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Variation of the Flue Gas Recirculation Rate for a Coal-fired Oxyfuel Power Plant with Circulating Fluidised Bed Combustion

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1. Introduction

The predominant view in society is, that carbon dioxide emissions into atmosphere are one of the main sources for climate change. To reduce the amount of emitted carbon dioxide in power generation three different approaches are under examination for carbon capture and storage. The oxyfuel process is one of these approaches for fossil fuel-fired power plants. It is based on the approved steam power process and therefore will profit from a high reliability and efficiency. The design of the process intends the combustion of coal in an atmosphere of oxygen, provided by an air separation unit, and recycled flue gas, resulting in a flue gas with high carbon dioxide concentrations. Due to the excessive adiabatic flame temperature for the combustion of coal with pure oxygen it is necessary to recirculate flue gas to the steam generator.

The amount of recycled flue gas in the oxyfuel process depends essentially on the deployed firing system. For most new build, high efficiency power plants pulverised coal (PC) firing is used as firing system. For this type of steam generator under oxyfuel conditions high temperatures can cause problems of uncontrollable slag formation and fouling of the heating surfaces. In order to control this issue a large quantity of flue gas is recycled back to the furnace to achieve an acceptable temperature level throughout the steam generator. As a consequence out of this the provided oxygen is diluted to a concentration approximately as low as in the air-fired case. An efficiency drop for the oxyfuel process results, caused by a significant auxiliary power consumed by providing oxygen, the purification and liquefication of the carbon dioxide-enriched flue gas and the fans for the recirculation of flue gas.

2. Motivation

To reduce the investment and operating costs a reduction of the recycled flue gas is needed. Approximately two thirds of the entire flue gas stream have to be recycled for an oxygen-fired power plant with PC firing. A possibility to reduce this amount is to adopt another heat sink in the system. As this opportunity does not exist for PC-fired units, the application of a circulating fluidised bed combustor (CFBC) seems appropriate. Huge amounts of solids are circulated in a CFBC. This material can be used as a heat sink in the furnace and simultaneously as a heat source in an external heat exchanger thus keeping the combustor temperature at a constant allowable level. The temperature

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of the combustion can be maintained when firing with oxygen by simply cooling a greater part of the large solid recirculation loop. By these measures it should be possible to sustain a mean temperature in the fluidised bed combustor between 850 and 900 °C, which is the typical operation temperature of CFBC units. To ensure that no agglomeration could occur in the CFBC the presence of hot spots in the bed has to be avoided.

In PC oxygen-fired systems the combustion of coal leads to higher concentrations of pollutants due to the missing dilution with nitrogen. If the recycled flue gas is untreated the concentration of sulphur dioxide in dry flue gas is about five times higher compared to the air-fired case and even if the recycled flue gas is fully desulphurised the sulphur dioxide concentration in the flue gas is doubled. Corrosion problems can occur due to these higher sulphur concentrations in the flue gas. Such problems are avoided in CFBC oxygen-fired systems due to the in-situ desulphurisation in the combustion chamber.

3. Work content

In this work the overall process of an oxyfuel power plant with circulating fluidised bed combustion and with a gross power output of 460 MW_{el} is modelled in the commercial software tool *EbsilonProfessional*®. The model is based on a system with external heat exchangers, concerning the data of available high end CFBC steam generators. Different factors are varied and their influence on the system is considered at full load operation. Main parameter varied is the amount of recycled flue gas. Similarly it is possible in an oxygen-fired CFBC system to obtain bed conditions within the combustor that are very similar to air firing using the proper amount of recycled flue gas. Systems can be designed to have the same ratio of flue gas flow to coal flow as for air firing. This scenario would represent the most conservative oxygen-fired condition with highest flue gas recirculation rates which is very similar to what is done in oxygen-fired PC systems, as mentioned above. In such a scenario the size and costs of the combustor, cyclones, convective heat exchanger section and other equipments of the boiler would also be approximately identical to the air-fired case.

In relation to the PC oxygen-fired system the CFBC oxygen-fired system does not only have the possibility to reduce the combustion temperature by flue gas recirculation but also by indirect cooling with ash which transfers its heat inside external fluidised heat exchangers to the water/steam side. Therefore the above mentioned conservative case is compared to design conditions with less recycled flue gas and changing requirements for the fluidisation boundary conditions. Due to a reduction of recycled flue gas the flue gas velocities in the combustor would decrease for a constant cross-sectional area and less particle mass flow in the flue gas would occur although just the opposite is necessary to transfer a larger amount of heat in the external fluidised heat exchangers. Either the cross-section of the combustion chamber or the size of the particles has to be fitted to the operating conditions to ensure that enough particles as heat carriers can be transported to the external heat exchangers.

Consequences for the size distribution of the bed material and the dimensions of the fluidised bed combustor are discussed. Beside changes in steam generator design a reduction of recycled flue gas leads to changing boundary conditions for the air separation unit (ASU) and the carbon dioxide purification unit (CPU). More oxygen has to be supplied by the ASU because less residual oxygen is recycled with the flue gas. If less flue gas is recycled the CPU is exposed to different operating conditions with an increasing flue gas mass flow and lower concentrations of carbon dioxide. In particular impurities like the residual oxygen in the flue gas are increasing if less flue gas is recycled. The consequences for the overall oxyfuel process induced by the reduction of recycled flue gas will be examined and summarised in this work. An optimum for the overall oxyfuel process can only be found under consideration of all these influencing factors.