



Full Length Article

Effects of CO₂ gasification reaction on the combustion of pulverized coal char

Yanqing Niu*, Siqi Liu, Bokang Yan, Shuai Wang, Xiao Zhang, Shi'en Hui

State Key Laboratory of Multiphase Flow in Power Engineering, Department of Thermal Engineering, School of Energy and Power Engineering, Xi'an Jiaotong University, 710049 Shaanxi, China

ARTICLE INFO

Keywords:

CO₂
Gasification
Oxidation
Combustion
Char

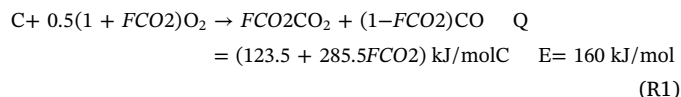
ABSTRACT

Although numerous studies on CO₂ gasification during coal char combustion have been documented, the effects of CO₂ gasification on high-temperature carbon oxidation, which is important for evaluation of carbon conversion during pulverized coal combustion under oxy-fuel and flue gas recirculation conditions, are unclear. Thus, the char conversion characteristics at various contents of O₂ and CO₂ were studied in a drop-tube furnace at 1373 K. Due to the cumulative effects of CO₂ gasification, which can not only suppress carbon conversion due to endothermicity but also consume part of carbon directly, there exists a minimal carbon conversion point around the CO₂ content of 9–13 vol%, where the growth of promotion effect with CO₂ content catches up with the suppression effect, and an inflection point around the CO₂ content of 17–25 vol%, where the promotion effect of the direct gasification reaction on carbon consumption surpasses the suppression effect. Increasing O₂ shifts both points towards high CO₂ contents, whereas increasing combustion gas temperature decreases the values. A mathematical formula including oxidation, effect of gasification on oxidation, and CO₂ gasification, is presented, which gives well prediction on high-temperature carbon conversion. With increasing CO₂ content, the reduction degree of CO₂ gasification on oxidation rate increases, and the synthesis oxidation rate slightly decreases, whereas there always exists a minimal point for gasification rate, gross carbon conversion rate, and gasification weightiness. With increasing O₂ content, the oxidation rate, reduction degree of CO₂ gasification on oxidation rate, and gross carbon conversion rate increase; the gasification rate increases below the minimal point, whereas decreases above the minimal point; the gasification weightiness decreases. Combustion gas temperature shows positive effect on all abovementioned parameters. The results derived here provide meaningful guidelines for practical application and kinetics research on pulverized coal combustion.

1. Introduction

Although the global coal-fired power plants provide electricity demand for about 81% of the world's population [1], regrettably, detailed information on both oxidation and gasification reactions on coal char conversion during combustion is obscure until now. For example, the weightiness of CO₂ gasification reaction during combustion [2], and gross carbon conversion rate as an equilibrium of additional gasification rate accelerating carbon conversion and decreased oxidation reaction rate due to the reduced particle temperature caused by gasification endothermic [2–4] need further exploration. During pulverized coal char combustion under both O₂/N₂ and O₂/CO₂ atmospheres in industrial and power plant boilers, besides the complex heterogeneous oxidation reactions expressed as R1 [5–7] with a CO/CO₂ split ratio of $50\exp(-3070/T)P_{O_2}^{-0.21}$ [7], CO₂ gasification reaction, R2, plays a key role in carbon conversion, especially in the atmosphere with high

content of CO₂ (for example, flue gas recirculation during traditional air combustion and oxy-fuel combustion) [5,6,8,9]. The gasification reaction influences carbon conversion rate and residence time [2,5], and consequently the boiler design. In this paper, we mainly focus on CO₂ gasification reaction and put steam gasification aside temporarily, which may inhibit the CO₂ gasification reaction by competing for the same carbon active site on the surface of char [10].



where FCO_2 presents the conversion fraction of carbon into CO₂ through oxidation reaction.

