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Oxidant control and air-oxy switching concepts for CFB furnace operation

Matias Hultgren[a,*], Enso Ikonen[a], Jenö Kovács[b]

[a] Systems Engineering Laboratory, University of Oulu, Linnanmaa, POB 4300, FI-90014 Oulun yliopisto, Finland
[b] Foster Wheeler Energia Oy, Relanderinkatu 2, POB 201, FI-78201 Varkaus, Finland

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ABSTRACT

Oxy combustion in circulating fluidized bed (CFB) boilers was investigated in this paper. Oxy combustion is a carbon capture and storage technology, which uses oxygen and recirculated flue gas (RFG) instead of air as an oxidant. Air and oxy combustion were compared through physical considerations and simulations, focusing on process dynamics, transients and control. The oxidant specific heat capacity and density are elevated in oxy combustion, which leads to slower temperature dynamics. Flue gas recirculation introduces internal feedback dynamics to the process. The possibility to adjust the RFG and oxygen flows separately gives an additional degree of freedom for control. In the simulations, "direct" and "sequenced" switches between air- and oxy-firing were compared. Fast "direct" switches with simultaneous ramping of all inputs should be preferred due to the resulting smooth temperature responses. If these process input changes are unfeasible, the fuel should be altered after the gaseous flows ("sequenced" method).

1. Introduction

This paper investigates the differences between oxy combustion ("oxyfuel" process) and air combustion in circulating fluidized bed (CFB) power plants, with a particular focus on the process dynamics and transient behaviour in the oxy-CFB. Oxy combustion is one of the major industrial carbon capture and storage (CCS) technologies, which also include pre- and post-combustion capture, as well as chemical looping combustion (CLC). Carbon dioxide emissions have received an increasing attention because of the concern for climate change, especially for industrial branches consuming fossil fuels. One solution for reducing CO_2 emissions in power plants is to capture the CO_2 from flue gases with CCS. The captured and processed CO_2 is transported to underground or underwater high-pressure storage sites or, alternatively, used in industrial applications.

In oxy combustion, solid fuel is combusted with a mixture of pure oxygen and recirculated flue gas (RFG) from the process instead of air as an oxidant, resulting in a flue gas CO_2 concentration of 70–98 vol.% (dry) and thus an easier recovery of the carbon dioxide from the flue gas. Oxy combustion has been deemed as one of the most promising options for CO_2 capture, when considering the energy, cost efficiency and extremely small atmospheric CO_2 release of the process. The main structural and operational differences between air and oxy combustion plants are presented in this paper, concentrating on the dynamic aspects leading to control considerations. Even though the ultimate goal of the overall research is to develop controls for oxy-CFB, this paper deals with the general aspects and concepts of combustion control suitable for both air- and oxy-fired CFB boilers.

In fluidized bed (FB) combustion of solid fuels, fuel particles are fluidized and combusted in a bed of incombustible material of e.g. sand or ash in the furnace riser. The fluidizing medium is the primary input gas flow, which commonly contains the oxidizing agent needed for combustion. In circulating fluidized beds (CFBs), a sufficiently high gas velocity and small particle size enable the solids to become entrained with the bed and to leave the furnace riser tube. The solids are separated from the flue gas in a gas–solid separator, from which the flue gas continues to the backpass and the solids are recycled back to the bed through the solids circulation system. Together, these process components form the hotloop (Fig. 1), which is the studied CFB boiler subsystem of this paper. CFB combustion is used for solid fuels and also for liquid fuels to some extent.

When designing control solutions for CFB combustion, the main issues affecting both the steady-state and dynamic behaviour of the process can be summarized with the key points below:

- Fluidization

As the furnace input gas (oxidant) flows are responsible for the fluidization in the CFB, any effects the oxy-firing process

* Corresponding author. Tel.: +358 503502923; fax: +358 85532304.
E-mail addresses: matias.hultgren@oulu.fi (M. Hultgren), enso.ikonen@oulu.fi (E. Ikonen), jeno.kovacs@fwfin.fwc.com (J. Kovács).

