Applied Energy 211 (2018) 631–638

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Combustion behaviors and pollutant emission characteristics of low calorific oil shale and its semi-coke in a lab-scale fluidized bed combustor

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HIGHLIGHTS

- Co-combustion performances of oil shale and its semi-coke were studied in a lab-scale bubbling fluidized bed combustor.
- Synergic reactions between oil shale and its semi-coke were identified in terms of emissions.
- It was recommended to increase the blending ratio of oil shale up to 50%.
- The ultra-low emission of SO_2 and NO was able to be achieved.

ARTICLE INFO

Keywords:
Oil shale
Oil shale semi-coke
Combustion behaviors
Pollutant emission and control characteristics
Fluidized bed combustor

ABSTRACT

Experiments on co-combustion of oil shale and its semi-coke were conducted in a lab-scale bubbling fluidized bed. Oil shale blend ratios from 0 to 100% at the interval of 25% were separately tested at 800, 850 and 900 °C, to clarify combustion behaviors and pollutant emission characteristics. Results indicated that as oil shale mass fraction increased, the combustion efficiency of samples firstly increased, and then decreased. Positive synergistic relationships between oil shale and its semi-coke were identified. The addition of oil shale could help reducing the SO_2 emissions during co-combustion, while the NO emissions showed no significant change. Meanwhile, with temperature rising, the CO concentrations of samples with lower oil shale blend ratios (0, 25% and 50%) slightly decreased, on the contrary, for higher oil shale blend ratios (75% and 100%), the CO concentrations increased, however, the SO_2 and NO concentrations got a monotonic increase for all the samples. Hence, from the view point of combustion efficiency and pollutant emission performances, it was recommended that the oil shale blend ratio was 50% and the bed temperature was about 800 °C. Besides, the ultra-low emission of SO_2 and NO emitted from the co-combustion of oil shale and semi-coke were able to be achieved by adopting appropriate pollutant control measures.

1. Introduction

In China, abundant oil shale (OS) resources are mainly used by retorting for the production of shale oil to alleviate the shortage of petroleum [1–3]. Currently, its prevailing method is still using Fushun-type retorts, thus resulting in a portion of fine OS particles being unable to meet the demand of retorting technique and discarding as the tailings [4,5]. Meanwhile, around 10–30 tons of oil shale semi-coke (SC) per ton of shale oil is left after production [6]. Owing to the absence of available techniques, landfill is always adopted to dispose of SC. However, this method occupies a lot of land, but also causes great hazards to the environment [7–10].

Co-combustion of SC and fine OS particles at a certain proportion in the fluidized bed combustor with appropriate pollutant control measures is considered to be one alternative to dispose of SC environmental-friendly and make full use of OS resources [11]. Hence, it is essential to investigate combustion behaviors and pollutant emission characteristics of OS and its SC during co-combustion in the fluidized bed combustor. Until now, there are a lot of experimental researches and theoretical analyses about co-combustion performances of OS and SC in the thermogravimetric analyzer [12–14] and the lab-scale circulating fluidized bed combustor [15,16]. Results demonstrated that the advance ignition and burnout could be achieved when SC was mixed with OS, and combustion characteristics of blended samples were greatly improved. Meanwhile, adding OS could promote the stable and efficient combustion in the furnace. Besides, blending is simple physical

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https://doi.org/10.1016/j.apenergy.2017.10.071
Received 16 August 2017; Received in revised form 10 October 2017; Accepted 23 October 2017
Available online 22 November 2017

Nomenclature

OS	oil shale
SC	oil shale semi-coke
TGA	thermogravimetric analyzer
FC	fixed carbon
UC	unburned carbon
SCR	selective catalytic reduction
SNCR	selective non-catalytic reduction
Q_{net}	net heat output of the in-furnace desulfurization reaction
$S_{t,ar}$	sulfur content
K	Ca/S molar ratio
φ_{cal}	theoretical gas concentration
x_{os}	mass fraction of oil shale
x_{sc}	mass fraction of oil shale semi-coke
φ_{os}	experimental gas concentration of oil shale
φ_{sc}	experimental gas concentration of oil shale semi-coke
φ_{NO}	original NO concentration
$\varphi_{reb,NO}$	NO concentration with the natural gas reburning measure
η	combustion efficiency
η_s	desulfurization efficiency
η_N	NO reduction efficiency