The elevated level of CO₂ affects the heat capacity, radiant

* Corresponding author.

E-mail address: yqniu85@mail.xjtu.edu.cn (Y. Niu).

transport, oxygen diffusion, subsequently CO_2 gasification reaction rate and oxidation reaction rate, and consequently the gross carbon conversion rate [4,8,11,12]. Huang et al. [3] conducted bituminous combustion experiments at 1670 K in O_2/CO_2 atmosphere, and announced that the suppression effect of CO_2 on char burnout is stronger than the promotion effect of CO_2 gasification reaction on char consumption at high oxygen conditions. Based on the statistical optimum relative rate coefficients of CO_2 gasification to oxidation at 800 °C (6.2×10^{-5}) [2], Hecht et al. [2,8] computed the char consumption characteristics using Surface Kinetics in Porous Particles (SKIPPY) code and revealed that gasification reaction reduced the rate of char oxidation due to decreasing char particle temperature caused by gasification endothermicity, whereas increased the total carbon consumption rate [5,8].

Given the complex effects of CO_2 gasification reaction on char thermal conversion, numerous experiments and kinetics researches have been performed, and some sporadic suggestions have also been proposed. However, most of the previous studies addressing the effects of CO_2 gasification on coal/char combustion used Thermogravimetry Analyzer (TGA) [10,13,14] or TGA derived data [2,8], systematic reports on the weightiness of CO_2 gasification on pulverized coal char conversion in complex high-temperature combustion atmospheres are rare. That is essential for the proper evaluation of char conversion characteristics (residence time and carbon conversion rate) during combustion, especially under oxy-fuel and traditional air combustion with flue gas recirculation. Therefore, to give theoretical guidelines on flue gas recirculation proportion during air combustion, which affects the CO_2 content in combustion atmospheres, and parameters selection for kinetics modeling of pulverized coal char combustion under both O_2/N_2 and O_2/CO_2 atmospheres, experimental studies on the effects of CO_2 gasification reaction on pulverized coal char combustion at high temperature with various contents of O_2 and CO_2 were conducted in a drop-tube furnace; meanwhile, a theoretic exploration on basis of the fitting analysis of experiment data was performed to provide in-depth insight on the complex effects of CO_2 gasification, particular in the weightiness of CO_2 gasification reaction to gross carbon conversion rate.

2. Experimental

As shown in Fig. 1, experiments were conducted in an electrical heating drop-tube furnace. The furnace consists of two segments, and the upper and lower segments are heated with Si-Mo and Si-C heating elements, respectively. A corundum tube, 1500 mm in length and 51 mm in inner diameter, is fixed in the center of the furnace to avoid gas leakage and maintain unchanged reaction atmospheres.

To reveal the effect of CO_2 gasification reactions on combustion of pulverized coal char particle, the Huangling bituminous coal, a typical coal used in Chinese power plants, was devolatilized first at 1373 K in N_2 atmosphere with 2.0 vol% of O_2 . The minor oxygen content was used to oxide tar, which may condense on char particle surface and reactor surface. The coal properties are summarized in Table 1. It has a high volatile content of 30.34 wt% and moderate ash content of 13.63 wt%.

After devolatilization, the coal char particles with a size of $75\text{--}90\text{ }\mu\text{m}$ were burned at $1373 \pm 50\text{ K}$ and in mixture gases of O_2 with a content of 21 or 36 vol%, CO_2 at 0, 5, 10, 15 and 25 vol%, and N_2 as balance gas. Among the constant total gas flow rate at 10.78 slpm, 150 smlpm of N_2 used to carry the pulverized coal char particles was injected into the micro feeder (right-upper part of Fig. 1), which then introduced the gas-solid mixture into a water-cooling feeding probe at the top of the reactor (middle-upper part, Fig. 1). To assure that the injected particles burned in isolation from one another, the pulverized coal char particles were feed at a feeding rate of $20\text{ mg}\cdot\text{min}^{-1}$. The residual carbon particles were isokinetically collected at the bottom of the furnace by a water-cooled and high purity N_2 quenched probe

