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Oxy-Combustion Testing In 30MWth Pilot Plant Schwarze Pumpe

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1. Introduction

Power generation is one of the biggest sources of man-made CO₂ emissions. As the combustion of fossil fuels plays a key role in the global emissions of CO₂, new technologies are required to enable the power sector to continue meeting the global demand for electric power, while controlling emissions of CO₂ and contributing to reduce the impact on global warming. To achieve meaningful reductions, it is necessary to develop technologies that not only can be applied to new projects but also can be cost-effectively retrofitted to the existing fleet.

The oxy-combustion technology is one of the most promising CO₂ capture technologies in terms of performance, life cycle costs, and development time as a result of the adaptation and integration of proven large scale industrial equipment, and it can be employed for both new plants and as retrofit for existing power plants.

For several years, Alstom has been involved in numerous public and private research projects and initiatives for the development of the oxy-combustion technology and is currently executing comprehensive pilot projects at Vattenfall’s Schwarze Pumpe 30 MWth Oxyfuel Plant (started operation in September 2008) and at Alstom’s 15 MWth Boiler Simulation Facility (started oxy-fired operation in September 2009). The knowledge being gained from these oxy-combustion pilot projects is very encouraging and constitutes a solid basis for the design, construction and operation of an oxy-combustion large-scale demonstration plant.

This paper provides results from the operation of the Vattenfall’s pilot plant (30 MWth). The results have been obtained in the framework of a technology partnership between Vattenfall and Alstom with the objective of a

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common development of the oxy-combustion technology. The pilot plant consists of all components that are necessary to demonstrate and validate on an industrial scale all the required process steps for the oxy-combustion technology. The pilot plant provides information on the overall operational behavior of the whole plant, on the interaction between different components as well as detailed information on individual components. Alstom has supplied for the pilot plant the pulverized coal fired boiler including an indirect firing system with a single burner, the electrostatic precipitator and further equipment of the flue gas path /1/.

2. Equipment Description and Test Program

The 30 MW$_{th}$ pulverized coal fired boiler and the firing system with a single burner (arranged on the top of the furnace) are designed to allow for a maximum of operational flexibility, i.e., 100 % load can be operated both at air and at oxy-firing conditions, detailed descriptions of the equipment, principles of operation and test program of the pilot plant can be found in several publications by Vattenfall and Alstom /1,2,3,4/. In Figure 1 a process scheme of the pilot plant is shown with the main components as well as the burners tested by Alstom.

![Figure 1: Scheme of the pilot plant and Alstom burner types](image)

3. Test Results

Test results of the oxy-combustion performance are promising. Testing was conducted under various oxy-combustion process scenarios (intermixing of oxygen), and over a broad range of operating parameters. Test results reveal no technical barriers that would impede development and commercialization of oxy-combustion for CO$_2$ capture technology.

3.1. Burner and boiler performance

Overall, combustion performance was very good during both air and oxy-combustion testing with all the lignites tested, during oxy-firing CO$_2$ concentrations downstream of the ESP were typically more than 85 Vol.-%, dry. Measured NO$_x$ emissions and the methods applied for NO$_x$ reduction during air-firing were consistent with utility boiler experience. The NO$_x$ emissions during oxy-firing were typically less than 50% of the NO$_x$ levels during air-firing at comparable firing conditions. The primary measures for NO$_x$ reduction as applied in air-firing are effective
also for oxy-combustion. The amount of recirculated flue gas was varied in a broad range resulting in different oxygen concentration in the oxidant. The combustion performance was optimized towards low oxygen concentrations in the flue gas. The emission values for NO\textsubscript{x} and CO were always kept below the emission limits given by the authority according to “TA-Luft” standards for boiler in the actual size range.

The operational window of burner type B is shown in figure 2 for air- and oxy-combustion. Due to enhanced near burner zone mixing the operational window could be enlarged towards lower oxygen concentrations in the flue gas compared to burner type A. In the so called “Expert Mode A” all the oxygen is supplied via the burner into the furnace with equal oxygen level in all burner compartments and no oxygen is injected in the over-fire oxidant ports. In the “Pre-Mixed Mode” oxygen is mixed with flue gas at one location and is then distributed in the oxidant system.

The furnace temperatures and heat transfer profile could be changed during oxy-combustion tests by varying flue gas recycle rate. Furnace heat absorption and furnace heat flux profiles during oxy-firing could be controlled to similar levels as those measured during air-firing.