process, while co-combustion is a complex chemical process. Our previous work has already been performed in the TGA to further explore the interaction between OS and SC during co-combustion, and its synergy effect was also quantitatively evaluated by using the interaction coefficient and the relative error of mean square [17]. Results indicated that some little interaction did occur during co-combustion, but it was relatively slight, therefore, the co-combustion of OS and SC still could be expressed by the addition of individual components of the mixtures. However, there are some combustion parameters in the TGA different from those in the fluidized bed combustor, such as the fuel particle size, the oxygen concentration, the heating rate, the gas-solid mixing intensity, and so on. These differences would significantly affect combustion behaviors of the fuel. And thus far, there has been little work in the literature regarding the synergy effect between OS and SC during co-combustion in the fluidized bed combustor, as well as the optimal blending ratio. On the other hand, with the increasing attention on environment protection across the world, the Chinese government has enacted the so-called ultra-low emission standard that aims to limit the pollutant concentrations, i.e., the limitation for emissions of sulfur dioxide (SO_2) and nitrogen oxides (NO_x) in the existing power plants are set no more than 35 and 50 mg/m^3 (the oxygen content is 6%) by 2020 [18]. Currently, the removal efficiencies of SO_2 and NO_x can be 98% and 90%, respectively, by adopting the wet flue gas desulfurization and the selective catalytic reduction (SCR). In this case, the original pollutant concentrations of SO_2 and NO_x are separately limited to be lower than 1750 and 500 mg/m^3. However, both OS and SC contain high contents of converted sulfur and nitrogen, thus high concentrations of SO_2 and NO_x are generated during combustion. Hence, it is also imperative to carry out studies to further confirm whether the pollutant concentrations emitted from the co-combustion of OS and SC in the fluidized bed combustor can be lower than above pollutant emission limit values through optimizing the burning process and adopting appropriate in-furnace pollutant control measures.

Consequently, in this work, co-combustion performances of Fushun low calorific OS, its SC, and their blends with different mass ratios at different bed temperatures were investigated in a lab-scale bubbling fluidized bed combustor, trying to comprehensively reveal the combustion behaviors, mainly including the interaction between OS and SC, the optimal blending ratio, as well as the pollutant emission and control characteristics. In addition, the effects of limestone in-furnace desulfurization and natural gas reburning on pollutant emission concentrations were studied. Thus, this paper will offer the reference for industrial application of Fushun low calorific OS and SC co-combustion in the fluidized bed combustor.

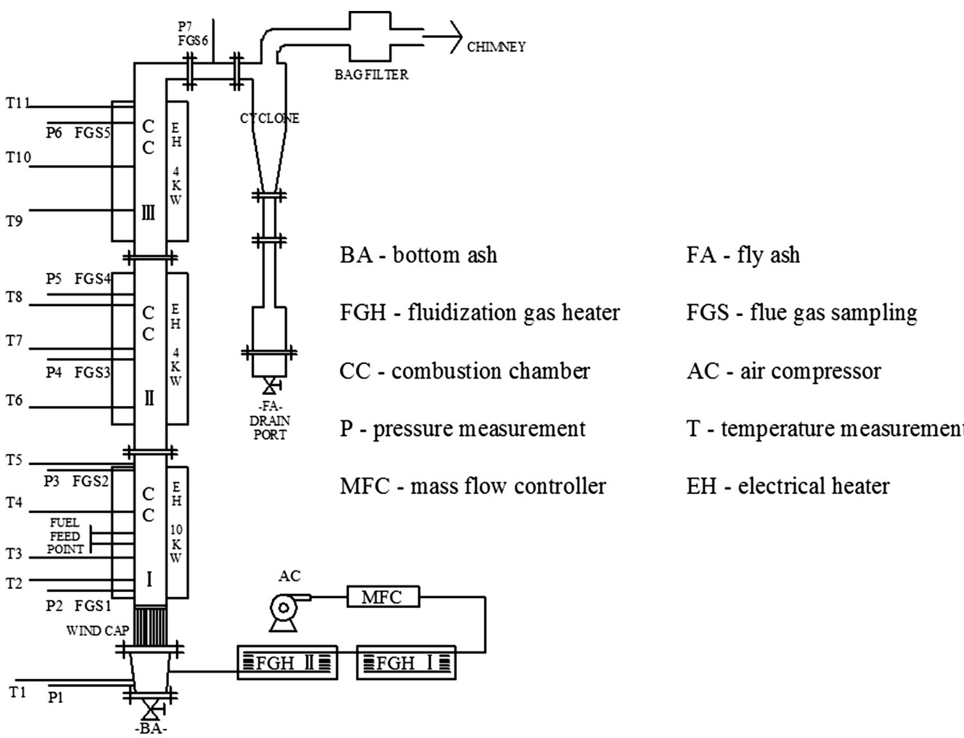

Fig. 1. Scheme of thermal-state fluidized bed combustion bench.