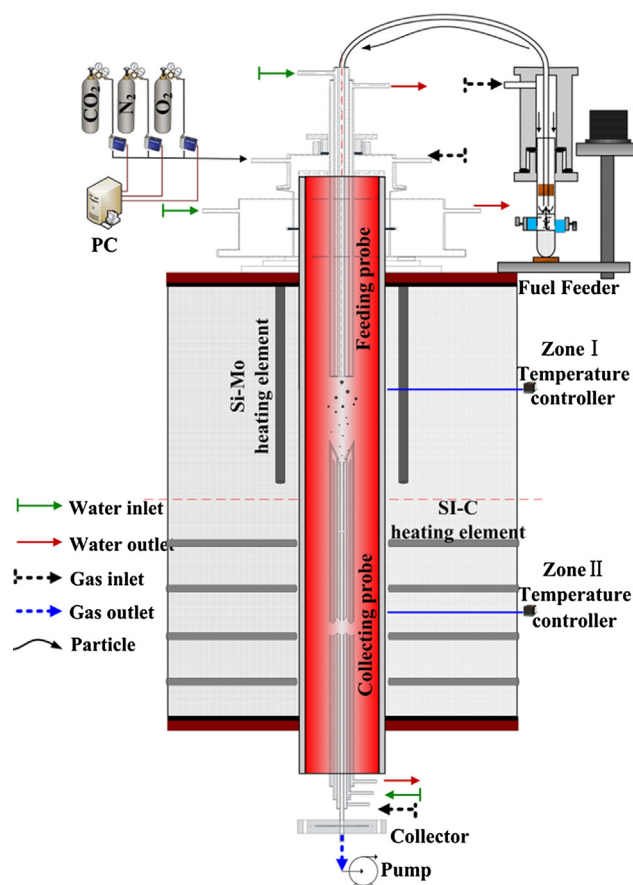


Fig. 1. Schematic of the lab-scale experiment system.

(bottom part of Fig. 1). The quenched probe was connected to a home-made collector, where a glass fiber filter with a pore size of $0.4\text{ }\mu\text{m}$ was employed. By locating the relative positions between feeding probe and collecting probe, three residence times (approximate 0.2, 0.3, and 0.4 s) of the pulverized coal char particle during combustion were designed.

The micro feeder consists of a storage tube used to load pulverized coal char, a top sealing unit used to swallow and spit the storage tube, and a stepping motor used to control the forward velocity of storage tube and consequently the fuel feeding rate. Carry gas is injected into the top sealing unit from the side, and carries the char particles out of the storage tube through a fine central tube. Meanwhile, two vibrators encompassing the storage tube are used to improve the fluidization of char particles. The water-cooling feeding probe consists of three concentric tubes, and the pulverized coal, cold feedwater, and hot yielding water flowed through the concentric tubes from the inside out; The water-cooling collecting probe consists of four concentric tubes, and the flowing medium were residual carbon particles flow, diluent gas, cold feeding-water, and hot yielding-water in turn. During experiments, the carbon conversion ratios of the collected char particles at different residence times were tested by TGA (STA409PC, NETZSCH, Germany).

3. Results and discussions

3.1. High-temperature carbon conversion under various $\text{O}_2/\text{CO}_2/\text{N}_2$ atmospheres

Fig. 2 shows the experiment results of carbon conversion under various combustion atmospheres and residence times. With increasing CO_2 content, the carbon conversion ratio first decreases and then increases in both oxygen contents of 21 and 36 vol%. At various residence times and O_2 contents, there always exists an inflection point around

Download English Version:

<https://daneshyari.com/en/article/6630173>

Download Persian Version:

<https://daneshyari.com/article/6630173>

[Daneshyari.com](https://daneshyari.com)