

# OXY-FUEL COMBUSTION ASH FORMATION MECHANISMS

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Oxy-fuel combustion is a process of burning coal in O<sub>2</sub>/CO<sub>2</sub> instead of air to generate a CO<sub>2</sub>-rich flue gas which has the potential to be directly sequestered and/or stored with minimal further treatment (Buhre et al., 2005). Due to the different physical properties of CO<sub>2</sub> relative to N<sub>2</sub>, a variety of distinct phenomena relating to coal combustion performance and gaseous emissions in O<sub>2</sub>/CO<sub>2</sub> have been observed in both field and laboratory studies (Buhre et al. 2005; Pathnam et al 2009; Molina and Shaddix 2007). Elucidation of the ash formation mechanisms in oxy-fuel combustion is also imperative, as minerals in coal links with corrosion and erosion problems in furnace as well as the release of inhalable, potentially toxic airborne particulates.

A variety of variables could be significantly changed with gas shifting from air to a mixture of O<sub>2</sub> and flue gas. Depending on where the flue gas is re-circulated and if it is cleaned and/or dehydrated, the gas environment in an oxy-fired boiler could be very different. As illustrated in figure 1, in the *case 1* where flue gas is completely cleaned and dehydrated, the flue gas re-circulated back into the boiler can be

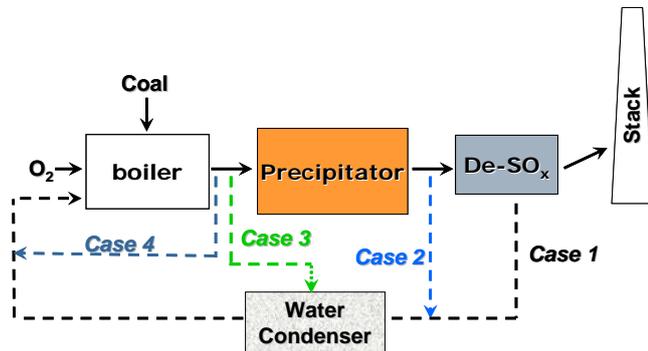


Fig 1 Schematic of flue gas re-circulation during oxy-fuel combustion

regarded as a nearly pure CO<sub>2</sub>. Therefore, oxy-fuel combustion only refers to a substitution of CO<sub>2</sub> for N<sub>2</sub> and a higher O<sub>2</sub> content in the boiler. However, in the other *cases 2-4* where flue gas is less cleaned and/or dehydrated to avoid the loss of the heat in the flue gas, the gas environment in a boiler will be greatly different from air. Plausibly, the gas impurities including steam, SO<sub>2</sub>, HCl and even a portion of fine ash particles can become dominant in an oxy-fuel boiler, which are vital to ash formation. A detailed understanding on these issues is essential for managing the ash-related furnace troubles and environmental impacts. It is also important for managing the CO<sub>2</sub> quality for the downstream carbon capture and storage (CCS).

For the *case 1* with a mixture of pure O<sub>2</sub> and CO<sub>2</sub> for coal combustion, the char temperature, local gas environment on char surface, and the char reaction rate could differ considerably from that in air combustion. In a given O<sub>2</sub> content, coal combustion

possesses lower temperatures for both flame and char in  $O_2/CO_2$  than in  $O_2/N_2$ , due to the larger specific heat capacity of  $CO_2$ . As the diffusivity of  $O_2$  in bulk  $CO_2$  is 20% less than in  $N_2$  with a same content of  $O_2$  (Shaddix and Murphy 2003), replacing  $N_2$  by  $CO_2$  bulk gas could reduce the content of local  $O_2$  while increase the content of  $CO_2$  on char surface. The potential  $CO_2$ -gasification reaction on char surface could also increase the  $CO/CO_2$  ratio. These factors have the potential to affect the vaporization and melting propensities of the mineral grains embedded in char matrix. Figure 2 for the mass loss of individual metals during Victorian brown coal combustion supports this hypothesis. As can be seen, the mass loss of Na is higher in two  $O_2/CO_2$  mixtures than in air, due to the preferential vaporization of Na as NaCl in  $O_2/CO_2$  (Zhang et al, 2010). In addition, the consumption rate of char in  $O_2/CO_2$  would differ from that in  $O_2/N_2$ , it is referable that the collision/agglomeration frequency among the included minerals in char would be distinct in  $O_2/CO_2$ , as evidenced by the results in figure 3 for the particle-size distribution (PSD) of ash formed from combustion of a bituminous coal in air versus two  $O_2/CO_2$  mixtures (21/79 and 27/73) at 1273 K (Zhang et al., 2010).

The gas impurities including steam,  $SO_2$  and HCl in flue gas are influential on ash vaporization, as evidenced in figure 4 for the overall brown coal ash mass loss as a function of the contents of  $SO_2$  or HCl in  $O_2/CO_2$  at 1273 K. This is because of the formation of gaseous chlorides and liquidus sulfates which preferentially condense into ultra-fine particulates that are difficult to capture. Introducing steam into the reactor however inhibits the ash vaporization/loss, due to the preferential formation of solid/molten alumino-silicates which rarely vaporize. Recirculation of fine ash particles into a boiler is also one influential issue which greatly affects the ash formation.

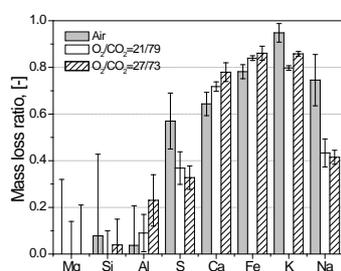


Fig 2 Mass loss of individual metals during Victorian brown coal combustion at 1273 K in Different gases in drop-tube furnace

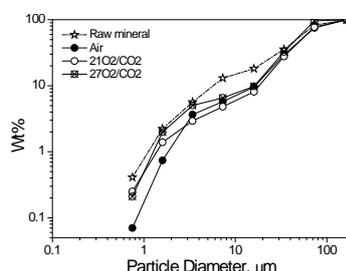


Fig 3 PSD of the ashes of a bituminous coal formed in three gases at 1273 K in DTF

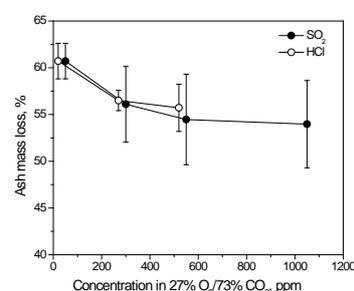


Fig 4 Overall ash mass loss during Victorian brown coal combustion in 27%  $O_2/73\%$   $CO_2$  doped with HCl and  $SO_2$  at 1273 K

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