The Oxyfuel Process with Circulating Fluidised Bed Combustion and Cryogenic Oxygen Supply

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1. Motivation

For a pulverised coal-fired (PC) power plant the adaption of the Oxyfuel process leads to a flue gas recirculation of about two thirds of the flue gas, referring to the mass flow downstream of the economiser. The amount of recycled flue gas becomes necessary, to protect the boiler materials against the excessive adiabatic flame temperature arising from the combustion of coal with nearly pure oxygen. As a consequence out of the flue gas recirculation the provided oxygen is diluted to a concentration of approximately 30 vol.-% (dry). In order to reduce the amount of flue gas recirculated another heat sink is necessary. Using a circulating fluidised bed combustor (CFBC) instead a PC-fired system offers the possibility to reduce the amount of the flue gas recirculation because a larger amount of heat transferred in the combustion chamber can be transferred to the circulating solids which can be cooled down in external heat exchangers. By this the oxygen concentration at the entrance of the boiler is increased up to very high values.

The goal of this work is to identify the feasibility and the main influencing parameters of an Oxyfuel CFBC concept with a minimal flue gas recirculation. On the one hand the boiler island can turn out to be smaller and cheaper, on the other hand the sum of energy demand of peripheral components can be decreased.

2. Work content

The integrated overall process of the Oxyfuel power plant with CFBC is modelled in the commercial software EbsilonProfessional® and Aspen®Plus, both linked with a programmable dynamic link library. Solely the isobaric two stage CO₂ condensation with external cooling system is modelled in Aspen®Plus while the steam generator and other components are modelled in EbsilonProfessional®. The simulated process is a supercritical greenfield power
plant considering the state-of-the-art. The gross power output is 460 MWel and the steam parameters are 275 bar, 560 °C/580 °C. The fuel is a South African hard coal with a lower heating value of about 25.1 MJ/kg.

To realise a conservative Oxyfuel case, close to the air case, more than 70 % of the flue gas downstream of the boiler have to be recycled in a CFBC. Therefore the oxygen in the fluidising medium of the combustion chamber is diluted to a concentration of about 35 vol.-% (dry). For this configuration approximately 30 % of the overall heat has to be transferred in external heat exchangers.

For an Oxyfuel CFBC concept with decreased flue gas recirculation the assumption of a constant flue gas velocity in the combustion chamber leads to a smaller cross-sectional area. Due to the reduction of the combustion chamber size on the one hand less space inside the combustion chamber for additional heat exchanging surfaces like wing walls and platen superheaters is available, on the other hand less space around the combustion chamber for additional external heat exchangers is available. In order to balance the system and the heat quantities transferred in the steam generator, more heat has to be transferred within the external heat exchangers while the heat quantities transferred in the combustion chamber and the convective heat exchangers decrease. Especially the installation of external heat exchangers is limited by the restricted space around the combustion chamber which is a decisive factor for the feasibility of an Oxyfuel CFBC process with decreased flue gas recycle.

How far the process feasibility is influenced by this restriction is part of the process analysis and will be presented within this work. For selected assumptions the flue gas recirculation can be reduced to approximately 60 %. Due to this the resulting oxygen content in the fluidising medium of the combustion chamber arises to about 60 vol.-% (dry). Corresponding to these design conditions more than half of the heat has to be transferred in the external heat exchangers. Therefore this work is focussing on the distribution of heat quantities within the steam generator and influencing effects on the boiler design for a CFBC Oxyfuel concept with reduced flue gas recycle. A closer look is taken at theoretical and practical limitations to achieve a minimal flue gas recirculation rate as well as changing gas concentrations in the flue gas and in the fluidising medium of the combustion chamber. Furthermore a potential net efficiency gain of about 0.6 %-pts. for a CFBC-fired concept with lowest flue gas recirculation is discussed. Moreover the structure of the auxiliary power demand of the overall process at full load operation is examined. The maximum efficiency for the integrated overall process will be compared to the PC-fired process considering same steam parameters and concepts for air separation and CO₂ processing unit, ensuring comparability of PC- and CFBC-fired Oxyfuel processes.

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