxidant temperature and ignition delay time [15–17]. In these studies, researchers varied the following parameters: (i) properties of solid and liquid fuel components, such as ash content, moisture content, volatile content, and combustion heat; (ii) concentration of water, coal and a liquid fuel component; (iii) coal grinding fineness; (iv) size, surface area and shape of fuel particles; (v) methods and duration of fuel preparation; (vi) stability and viscosity of fuel compositions; and (vii) temperature and velocity of the oxidant flow. Now, it is reasonable to estimate the effect of component composition and concentration of each component in CWSP. This can be achieved by monitoring the temperature at the center and on the surface of the CWSP droplet. For precise measurements, thermocouples and a high-speed thermal imager should be used. They allow the control of maximum temperatures in the reacting fuel droplet, since they indicate the maximum values at different stages of fuel reaction. The problem of optimization of CWS and CWSP combustion is especially urgent in power engineering, since many power plants operate on coal burning. As a result, the amount of waste from mining, production, and washing of coal continues to grow [19–22].

The objective of this study is to detect how the component composition of CWSP influences its maximum combustion temperature.

2. Experimental details

2.1. Materials

For this study we selected filter cakes as solid combustible

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