Effect of oxidation treatment on structural characteristics and combustion kinetics of residual carbon from coal gasification fine slag

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Highlights

- The combustion performance of the oxidized residual carbon (RC) is improved.
- CO_2 treatment shows a greater impact on combustion behavior of oxidized RC than air.
- Pore is the main factor determining the combustion performance of oxidized RC.
- The increase of oxidation temperature is conducive to the formation of pores of RC.

1. Introduction

The coal gasification fine slag (CGFS) composed of residual carbon (RC) and inorganic minerals, as gasification solid waste, is produced in large amount with the large-scale application of entrained-flow gasification technology. Combustion is a potential way to realize large-scale utilization of CGFS [1]. However, the poor reactivity is the main problem limiting the large-scale combustion of CGFS [2]. The enhancement of RC reactivity necessitates structural modification. Oxidation treatment has been proved to have a significant modification effect on the structure of RC [3]. In this study, air and CO_2 were employed as oxidants to thoroughly examine the influence of oxidant type, oxidation temperature, and duration on the structures, combustion characteristics and kinetics of RC. The results of this study are expected to introduce new ideas and insights into the structural modification and enhancement of combustion performance of RC in CGFS.

2. Methods

The oxidation of RC was carried out using air and CO_2. The oxidation temperatures of RC were set at 200, 300 and 400 °C, and the oxidation time was set at 2, 4, 6, 8 and 10 h. Combustion experiments on RC and oxidized RC were performed utilizing a thermogravimetric analyzer. The samples were placed in an aluminum oxide crucible and heated from 30 to 1000 °C under an air flow of 100 mL/min. For assessing combustion characteristics, heating rate of 10 °C/min was employed. Additionally, for the analysis of combustion kinetics, four different heating rates (5, 10, 15, 20 °C/min) were selected. The comprehensive combustion characteristic index (S), ignition index (Di), and burnout index (Db) were used to evaluate the combustion, ignition, and burnout performance of the samples. Moreover, the KAS and FWO methods were used to calculate the Eα of the combustion reaction.

$$\text{KAS: } \ln\left(\frac{\beta}{T_\alpha^2}\right) = \ln\left[\frac{AE_\alpha}{Rg(\alpha)}\right] - \frac{E_\alpha}{RT_\alpha} \quad (1)$$

$$\text{FWO: } \ln(\beta) = \ln\left[\frac{AE_\alpha}{Rg(\alpha)}\right] - 5.331 - 1.052\frac{E_\alpha}{RT_\alpha} \quad (2)$$

where for a given α, E_α for KAS and FWO can be estimated from the slopes of the straight lines of $\ln\left(\frac{\beta}{T_\alpha^2}\right)$ vs. $1/T_\alpha$ and $\ln(\beta)$ vs. $1/T_\alpha$, respectively.

3. Results and discussion

The relationship between Eα and α of oxidized RC notably is different from that of RC. For RC-C10-400, both KAS and FWO methods exhibited substantial fluctuations in Eα. Compared with RC, the $E_{0.1}$ of RC-C10-400 showcased a significant increase and a decrease in $E_{0.9}$. Throughout the combustion, Eα of RC-C10-400 demonstrated a continuous decreasing trend. The decline rate of Eα ($0.2<\alpha<0.8$) for RC-C10-400 greatly surpassed that of the second stage of RC and RC-A8-300. This indicates that once ignition begins, the combustion reactions of RC-C10-400 are more likely to sustain themselves.

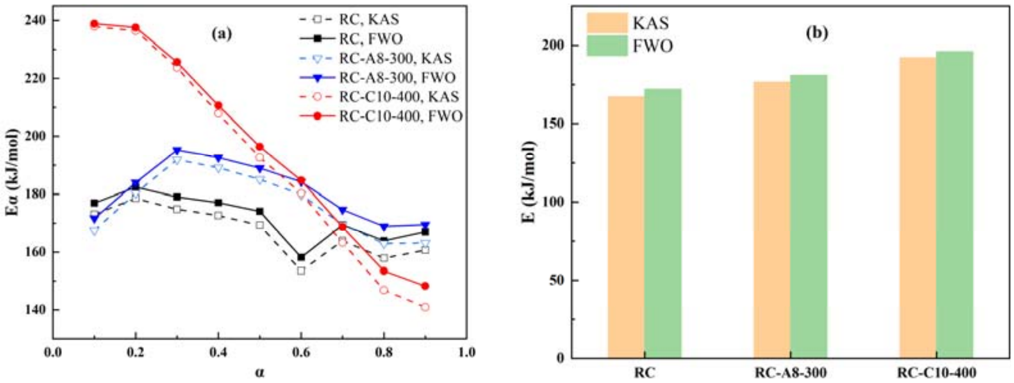

Figure 1. (a) Relation between Eα and α for the samples and (b) The average E values determined via KAS and FWO methods.

The change in the structural characteristics of oxidized RC stands as the primary reason behind the improvement in its combustion behavior. The carbon microstructure, oxygen-containing groups, and pore structure jointly determined the combustion behavior of oxidized RC, and the surface pore structure appeared to be the main contributing factor. Suitable oxidation temperature helps to improve the surface structure of oxidized RC.

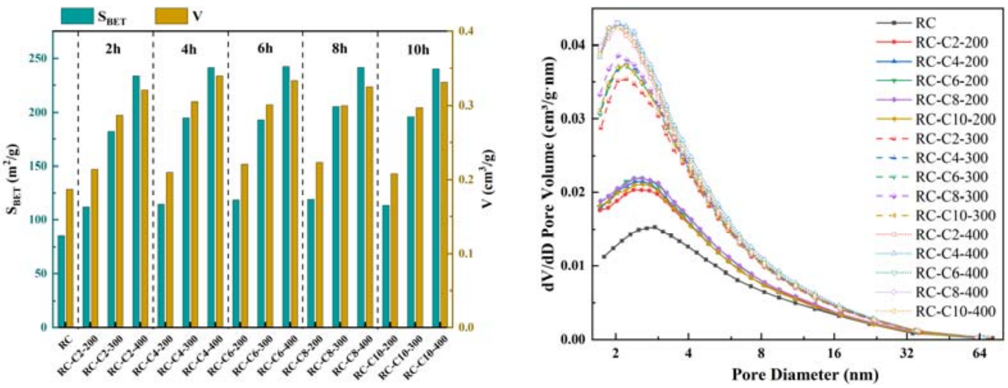

Figure 2. Specific surface area, pore volume, and pore size distribution of the samples.

4. Conclusions

CO_2 treatment significantly impacted the combustion behavior of RC compared to that of air. RC oxidized by CO_2 displayed increased ignition temperature, significantly reduced burnout temperature, and notably shortened combustion processes. Moreover, the kinetic parameters revealed that once ignited, the combustion of RC oxidized by CO_2 was more rapid and stable. In addition, all the combustion evaluation indexes of oxidized RC increased with rising oxidation temperature. However, excessively high oxidation temperature led to increase the carbon loss during oxidation and inhibited the combustion reactivity of the corresponding oxidized RC. The structural changes emerged as the essential reason for improved combustion performance of oxidized RC. The surface pore structure of the oxidized RC played a crucial role in its combustion performance, and the oxidized RC with a well-developed pore structure exhibited superior combustion performance. Additionally, the merging of small-sized pores and the collapse of large-sized pores, caused by excessive air oxidation, were the main reasons contributing to the reduction in the combustion performance of RC-AX-400.

References

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Keywords

Coal gasification fine slag, Residual carbon, Oxidation, combustion kinetics