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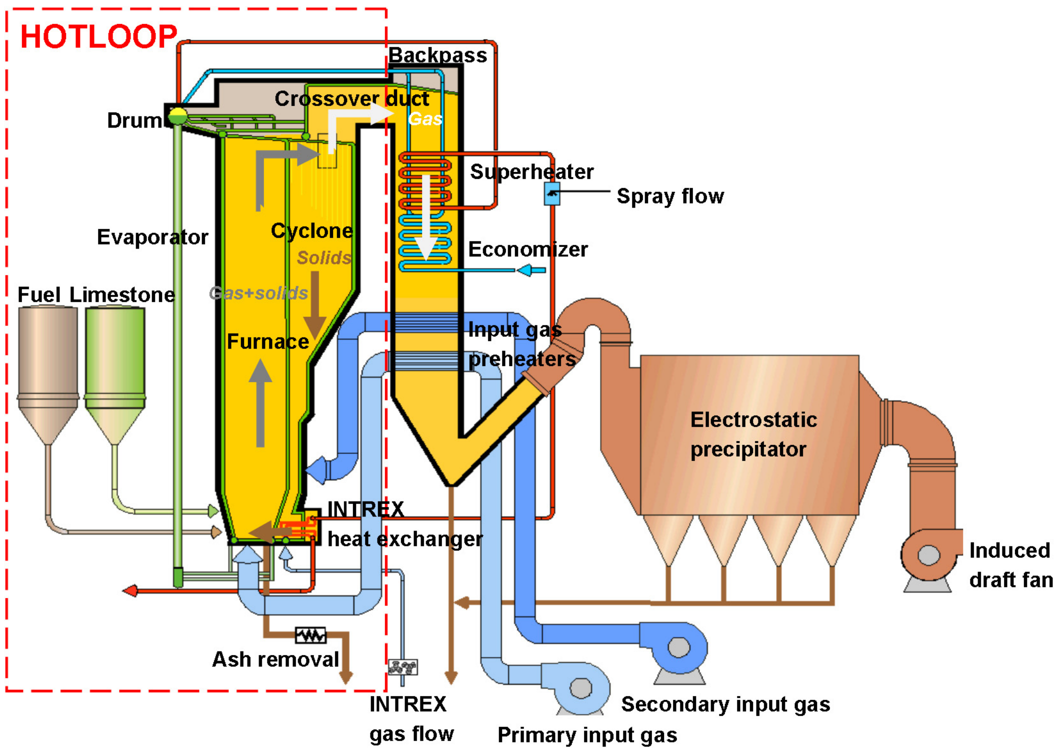

Fig. 1. Operation schematic of the CFB boiler, with the hotloop highlighted with the dashed line. Modified from Foster Wheeler Energia Oy (2012).

configuration has on the gas flows have the potential to alter the fluidization and thus the mixing and heat transfer in the bed. Proper fluidization has to be maintained in the bed.

• Input oxidant flows, i.e. input gas flows

The oxidant flow is air for air-fired FB processes and oxygen + recirculated flue gas for oxy combustion. This is the main cause for the differences between air and oxy combustion. The heat capacity, density and chemical component concentrations of the oxidant are directly related to the differences between the combustion atmospheres. For the combustion dynamics, especially the oxygen input and thus the oxidant O_2 percentage are of importance.

• Heat transfer & boiler MW output

The heat transfer in the dense bed, the upper furnace, the flue gas path and the return leg affects the selection of heat exchanger sizes and the power plant performance optimization. The differences in heat transfer between air and oxy combustion are thus significant factors for combustion control. Maintaining a correct heat transfer distribution is especially important for once-through (OTU) boilers, as these units don't contain a water-steam drum as a buffer for steam generation.

• Combustion & firing power

The combustion in the CFB furnace riser determines the generated amount of heat in the boiler. When comparing air and oxy combustion, the effect of the atmosphere change on the combustion reactions and the heat generation has to be considered. Important process variables are furnace temperatures at different points in the riser and the flue gas O_2 content.

• Combustion-related reactions

Because of the flue gas recirculation and absence of air in oxy combustion, the concentrations of emission components such as SO_x, NO_x and CO will be affected by the combustion mode. This has the potential to cause changes in the gaseous emissions of power generation, as well as in the mechanisms and balances of emission formation reactions.

• Fuel

The fuel input determines the combustion progression and the emission formation. Knowledge of fuel flow properties such as heating values, carbon and moisture contents, solids/volatiles distributions, as well as mass flow accuracies can be used in feed-forward and model-based control solutions. As the fuel flow is set separately from the input gas flows, no notable differences between air and oxy combustion should occur because of the fuel alone.

• Integration of the boiler and supporting units

In oxy combustion, the boiler island depends on the oxygen production and CO_2 post-processing units. As a result, coordinated or plant-wide boiler island control might be of importance. The O_2 is produced with an air separation unit (ASU), while the CO_2 is captured using carbon compression (CCU) and purification (CPU) units. Dynamic properties such as production rates, startup times and load following capabilities of these units need to be considered in the overall control design.

• Water-steam cycle

The water-steam cycle contains the main power plant control loops, such as live steam temperature control, boiler-turbine unit control, feedwater control and drum level control. As the heat used on the water-steam side comes from the combustion and as the