



SP3 Public Summary Report

*Based on the Del3.1.4 Final report on combustion fundamentals, slagging and fouling
and analysis of impact on flue gas treatment equipment*

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This report should be cited as:

Andersson, Klas et al. Public summary report of ENCAP deliverable D3.1.4 Final report on combustion fundamentals, slagging and fouling and analysis of impact on flue gas treatment equipment [online]. Available from Internet: www.encapco2.org

The ENCAP SP3 is focused on oxy-fuel technologies where combustion using almost pure oxygen and recycle of flue gas to moderate the combustion temperature is carried out. In general the oxy-fuel process used for power generation of large scale coal fired boilers is a new technique. To demonstrate this new technology information is required from several different areas such as combustion and boiler technique, oxygen production, flue gas treatment and storage, process and emission control, safety requirement, etc. Within the ENCAP SP3 a fundamental understanding of combustion in denitrogenated air has been obtained throughout the extensive experimental work performed in the 100 kW gas-fired test unit of Chalmers and in the 20 kW coal-fired unit of IVD at the University of Stuttgart.

Results from Chalmers Test Facility

Chalmers oxy-fuel test facility was specifically designed to perform the experiments and to study the oxy-fuel (or O₂/CO₂) combustion process under real flue gas recycling conditions (Fig. 1).



Figure 1: Front side of the Chalmers 100 kW oxy-fuel combustion test unit showing top fired 3 meters high combustion

The objectives of the experimental activities at Chalmers were to carry out tests, using liquid petroleum gas (>98 mole% propane) as fuel, during air-fired conditions and oxy-fuel tests with 21% by volume (case OF 21) and 27% oxygen (case OF 27) in the recycled feed gas. The measurement data (gas concentration, temperature, radiation intensity and velocity) together with the measurement conditions were analysed and reported. The experimental work carried out at Chalmers included the radial and axial distributions reactor temperature and reactor gas composition and stack gas composition of O₂, CO, CO₂ and total hydrocarbon concentrations but also velocity measurements near burner at STP conditions (cold conditions) in air. The well documented flow and temperature data to close heat and mass balance of the reactor (wall temperatures, heat extraction from furnace etc.) was given for modelling purposes.

The results of the experimental work carried out was to improve the knowledge on the oxy-fuel combustion technique with respect to the flame characteristics with an emphasis given the radiative heat transfer and burn-out behaviour. More specifically

the tests have shown that the temperature levels of the OF 21 flame are significantly lower than in the reference conditions in air due to the cooling by the recycled CO_2 , which results in a suppressed development of the OF 21 flame, which is seen from the profiles of O_2 , CO and total hydrocarbon. Compared to the OF 21 case the fuel burn-out of the OF 27 case is favoured by the increased temperature level and improved mixing conditions between fuel and O_2 and in general, the OF 27 case exhibits similar overall combustion behaviour as the air-fired reference case in terms of gas concentration and temperature profiles.

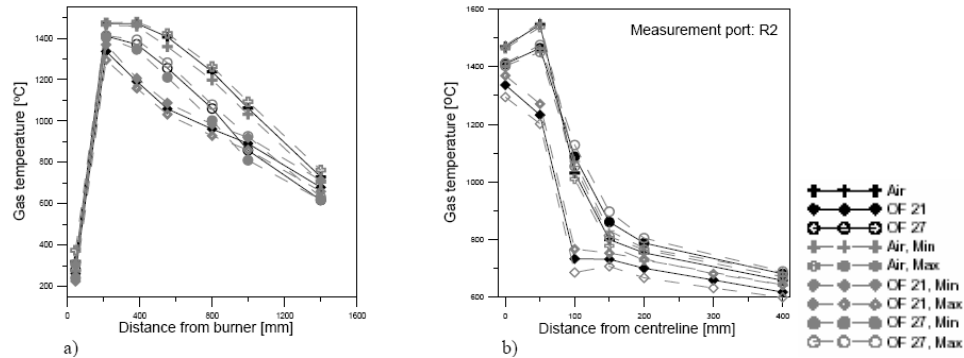


Figure 2: Measured mean, minimum and maximum centreline temperature profiles

Furthermore, the systematic picture of the temperature and radiation profiles (Fig. 3, 4) suggests a significant change in emissivity for the oxy-fuel environment compared to reference conditions in air. The difference in total mean emissivity compared to the difference in gas emissivity at similar mean radiation temperatures for the air and the OF 27 case suggest that the higher radiation intensity in the OF 27 case can partly, but not solely be explained by an increased gas emissivity.

