

A study of combustion characteristics of pulverized coal in O₂/H₂O atmosphere



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HIGHLIGHTS

- The burning process in O₂/H₂O mixtures is delayed compared with that in O₂/N₂ atmosphere.
- With increasing of the oxygen concentration, the comprehensive combustibility index increases.
- In O₂/H₂O atmosphere, the increase of heating rate can enhance the coal combustion property.
- In O₂/H₂O mixtures, as the particle size decreases, the ignition and burnout temperature decrease.
- The combustion reactions in O₂/H₂O atmosphere follow the first-order kinetic.

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ABSTRACT

Oxy-steam combustion technology in which the mixtures of oxygen and steam are used as oxidizer instead of air is a new generation oxy-fuel combustion technology. The combustion characteristics of SH and PDS pulverized coal in O₂/H₂O mixtures are studied using non-isothermal thermogravimetric analysis technology in this paper. The effect of combustion atmosphere, oxygen concentration, heating rate and particle size on the combustion characteristics of SH and PDS pulverized coal in O₂/H₂O mixtures are analyzed based on the combustion profiles and kinetic analysis. The results show that replacing the inert N₂ gas in the oxidizer with steam delayed the burning process of SH and PDS pulverized coal. With the increasing of the oxygen concentration, the ignition T_i and burnout temperature T_b decrease and the comprehensive combustibility index S increases both in O₂/H₂O and O₂/N₂ atmosphere. In O₂/H₂O atmosphere, the combustion of SH and PDS coal occur in a higher temperature region as the heating rate increases, but the increase in heating rate can enhance the coal combustion property. As the particle size decreases, the maximum mass loss rate increases and the ignition and burnout temperature decrease. The results of kinetic analysis indicate that the combustion reactions of SH and PDS pulverized coal in O₂/H₂O mixtures follow the first-order kinetics through linear fitting of experimental data using Coats–Redfern integral method, and compensation effect exists between apparent activation energy and pre-exponential factor in different oxygen concentrations during coal combustion in O₂/H₂O mixtures.

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1. Introduction

The global climate change caused by greenhouse-gases has become a hot issue of the world. The climate change 2007 synthesis report of Intergovernmental Panel on Climate Change (IPCC) indicates that fossil fuel combustion for energy supply and consumption is one of the main sources of carbon dioxide (CO₂) emission [1]. It is now generally believed that carbon capture and storage (CCS) technology is one of the real options to reduce CO₂ emissions from fossil fuel combustion, especially in power plants. Oxy-fuel combustion technology, one of three main CCS technologies, has

attracted considerable attention in recent years because it is feasible to produce high CO₂ concentration in exhaust gas (greater than 90% by volume), which is almost sequestration-ready in the flue gas [2]. Oxy-fuel combustion technology is represented by O₂/CO₂ recycled combustion at present, in which the combustion of fuel occurs in an atmosphere of oxygen and recycled flue gas (RFG) [3,4].

The main disadvantages of O₂/CO₂ recycled combustion are the higher economic costs and lower efficiency of power plants compared to air-fired plant. Canadian Centre for Mineral and Energy Technology (CANMET) proposed a zero-emission system based on oxy-steam combustion technology in 2007 [5]. Seepana and Jayanti [6] proposed a power generating system based on oxy-steam combustion, called steam-moderated oxy-fuel combustion

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Nomenclature

A	pre-exponential factor (s^{-1})
C_p	specific heat at constant pressure (J/mol K)
C_v	specific heat at constant volume (J/mol K)
E	apparent activation energy (kJ/mol)
n	reaction order (–)
R	universal gas constant (J/mol K)
S	comprehensive combustibility index (%/min K ³)
t	time (s)
T	temperature (K)
T_i	ignition temperature (K)
T_h	burnout temperature (K)
W	weight of sample (%)
X	conversion rate (–)

Greek letters

α	thermal diffusivity (m^2/s)
β	heating rate (K/min)
ρ	density (kg/m^3)
λ	thermal conductivity (W/m K)
ν	viscosity (Pa s)

Subscripts

max	maximum value
$mean$	average value
0	start
∞	end

(SMOC). Oxy-steam combustion is that combustion takes place in the mixtures of oxygen and steam instead of air or the mixtures of oxygen and recycled flue gas. The schematic diagram of steam-moderated oxy-fuel combustion process they proposed is shown in Fig. 1.

