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Research article

Xinjiang lignite ash slagging and flow under the weak reducing environment at 1300 °C – Release of sodium out of slag and its modelling from the mass transfer perspective

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ABSTRACT

This study examined the Na loss upon the slagging of five typical Xinjiang lignite ashes and their blends with clay at different ratios, under the simulated cyclone combustion conditions. The ash samples were laden on a 25° – inclined plate and exposed in 1% CO (nitrogen balanced) at 1000–1300 °C for maximum 2 h at each temperature. Apart from experimental approach, modelling based on the mass transfer mechanism was also attempted. The results show that, the Na loss ratios achieved are lower than that has been reported for the combustion of the same coals in the pulverised – coal fired plants, varying from 40 to 70% of the entire Na that largely depends on the basicity of ash or ash – clay blend. The reaction temperatures examined here exert a marginal influence on the Na loss. The addition of clay to raw coal ash and its dosage amount are crucial. At a mild combustion temperature of 1300 °C, the addition of 8–10wt% clay, on the ash mass basis to a basic lignite ash is the optimum, simultaneously accelerating both slag flow rate and Na retention in slag matrix. Additionally, the addition of clay alleviated the penetration and corrosion of Na vapour into the refractory corundum, thus extended its lifespan. The Na loss rate is dominated by the internal mass transfer rate of Na vapour inside slag film, in particular at the elevated temperatures from 1300 °C when ash is partially/mostly molten, as well as when the clay is added into the original Xinjiang ash. For the original ash which is rarely molten before 1200 °C, the gas-solid reaction prevailed, leading to the capture of Na vapour by Al and Fe – bearing solid species and even the refractory corundum plate. In contrast, at 1300 °C, the formation of slag film decreased the Na vapour mass transfer coefficient drastically. The resistance was further enlarged by the formation of more molten species and a denser slag film upon the addition of clay. The original Na content in ash has proven insignificant in the mass diffusion control regime.

1. Introduction

Vapourisation of alkali elements including sodium (Na) and potassium (K) causes severe deposition and fouling in the coal/biomass-fired boilers [1–2]. It also fouls the syngas cooler in the downstream of a gasifier [3]. Understanding the emission and speciation of Na in a hot gas environment, either oxidising or reducing is essential in terms of boiler/gasifier design and operation. This is especially significant for the use of high - sodium lignite. Compared to the bituminous coal and anthracite with a decreased reserve, lignite such as Xinjiang lignite from China has much larger reserve and can be used for hundred years based on the current usage rate [4]. One of the critical issues related to the use of Xinjiang lignite is the large content of sodium within it, which can go up to 5–10 wt% on the total ash-forming element basis. That is far more than the normal sodium content level (< 2%) [5]. Such a high sodium content has been found to possess the strongest slagging and fouling propensity compared to the other lignites in the rest of the world [2,6].

Since Na is a key trigger for the ash fouling and slagging inside a furnace, plenty of researches have been conducted on the Na vapourisation, especially for high sodium Xinjiang coal. The ash deposition of coal with high Na/Ca content was studied in full-scale and lab-scale furnaces [7]. The effect of alumina - silica additives on ash fusion and transformation of Xinjiang high-sodium coal was revealed [8]. The emission behaviour for organically bound elements in Xinjiang lignite during air and oxy-fuel combustion was also studied and compared with

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Table 1
Literature review and summary on the release/loss of sodium from slag, in particular from Xinjiang lignite ash [10–16].

Coal type	Size	Na_2O wt% in ash	Experimental rig	Temperature range, °C	% Na lost	% Na captured in solid/slag	Notes
High-sodium Zhundong coal [10]	< 2.5 mm, mean diameter of 0.77 mm	8.53	CFB gasifier	850–1000	Not mentioned	20–60	Na release augmented by chlorine (Cl) Na retention into $NaAlSiO_4$ at high temperature
Zhundong coal [11]	Not mentioned	4.46	Computer modelling	1000–1300	Not mentioned	N/A	Addition of kaolin increases the ash fusion temperatures by 250 °C maximum
Slag from a PPCC pilot plant [12]	Raw slag mixed with different additives	2.1	Knudsen effusion mass spectrometer (KEMS)	1250–1450	Na loss decrease by 30% upon adding 5% SiO_2/TiO_2 at1400 °C	30	TiO_2 is stronger than SiO_2 for Na retention and network formation;
					Na loss decreases by 50% upon adding 10% SiO_2 at1400 °C	50	Addition of MgO increases the activity (and loss) of Na out of slag
Na-rich Xinjiang lignite [13]	< 74 μm	4.64–12.21	Lab-scale coal steam gasifier (40% steam in 60% N_2)	900–1000	5–15% at1000 °C		Na loss correlates well with Cl in coal
Australian Loy Yang [13]	< 74 mm	20.55			25% @ 900 °C, 50% at 1000 °C, and		Na loss correlates well with water-soluble Na in coal
Yidong [13]	< 74 mm	4.27			20% at 1000 °C		Na retention into $NaAlSiO_4$
Ash slags from gasifier [14]	Ultrafine	1.5–5.8	KEMS	1300–1600	Not mentioned		High SiO_2/Al_2O_3 slag favours the capture of Na vapour Na captured in anorthite ($CaAlSiO_4$) The draining slag rich in SiO_2 can capture Na vapour
Synthetic high-Na ashes [15]	Ultrafine	0–10	High-temperature horizontal tube furnace	Up to 1700	Not mentioned		Addition of Na_2O reduces ash fusion temp by max 200 °C, down to minimum 950 °C Minerals albite ($NaAlSi_3O_8$) and nepheline ($NaAlSiO_4$) react with anorthite ($CaAl_2Si_2O_8$) to form low-temp eutectics
High-Na Zhundong coal [16]	180–355 μm	7.28	Lab-scale quartz - made fluidised bed reactor for pyrolysis and gasification	850–950	Na loss: 38.8% at 850 °C, 40% at 900 °C and 76.2% at 950 °C in total. For the char gasification stage, Na loss: 24.1% at 850 °C, 25.6% at 900 °C and 64.4% at 950 °C.		Water-soluble and organic - Na released during pyrolysis stage