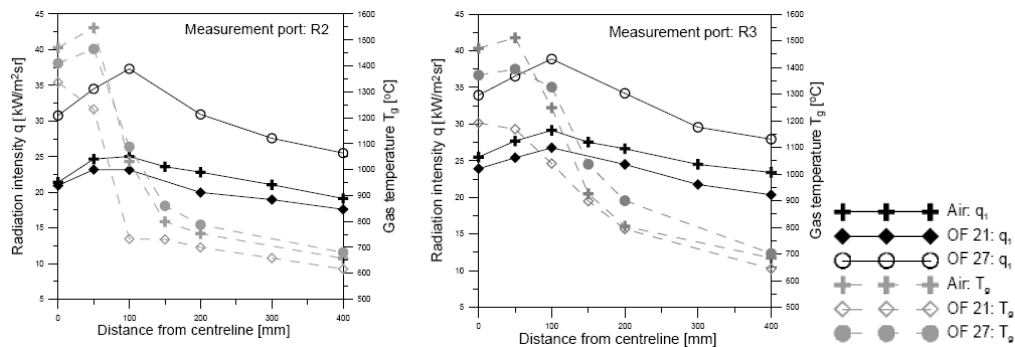


Figure 3: Mean values of the measured radial radiation intensity profiles

Results from IVD test facility

The tests and experiments at IVD were carried out at the atmospheric 20kW_{th} BTS test facility for pulverized fuel combustion. While the tests in the Chalmers 100kW_{th} unit served to investigate reactions and properties of the gas phase, the focus of interest at the IVD 20kW_{th} unit was put on the characterization of pulverized fuel combustion under oxyfuel conditions.

Different coal qualities (bituminous coal and lignite) have been characterized in terms of combustion, emission and fly ash behavior under un-staged and staged combustion conditions, with both air (called baseline case) and an O_2/CO_2 mixture containing 27% oxygen (hereafter referred to as OF27 case).

Existing measurement instrumentation was up-graded and adapted for increased process requirements. The tests and experiments carried out aim at identifying characteristics of oxyfuel combustion and to compare them with parameters characteristic for pulverised fuel combustion under air conditions. Several data sets were compiled and delivered to validate combustion simulation models under oxyfuel conditions. Primary measures to reduce NO_x emission were tested for suitability for the oxyfuel process. Further emission investigations related to the recirculation of flue-gases were performed successfully. Preliminary fly-ash analyses and deposit tests were performed to identify major effects of an oxyfuel environment on fly-ash and deposit properties. The investigations were performed with three pulverized fuels which were a medium bituminous import coal (Kleinkopje) and two different German lignites from the Lausitz and Rhenish region. Kleinkopje and Lausitz were used as reference fuels. As reference flames each one air and one oxyfuel case (27% O₂, 73% CO₂) in the feed gas were investigated. For comparison and to characterise the different flames on an equal basis the gas emission results were calculated and presented as emission rates in mg/MJ (mass emitted referred to energy put in). Experiments were carried out using both pure CO₂ and a synthetic oxyfuel flue gas to simulate flue gas recycle.

Kleinkopje profile measurements

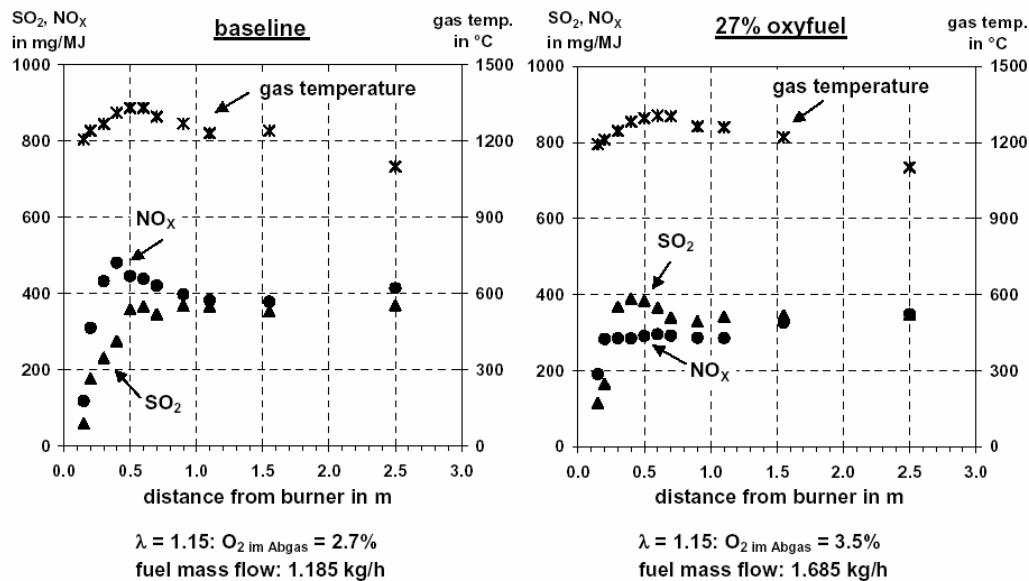


Figure 3. Kleinkopje –NO_x, SO₂, and gas temperature profiles for baseline and 27% oxyfuel, pure CO₂ is used to simulate flue gas recycle.

