



Research article

The influence of air and oxy-fuel combustion on fly ash and deposits



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ABSTRACT

This article summarizes the results on the influence of combustion conditions (air, oxy-fuel) on deposit and ash formation and transformation and their implications on plant operation. The investigations involved thermodynamic equilibrium simulations as well as experiments at IFK's 20 kW_{th} and 0.5 MW_{th} combustion test rigs and Vattenfall's 30 MW_{th} oxy-fuel pilot plant "Schwarze Pumpe". Comparative air and oxy-fuel experiments with Lusatian lignite showed a considerable increase of sulfur in ash and deposits and a 12 percentage point lower sulfur release to SO₂ in oxy-firing. One reason for this is the higher SO₂ partial pressure in oxy-fuel combustion that stabilizes sulfates. Therefore, sulfates can form at higher temperatures and more extensively. Oxy-fuel deposits may be more sintered by sulfates and therefore more difficult to remove by soot blowing. However, the experimental and theoretical considerations presented here support the conclusion that SO₂ levels and therefore sulfate stability in oxy-fuel combustion of low sulfur coals is comparable to conditions experienced in air-firing of high sulfur fuels. Thus, it can be expected that problems associated with sulfatic deposits (e.g.: fouling) in low sulfur coal oxy-fuel combustion can be handled by standard techniques (e.g. soot blowing). For high sulfur fuels with considerable sulfur capture potential (e.g.: high Ca), this may not be true and additional measures may be required for a reliable plant operation.

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1. Introduction and background

1.1. Oxy-fuel combustion

To reduce the impact of anthropogenic greenhouse gas emissions on the earth's climate, CO₂ capture technologies for coal-fired power generation were developed to concentrate the CO₂ for processing and sequestration/utilization. Oxy-fuel combustion is one of these CO₂ capture technologies. In oxy-fuel operation, coal is combusted in a mixture of O₂ and recirculated flue gas, instead of air. The flue gas recirculation is, among other issues, necessary to lower the temperature in the furnace which otherwise would exceed the limits of boiler construction materials [1]. Due to the lack of flue gas dilution by airborne N₂, the concentrations of flue gas components such as CO₂, SO₂ and H₂O under oxy-fuel conditions generally increase considerably by a factor of around 4 [1–4].

Oxy-fuel combustion technologies have been investigated for approximately two decades, which ultimately led to the construction of several oxy-fuel pilot and demo plants (e.g.: Schwarze Pumpe, Germany; Callide, Australia). Even though, those projects proved that

oxy-fuel combustion can be applied in industrial scale, several questions require further R&D activities. This study focusses on such questions, investigating the influence of fuel composition and combustion conditions (air, oxy-fuel) on deposit and ash formation and transformation and associated impacts on oxy-fuel plant operation. The presented results were obtained from simulations and experiments at IFK's 20 kW_{th} and 0.5 MW_{th} combustion test rigs and Vattenfall's 30 MW_{th} oxy-fuel pilot plant "Schwarze Pumpe".

1.2. Ash and deposit formation and transformation under oxy-fired conditions

The altered flue gas composition and changes in the temperature profile of an oxy-fuel fired process can impact the formation and transformation of ashes and deposits. Previous studies indicated that the changes in firing mode may not necessarily change the ash transformation behavior [5,6], but doubts remained how altered process conditions (e.g. the higher CO₂ and SO₂ partial pressures) affect oxy-fuel ashes and deposits [7–9]. Available literature on transformation of carbonate minerals (e.g.: CaCO₃, FeCO₃, Ca(Fe,Mg)(CO₃)₂) suggests that under oxy-fuel conditions carbonate decomposition temperatures are significantly increased [5]. Wigley et al. [5] also highlighted that mineral conversion extents can be altered considerably if combustion temperatures are changed in oxy-firing. Thus, not only the changed flue gas atmosphere may play a decisive role in oxy-fuel ash/deposit formation and transformation. Other changes in the process, e.g. a different char burning

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behavior and locally higher CO concentrations may also impact the transformation of ashes.