3.2. ESP Performance

The three-field ESP is located downstream the boiler and treats the entire flue gas stream. Since the ESP was designed to handle a selection of bituminous coals in future test campaigns, it has very high particle collection efficiency when the standard Lusitian lignite is being fired. This in turn gives an opportunity to reduce the current input to the ESP fields to save power, or to turn off one of the fields completely. Most of the test campaigns for the ESP have been carried out with one of the three fields out of service in order to reach dust emissions above the measurement precision of a gravimetric sampling.

In the ESP test campaign carried out in September 2009 both iso-kinetic gravimetric samplings and on-line particle size measurements were carried out. Both conventional air-firing and oxyfuel combustion were investigated during the test and ash and coal samples were collected at regular intervals and sent for analysis. The paper will focus on the results from the September 2009 campaign, although the ESP performance at Schwarze Pumpe has been investigated also at several other occasions.

The gravimetric measurements were carried out with two ESP fields energized, and with varying current/voltage settings. Even with only the two fields in operation, far from the maximum possible power input, the total dust emission from the ESP was clearly below 10 mg/Nm\textsuperscript{3} at oxyfuel operation. The concentration of fly ash entering the ESP was measured to be around 6500 mg/Nm\textsuperscript{3} for the standard low-ash lignite fired.

Particle concentration and number size distributions were also established on-line between 0.015-10 microns, using the combined ranges of an electrical mobility spectrometer and an aerodynamic particle sizer. The results imply very small differences between oxyfuel and air combustion regarding the particle size distribution and total emission after the ESP.

3.3. SO\textsubscript{x} Measurements

During the combustion of sulfur-containing fuels, a small fraction of the sulfur dioxide (SO\textsubscript{2}) is oxidized to SO\textsubscript{3}. SO\textsubscript{3} causes corrosion problems when condensing on cold surfaces downstream of the economizer. To avoid corrosion, the plants have to be operated at temperatures above the sulfuric acid dew point, which leads to decreased plant efficiency. In Oxyfuel firing system, SO\textsubscript{x} concentration is a key factor in determining where recirculated flue gas.
gas is taken, i.e. upstream or downstream of the desulfurization unit. At Schwarze Pumpe the desulfurization unit is outside of the recirculation loop. When burning dried lignite with sulfur content of about 1%, SO₂ concentration is thus high under the oxy-condition. Reported values and conversion rate of SO₃ from fuel-sulfur varied largely. Vattenfall has spent great efforts in quantifying SO₃ at the Schwarze Pumpe oxyfuel pilot. During February 2010, two dried lignite coal blends with different sulfur contents were fired. Measurement of SO₃ was one of the main objectives in the test campaign. SO₃ may exist in flue gas in the forms including SO₃ gas, SO₃ aerosol, H₂SO₄ vapor and H₂SO₄ aerosol, depending on gas temperature, water content and SO₃ concentration.

Methods for SO₃ measurement are still under development. Controlled Condensation Method (CCM) is currently considered to be the best measurement method. Flue gas is extracted through a heated, glass-lined sample probe and a quartz filter, both heated to above acid dew point. Gaseous SO₃ is collected in a glass condenser maintained at above water dew point. The Controlled Condensation Method generally gives reliable results although there are still some concerns for biased measurements. Therefore both Vattenfall and Alstom did measurements of SO₃ in parallel to collect more information aiming at verifying the SO₃ measurements. During the test campaign at the Schwarze Pumpe oxyfuel pilot, the SO₃ and SO₂ were measured at two locations, downstream of the ESP and after mixing with oxidant before entering the boiler. SO₃ is measured by controlled condensation method.

The samples of the two dried lignite coal blends contained 0.93% and 1.2% sulfur, respectively. Under oxy-firing conditions, the level of SO₃ was found to be relatively low with regard to the SO₂ level. SO₃ was about 40-60 mg/Nm³ dry gas and about 10 mg/Nm³ dry gas at the outlet of the ESP, for the higher sulfur lignite and the lower sulfur lignite, respectively. The measured results were in line with the values obtained by Vattenfall. The relative ratio of SO₃ to SO₂ found after the ESP was in the range of 0.15% to 0.45%. The ratio was low and the results were specific for the dried lignite coal blends.

Literature