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Interactions of high-chromia refractory materials with infiltrating coal slag in the oxidizing atmosphere of a cyclone furnace

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Abstract

The mechanism of high-chromia refractory failure in the oxidizing atmosphere of cyclone furnaces differs from the reducing atmosphere in gasifiers. In this paper, postmortem analysis was conducted to investigate the changes in the microstructures of exposed high-chromia refractory caused by its interaction with infiltrating coal slag under cyclone furnace conditions. The effects of the temperature level and viscosity of the molten slag were also investigated. Postmortem analysis confirmed that the form of Fe found in the slag in an oxidizing atmosphere was Fe_2O_3 rather than FeO, the phase present in a reducing atmosphere of gasifiers. Furthermore, the higher melting temperature of Fe_2O_3 weakened the slag penetration and chemical corrosion in an oxidizing atmosphere. As coal slag infiltrated a high-chromia refractory, Fe_2O_3 in the slag reacted with Cr_2O_3 until Fe_2O_3 was depleted in the penetrating slag. Cr_2O_3 was dissolved in the slag because of the permeation of the slag in large pores of the refractory. The depth of the slag penetration increased as the temperature increased because of its lower viscosity at higher temperature.

Keywords: B. Failure analysis; C. Corrosion; E. Refractories; Coal slag

1. Introduction

Over the past few decades, coal-water slurry (CWS) has been developed as a substitute for oil in most industries, including power station boilers, gasification technologies, and fluidized bed combustors [1]. The combustion of CWS generally emits less fly ash, SO_2, and NO_x than coal-fired boilers [2]. Slag-tap cyclone furnaces used in clean combustion technology of CWS can substitute for oil and gas combustion systems, and can be used to reduce the emission of fly ash in order to provide clean, high-temperature flue gas for numerous industrial fields.

Similar to coal gasifiers [3,4], slag-tap cyclone furnaces have challenging service conditions, including high temperatures and pressures [5]. During combustion, coal feedstock impurities form a liquid slag when temperatures exceed the melting point of the ash. The molten oxide slag then flows along the surface of the furnace liner, reacting with the refractory at the liner hot-face. Considering the refractories in the combustion chambers are seriously corroded by the molten slag, improving the durability of the refractory materials in it is important. In coal gasification, many refractory compositions are considered or were evaluated as furnace liner materials before the current liner materials were selected. Materials evaluated included sintered or fused cast alumina–silicate, high alumina, chromia–alumina (Cr_2O_3–Al_2O_3), chrome–magnesia, alumina and magnesia, as well as refractories containing SiC and Si_3N_4 [6–8]. Based on laboratory testing [9] and observations after significant service life in gasifiers, refractory materials containing high levels of chrome oxide have been found to have high corrosion resistance against coal slags. They also have the best overall properties for hot-face refractory materials [10]. High-chromia refractory may also be the best choice for a CWS slag-tap cyclone furnace.

Although chromia or chromia–alumina refractory have low solubility in slag and zirconia added in those refractories improves thermal shock resistance, the service life of hot-face Cr_2O_3–Al_2O_3 and Cr_2O_3–Al_2O_3–ZrO_2 compositions in gasifiers is still limited to between 3 months and 36 months [7]. Spalling and slag penetration with chemical corrosion are the primary causes of refractory degradation in a gasifier [11].

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Table 1
Properties of CWS for study.

Proximate analysis (wt%, as received basis)				
Moisture	Ash	Volatile matter	Fixed Carbon	Concentration
37.48	7.31	20.50	34.71	65.67
Net calorific value (kJ/kg)			Viscosity (mPa s, 20 °C)	
17238			727.59	
Ultimate analysis (wt%, as received basis)				
C	H	N	S	O
44.26	3.11	0.66	0.43	6.73
Ash fusion point (°C)				
Deformation temperature	Softening temperature	Hemisphere temperature	Flow temperature	
1209	1326	1353	1395	