2. Material and methods

2.1. Thermodynamic equilibrium simulation

Thermodynamic equilibrium simulations reported in this article have been performed using the ‘Phase Diagram’ module and the [ELEM], [FACTPS], [FTsalt] and [FToxid] thermodynamic databases of the software package FactSage 6.3.

2.2. Experimental combustion rigs

2.2.1. 20 kW_{th} combustion test rig

Part of the experiments was carried out at IFK’s 20 kW_{th} electrically heated, once-through combustion rig (Fig. 1). The electrically heated furnace (length: 2.5 m; diameter: 0.2 m) has 5 heating zones that were operated to reach a temperature of 1200 °C in a distance of 1.5 m from the burner and a temperature of 1100 °C in 2.5 m distance. At these locations/temperatures in the furnace, deposits were sampled with an uncooled ceramic probe (sampling time: approx. 2 h). The flue gas product rate was kept constant at 11.5 m³ (STP)/h to maintain comparable gas residence times in the system for all experiments. For the performed oxy-fuel experiments, the combustion rig’s top-mounted burner was fed with a mix of CO₂ and O₂ (28 vol% (dry) O₂) to simulate oxy-fuel flue gas recycling. For the investigation of the impact of high SO₂ concentrations under oxy-fuel combustion conditions on ash and deposits, the oxidant gas was doped with SO₂.

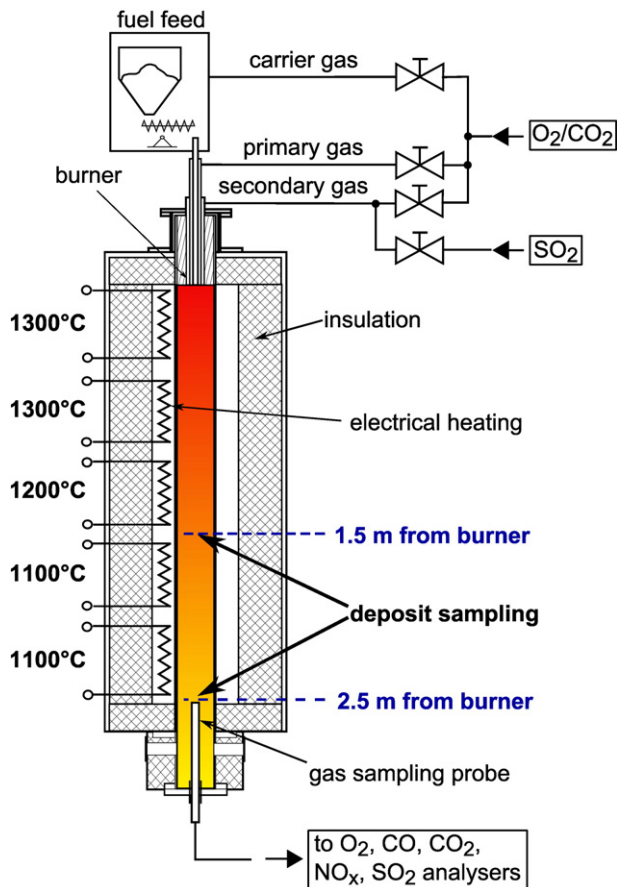


Fig. 1. Scheme of IFK’s 20 kW_{th} experimental combustion rig.

