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Three-dimensional modelling of a 300 MWe Flexi-Burn® CFB for multifuel combustion in oxygen-fired and air-fired modes

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1. Introduction

A Flexi-Burn CFB is a concept, in which a circulating fluidized bed (CFB) boiler can be operated both in air-fired and oxygen-fired modes. In the air-fired mode, the operation is similar to a conventional CFB. In the oxygen-fired mode, the fuel is burned in a mixture of oxygen and recycled flue gas. This generates CO_2 rich flue gas from which the CO_2 can be separated and compressed and then transported to storage. The flexible operation reduces risks of outage in power generation due to e.g. failures in oxygen production and carbon capture and storage equipment. It also provides a possibility to determine the economically optimum operating mode depending on the price of CO_2 allowances and power requirements.

ENDESA Generación together with CIUDEN is considering the promotion of a commercial CCS demonstration plant with fully integrated CO_2 capture, transport and storage [1]. The OXY-CFB-300 project is based on supercritical oxy-combustion concept applying the Flexi-Burn CFB technology. The main target of this demonstration plant is to validate a CCS technology at commercial scale, using a wide range of coals and biomass, allowing the renovation of the existing fossil thermal plants from 2020. The currently foreseen plant location is the ENDESA's Compostilla Power Plant, in El Bierzo (Northwest Spain).

The development of the Flexi-Burn CFB design is supported by modelling. In a large-scale CFB furnace, the local feeding of fuel, oxidant, and other input materials, and the limited mixing rate of different reactants produce spatially non-uniform process conditions. To simulate the real conditions, the furnace should be modelled three-dimensionally or the three-dimensional effects should be accounted for. Comprehensive 3D modelling of large scale CFB processes cannot yet be done by fundamentals-oriented meso-scale two-fluid CFD models but requires a simplified, semi-empirical, macro-scale modelling approach.

The following paper presents the Flexi-Burn CFB concept, the 3D model, which has been applied for studying the furnace process, and modelling results of the initial design of the 300 MWe demonstration plant in oxygen-fired and air-fired modes.

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Flexi-Burn is a trademark of Foster Wheeler Energia Oy, registered in the US, EU, Finland.

2. Flexi-Burn CFB Concept

Fig. 1 presents a simplified process flow scheme of a power plant designed for both air-fired and oxygen-fired operation modes. It consists of an air separation unit (ASU), a high-efficiency steam cycle utilizing a Flexi-Burn CFB boiler and a CO_2 compression and purification unit (CPU).

For oxy-fuel combustion, which is the primary operation mode, oxygen is mixed with recycled flue gases, which creates a mixture of primarily O_2, CO_2 and H_2O used as oxidant in combustion instead of air. The absence of air nitrogen produces a flue gas stream with a high concentration of CO_2, making it much easier to separate the CO_2. In the air-firing mode, the ASU and CPU are out of service or in stand-by and the plant is operated like a conventional power plant, leading flue gases to the atmosphere.

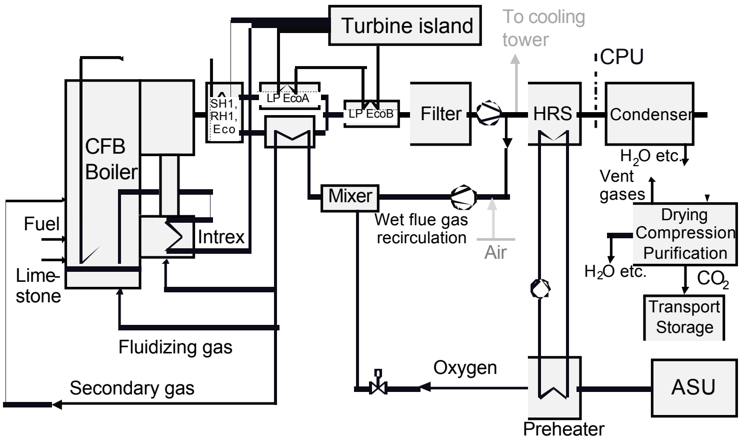

Figure 1. Schematic of a Flexi-Burn CFB power plant.

3. Three-dimensional Model for CFB

Only few models capable of simulating industrial scale CFB units have been published in addition to the presented model [2,3]. The model applied for the present work has been described in earlier papers [4,5].

The furnace of the CFB boiler is modelled three-dimensionally by applying a control volume method to discretize and solve the various balance equations in a steady state condition. The calculation mesh is structural with hexahedral calculation cells. The incorporated submodels include fluid dynamics of solids (fuels, limestones, sands) and gases, fuel combustion (and gasification), limestone reactions, comminution of solid materials, homogeneous reactions, heat transfer inside suspension and to surfaces, submodels for separators and external heat exchangers, and a post-solver for nitrogen oxide emissions. The validation of the different empirical submodels is based on measurements in bench scale, pilot scale and full-scale experiments.