Compared with O₂/CO₂ recycle combustion, oxy-steam combustion has the following advantages:

- (1) On account of the little recycled flue gas, the overall system is simple, compact and easy start-up and shut-down.
- (2) Because of the much greater specific heat of steam compared to CO₂, the amount of steam to achieve the same combustion temperature in oxy-steam combustion is much smaller than that of O₂/CO₂ recycled combustion. The sizes of the major and auxiliary equipments of the system are smaller than those of the O₂/CO₂ recycled combustion system.
- (3) The formation of NO_x and SO_x in the boiler can be reduced owing to the introduce of steam.
- (4) The pumping costs associated with recycling are relatively low because the transmission medium is water but not flue gas.

Therefore, oxy-steam combustion technology is a potential new generation combustion technology.

Obviously, the combustion characteristics of oxy-steam combustion of pulverized coal are different from those of conventional air combustion and O₂/CO₂ recycled combustion in that the

physicochemical properties of H₂O are much different from N₂ and CO₂ (Table 1). While the combustion characteristics of coal in O₂/CO₂ environments have already been thoroughly investigated, the combustion characteristics of coal in O₂/H₂O atmospheres have been the subject of few studies. Some relational research on the influence of steam as a diluent or additive on the combustion of gas fuel and coal are summarized below.

Studies of steam-added methane and hydrogen combustion flames showed that the concentrations of H and O decreased and the concentrations of OH increased with increasing steam quantity [7–9]. Richards et al. [10] studied the combustion performance of the oxy-fuel combustion diluted with CO₂ and H₂O by numerical calculations and experiments; computational results indicated that the required residence time in CO₂ diluted system was 5–7 times greater than that in H₂O diluted system, and the equilibrium CO levels were higher compared with the H₂O diluted cycle; full-scale H₂O diluted oxy-fuel combustion experiments found that CO levels were higher than equilibrium but were not unreasonable for the low levels of excess oxygen. Gil et al. [11] found out that substitution of steam for 10–20% of steam in the oxy-coal combustion could result in an enhancement of combustion reaction rate and a decrease in the burnout time. They attributed these to the lower specific heat capacity of H₂O than that of CO₂. The studies of the effect of steam on the combustion characteristics of oxy-coal combustion by Riaza et al. [12] indicated that the temperature of coal ignition rose and burn-out rate dropt when steam was added in oxy-fuel combustion atmospheres in an entrained flow reactor.

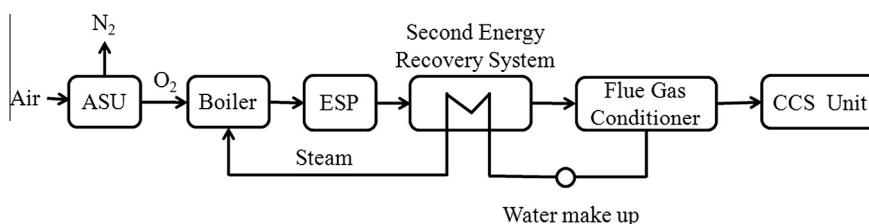


Fig. 1. Schematic diagram of steam-moderated oxy-fuel combustion process.

Table 1

Comparison of physical properties at 1000 K, 0.1 MPa.

Gas	ρ (kg/m^3)	C_v (J/mol K)	C_p (J/mol K)	λ (W/m K)	ν (Pa s)	α (m^2/s)
H ₂ O	0.217	32.96	41.29	0.097	3.76×10^{-5}	1.95×10^{-4}
CO ₂	0.529	46.01	54.32	0.071	4.13×10^{-5}	1.08×10^{-4}
N ₂	0.337	24.39	32.71	0.066	4.16×10^{-5}	1.68×10^{-4}

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