Besmann [12] conducted thermochemical calculations to simulate the corrosive attack of refractories in slagging gasifiers. Hirata et al. [13] developed an empirical relation for the corrosion rate in these systems. Williford et al. [14,15] explored the application of a volume-shrinkage spalling model to evaluate the material properties of high-chromia refractory and its performance under gasifier operating conditions. Many researchers have thoroughly studied the mechanism of refractory failure based on the postmortem analysis of refractories after significant service life in a gasifier and on laboratory 24-hour slag-refractory cup tests [16–18]. However, few studies have focused on the failure mechanisms of high-chromia refractories used in cyclone furnaces, which may also have similar issues limiting their service life in these applications. In a cyclone furnace, sufficient combustion is required to provide clean high-temperature flue gas for numerous industrial fields. A high air/fuel ratio also can maintain an oxidizing atmosphere, preventing the precipitation of iron in slag from jeopardizing the security of the whole operation. Oxidizing atmosphere [18,19] may induce several other effects on the mechanism of slag-refractory interactions.

In the present study, necessary postmortem analysis were performed to investigate the changes in the microstructures of exposed high-chromia refractory bricks from a pilot-scale cyclone furnace using CWS as fuel. The composition, crystalline phase, microstructures, and porosities of the unused and exposed refractories were analyzed to determine the causes of failure of refractories due to the interaction with the penetrating slag. The effects of temperature and the viscosity of the slag on slag penetration depth were also investigated.

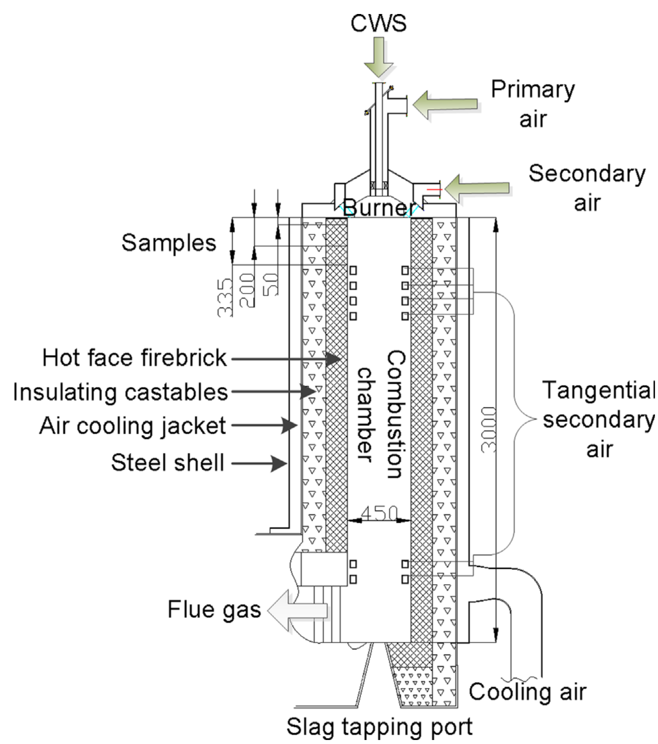

Fig. 1. Schematic of the cyclone furnace refractory structure.

2. Experimental method

The spent refractory liners evaluated in this paper were obtained from a 250 kg/h pilot scale vertical type slag-tap cyclone furnace. The diameter and height of the combustion chamber were 450 and 3000 mm, respectively. CWS was pneumatically injected into the burner from the top of the furnace to mix with the preheated primary air and high-speed tangential secondary air, thus forming an intense swirling motion for a high burn-out ratio. The test rig was operated with 100% load and an excess air ratio α=1.4. The excess air ratio was defined as the ratio of the actual air to fuel ratio divided by the stoichiometric air to fuel ratio required for complete combustion. The environment near the hot face refractory was an oxidizing atmosphere. The characteristics of CWS are shown in Table 1. The schematic of the cyclone furnace refractory structure is shown in Fig. 1. High-chromia refractory bricks were used to line the hot face of the furnace, with a castable refractory made of alumina applied as the insulating layer.

The chemical composition of the high-chrome refractory selected for this study and the slag from a continuous slag-tapping port is shown in Table 2. The refractory was removed