4. Model Results

Two model cases were calculated: an air-fired case and an oxygen-fired case, in which the oxygen content of the inlet gas was about 24%. The fuel was a mixture of anthracite (70%) and petroleum coke (30%).

Based on this study, the combustion reactions are fairly similar in oxygen- vs. air-fired mode, if the oxygen content of the inlet gas is close to air-fired mode (Fig. 2). This results to similar temperature fields in both modes (Fig. 3). Consequently, the heat flux profiles are similar as well. This finding is supported by earlier studies [6].

However, large differences may occur due to changing limestone reaction mechanisms when operating at high partial pressure of carbon dioxide. In the oxygen-fired case, the furnace temperature was targeted above the calcination temperature, which would result in sulphur capture by normal calcination-sulphation. At the lower part of the furnace, due to cooling effect of circulated solids and fluidization gas, the modelled temperature was lower than calcination temperature resulting in local carbonation of limestone (Fig. 4). At the elevation above the secondary air inlets, the temperature was higher, which resulted in calcination (Fig. 5). In air-fired mode, the calcination occurred only for the fresh limestone, as seen in Fig. 5. These changed limestone reaction mechanisms can have a large impact on local gas concentration, velocity fields and temperature profiles inside the furnace and need to be considered when changing the operating mode.

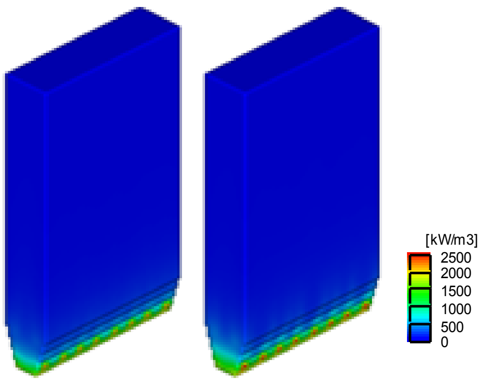

Figure 2. Heat from combustion reactions.

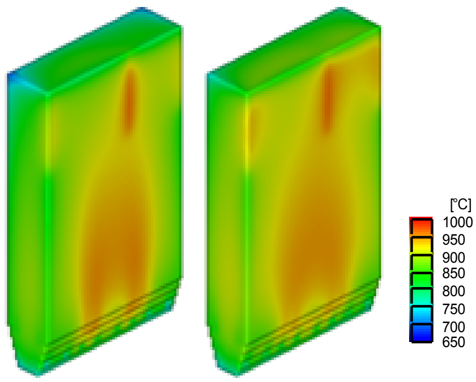

Figure 3. Temperature.

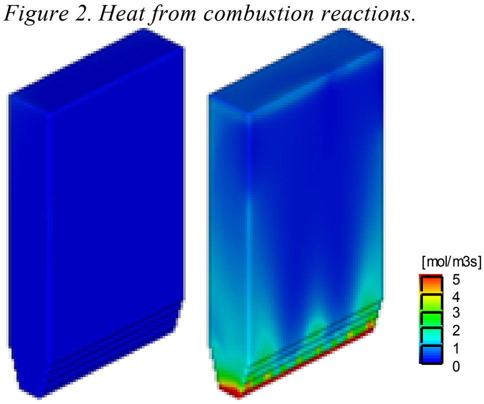

Figure 4. Carbonation.

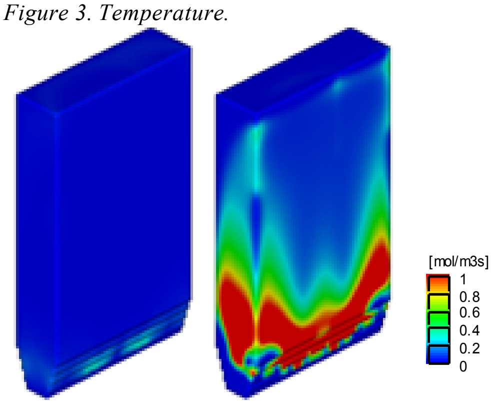

Figure 5. Calcination.

Left figures = air-fired case, right figures = oxygen-fired case.

5. Conclusions

The findings of this study can be used to support the further design of the OXY-CFB-300 demonstration plant. For future improvement, the different correlations describing the essential phenomena need to be further validated based on experimental studies in different scales.

Acknowledgements

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