2.2.2. 0.5 MW_{th} combustion facility (KSPA)

The 0.5 MW_{th} atmospheric, pulverized fuel combustion rig KSPA (Fig. 2) can be operated in air and in oxy-fuel combustion mode with flue gas recirculation. The plant is suitable to study the combustion behavior of pulverized fuels (e.g.: coal, lignite, biomass, SRF, etc.). Similar to a power station, the plant is equipped with an air/oxidant preheater and flue gas cleaning equipment, such as a high dust SCR unit and an ESP. The plant’s furnace has a total length of approx. 7 m and an internal diameter of 0.8 m. The milled fuel is fed to the top mounted burner pneumatically by air or CO₂ in oxy-fuel operation. At the burner, the fuel is mixed with oxidant gas (air/oxygen enriched recirculated flue gas). In oxy-fuel operation, the flue gas is recirculated wet after the ESP, preheated in the oxidant preheater, mixed with O₂ from a tank and supplied to the burner. There are measuring ports all along the furnace that can be used for gas composition, heat radiation and temperature measurements and to sample fly ash and deposits from the furnace with dedicated sampling probes. A permanent flue gas measuring system is installed at the end of the furnace for continuous measurement of O₂ (paramagnetic sensor), CO, CO₂, SO₂ (NDIR analyzers), and NO_x (chemiluminescence analyzer). H₂O is continuously measured at the ESP outlet. During the air and oxy-fuel experiments reported here, fly ash and deposit samples were collected at level 11 (approx. 2 m from the burner mouth; $\vartheta_{FG} \approx 1100$ °C) and 26 (approx. 5.5 m from the burner mouth; $\vartheta_{FG} \approx 750$ °C). Moreover, ashes from the three precipitation fields of the plant’s ESP (samples: E1, E2, E3) were sampled and analyzed.

2.2.3. Vattenfall’s 30 MW_{th} oxy-fuel pilot plant “Schwarze Pumpe” (OxyPP)

Several authors previously described Vattenfall’s oxy-fuel pilot plant in detail [10–13]. The plant was operated successfully between 2008 and 2014 and was located in Lusatia (eastern Germany) next to the existing 1600 MW_{e1} lignite fired power plant “Schwarze Pumpe”. The oxy-fuel pilot plant is fired by a single 30 MW_{th}, top-mounted burner and is equipped with an air separation unit (ASU), flue gas cleaning equipment (i.e.: ESP, wFGD), a flue gas condenser and a CO₂ processing plant. The plant can be operated in air and oxy-fuel mode. For oxy-fuel combustion it uses a so-called “hot flue gas recycle”. In this configuration the recycle is located downstream the ESP (as in IFK’s 0.5 MW_{th} facility) and upstream wFGD. This implies that wet sulfur-rich flue gas is recycled to the boiler leading to considerably increased SO₂ levels in oxy-fuel operation, compared to air-firing. During the reported tests, pre-dried, pulverized Lusatian lignite (see: Tables 1 and 2) was combusted in a mixture of recycled flue gas and O₂ (oxidant O₂: ~28.5 vol% (wet)). During the experiments, fly ash and deposits were sampled from measuring ports in the 1st and 2nd drafts of the plant’s boiler at a distance of approx. 0.5 m from the furnace wall. Fig. 3 displays a sketch of the boiler’s 1st and 2nd drafts with the locations of measuring ports used for the present study at levels 4 (approx. 1100 °C) and 8 (approx. 750 °C) marked with red circles. “OxyPP” flue gas concentrations reported in this manuscript were sampled continuously downstream the ESP and analyzed by infrared photometry.

2.3. Deposit and fly ash sampling

A number of different sampling probes were used in this project to collect fly ash and deposit samples. Fly ash was sampled from furnaces using a cooled suction probe. Fly ashes (i.e.: fly ash together with unburnt carbon) are separated from the sample gas with a cyclone and filter. Deposits were sampled using uncooled and temperature controlled deposit sampling probes. So called “cooled deposits” were collected using a probe whose surface temperature can be controlled, e.g. to reach typical surface temperatures of superheater tubes (range in the present tests: 550–650 °C). The cooled deposit represents the primary layer of heat exchanger deposits. Due to low surface temperature of the probe (in comparison to surrounding flue gas), volatile mineral salts from the flue gas can condense on the probe and account for the development of the primary deposit layer. Other initial ash deposition

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