energy&fuels Article
pubs.acs.org/EF

Kinetic Study on Coal Char Combustion in a Microfluidized Bed

Yuan Fang, Renjie Zou, Guangqian Luo, Juan Chen, Zehua Li, Zhengjiang Mao, Xianqing Zhu, Fulei Peng, Shengqiang Guo, Xian Li, and Hong Yao*

State Key Laboratory of Coal Combustion (SKLCC), School of Energy and Power Engineering, Huazhong University of Science and Technology (HUST), Wuhan, Hubei 430074, People's Republic of China

ABSTRACT: The intrinsic kinetics of char combustion were commonly investigated using thermogravimetric analysis (TGA) in previous works at low temperatures to prevent oxygen limitations and temperature deviation. However, the low temperatures caused excess test time because the reaction rate was too slow. In this study, the microfluidized bed (MFB), which has effective heat and mass transfer, was used to investigate the intrinsic kinetics of char combustion at a higher temperature within less time. TGA was used to check the reliability of the MFB. The results suggested that, for fine particles (74−100 μm), the particle temperature deviation and gas distortion could be disregarded in the MFB. For four coal samples, the activation energy measured by the MFB was similar to the result measured by TGA, but the test time using the MFB was greatly shortened as a result of the higher temperatures. The kinetic parameters measured by the MFB were used to predict the char oxidation rate. The predicted rate fit the TGA experiment well at lower temperatures. These results demonstrated the reliability of the MFB and TGA measurements. However, at higher temperatures, the combustion rate in TGA was limited by oxygen diffusion, suggesting that the TGA measurement should be carried out at relatively low temperatures to prevent oxygen diffusion limitation. Instead, the MFB measurement was still valid at higher temperatures as a result of the effective mass and heat transfer.

1. INTRODUCTION

Char combustion plays an important role in the overall coal combustion process. It is the rate-determining step, taking up 70−90% of the whole combustion time.[1−3] A comprehensive understanding of char combustion is helpful for the design and operation of the actual combustion systems.[1−5] Smith[5] proposed an intrinsic reaction model, in which the combustion rate of pulverized coal in actual combustion systems was estimated on the basis of the intrinsic reaction rate. However, different types of coal have a wide range of intrinsic reaction rates. Hargrave et al.[6] took the petrographic structure into account and correlated the intrinsic reactivity with coal properties. Hurt et al.[7] pointed out that the char intrinsic reactivity decreased by a factor of 100−1000 after thermal annealing in pulverized-coal-fired boilers (1400−1800 K). The intrinsic reaction rate plays an important role in predicting char burnout; therefore, it is essential to investigate intrinsic char reactivity in the absence of the heat and mass transfer limitations.[2,3,8,9]

Thermogravimetric analysis (TGA), which is a common instrument in thermal analysis, has been widely used to estimate char oxidation kinetics. There are two main methods adopted by TGA to measure char intrinsic reactivity: (i) non-isothermal method, where char is heated at a constant rate,[10−12] and (ii) isothermal method, where char reacts with oxygen at a constant temperature.[13−15] Char combustion is a rapid exothermic reaction, and the released heat during the test would cause the particle temperature to differ from the preset temperature.[8,16] Char samples are placed in a crucible during the TGA test. The pile-up effect inhibits the transport of oxygen to the char surface.[17] To minimize oxygen diffusion limitations and temperature deviation, char must be tested at relatively low temperatures.[18] At such low temperatures (<773 K), it may take several hours for char to reach 50% conversion. In summary, the disadvantages mentioned above have restricted the further application of TGA to measure intrinsic kinetics of char combustion at higher temperatures.

On the basis of the Arrhenius equation, if the reaction temperature increased from 693−773 to 833−923 K in the chemically controlled regime, the test time would decrease by a factor of 100. The activation energy of char combustion was evaluated as 160 kJ/mol, as reported in previous works.[6,19] Then, the problem is how to prevent temperature deviation, oxygen diffusion limitations, and unstable atmosphere at the initial combustion stage after increasing the reaction temperature.

The microfluidized bed (MFB), which has the advantages of mass and heat transfer and instant online feeding samples, has been applied to the investigation on the kinetics of gas−solid reactions for various solid fuels.[20−29] During lignite char gasification at a constant temperature, the reaction rate in the MFB was higher than that in TGA, indicating the less diffusion limitation in the MFB.[21−23] Yu et al.[25] investigated combustion kinetics of graphite powder at a wide range of temperatures from 973 to 1273 K. Mueller et al.[23] found that the measured kinetic parameters of lignite char gasification between the MFB and TGA were different. This was because the heating rate of the MFB was much higher. The produced char showed high reactivity and experienced less thermal deactivation. As shown in previous works, it was possible for the MFB to measure the intrinsic reactivity of char combustion at higher temperatures within less time. However, the char reaction with O_2 was faster than the char reaction with CO_2 by a factor of 100 000,[30] suggesting that char combustion was more easily limited by

Received: November 27, 2016
Revised: January 24, 2017
Published: February 10, 2017

DOI: 10.1021/acs.energyfuels.6b03137
Energy Fuels 2017, 31, 3243−3252