Major results are summarised subsequently:

NO_x- Emissions

- Great effort was spent on investigating NO_x generation and depletion under various oxyfuel combustion conditions. Compared to air-fired combustion conditions oxyfuel conditions slightly reduce NO_x emissions in relation to energy input. Both, primary air ratio and fuel residence time, are key parameters of in-furnace staging to reduce NO_x emissions from air-fired combustion processes. The use of this primary measure under oxyfuel-fired

conditions showed comparable impact and dependency of the NO_x emission as already known for air-fired conditions.

- The re-circulation of NO_x with the flue gases will not lead to an increase of the NO_x emissions at the outlet of the combustion chamber if the combustion system is equipped with a primary NO_x reduction technique such as staging.
- Established state-of-the-art low-NO_x technology used for air-fired combustion systems is a suitable tool to minimise NO_x emissions from oxyfuel combustion processes in the same dimension as for air-fired processes.
- Recycled NO_x will be reduced to a large extent. Since its concentration in the flue gas is slightly lower and the flow rate of the remaining flue gas is significantly lower (e.g. 70 % lower) the NO_x-emission in absolute terms is reduced accordingly. Compared to air case the absolute amount of NO_x produced, i.e. NO_x leaving the boiler, is 60 to 80 % lower.

Burnout, CO, SO₂

- The burnout identified at OF27 conditions was sufficient and similar to that achieved at air conditions.
- In the near burner area higher CO concentrations were detected for un-staged and staged combustion conditions under oxyfuel-fired conditions (compared to air-fired conditions). However, the CO emissions at the reactor outlet were equal for the different combustion conditions.
- Extensive investigations were performed regarding impact of primary measures on NO_x reduction and regarding impact of the flue-gas re-circulation on SO₂ emissions which were measured at the outlet of the radiative furnace section. Similar to air-fired combustion processes, SO₂ emission rates were not affected by staging.
- SO₂ emission concentration will significantly increase under oxyfuel combustion conditions and with simultaneous flue-gas re-circulation. For large scale combustion processes increased H₂S concentrations have to be expected in the primary (substoichiometric) combustion zone and staging at the same time. However, the SO₂ emissions on a fuel basis is expected to remain approximately the same as in air-firing, based on the experimental results in WP 3.1. No additional desulphurisation effect was detected, however this will be further studied in the upcoming experiments in the 500 kW test facility in WP 3.5.

Ash Behaviour

The local conditions at the candle filter during ash sampling have been comparable to ESP conditions in terms of particle size and local temperature. Among others, the samples have been analyzed by XRF and XRD to determine major effects and influences of the increased CO₂ concentration in the flue-gas atmosphere on elemental and mineralogical composition. Particular interest was taken in identifying indicators for carbonation and interactions with sulphation reactions. The investigated coals represent the different mineral regimes of an acid and base rich fuel. However, none of the analysed fly-ash and deposit samples collected at air and OF27 combustion conditions give a clear indication of major changes neither in terms of element composition nor regarding mineral phases detected. Also the ash fusibility temperature was investigated. Further tests are required and will be performed within the WP3.5 tests with temperature-regulated deposition probes and with a real ESP to collect fly-ash.

Several data sets were compiled and delivered to validate combustion simulation models under oxy-fuel conditions. In commercial CFD codes it is assumed that fuel particles are spherical when pulverized fuel combustion is simulated. However the shape of the fuel particles is different for different fuels, due to the structure of the fuel material. In a study conducted by VRD it has been investigated how much effect this assumption has on the overall combustion behaviour, using the 10 kWth lignite flame from IVD to exemplify. It has been investigated how the assumed area/volume ratio of the particle affects the combustion process. However, the results indicate that the increase surface/volume ratio for the fuel particles does not affect the heating rate of the particles.

Regarding the objectives formulated in WP3.1 several promising results were presented in detail, contributing to improve technical scale combustion tests, to validate and adapt existing combustion simulation models and to support the design and layout activities of the (30 MW) pilot plant. Additional topics such as impact of re-circulated flue-gas and particle components on slagging, fouling, corrosion as well as behaviour of trace metal concentrations and emission rates are recommended and need to be investigated in larger scale.