1-D dynamic modeling of oxygen fired coal combustion in 30MWth CFB boiler

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1. Introduction

The size of the circulating fluidized bed (CFB) boiler for coal combustion has multiplied during recent decades. The modern-day big CFB is a once-through boiler with supercritical steam properties to keep the boiler efficiency as high as possible. Up-scaling and CCS technologies have created challenges for the design side due to the material issues and new implemented technology. The dynamics of the hot-loop and steam cycle has started to play a vital role in the control of CFB boilers. The modern-day demand is to control the fluidised bed systems with high efficiency also in transient situations, and the dynamic modelling approach is the tool to investigate such situations. Currently, the role of the dynamic modelling of CFBs with higher efficiencies and in oxy-combustion is growing rapidly.

The development of the oxygen fired CFB technology is supported by one dimensional dynamic modelling of the furnace process. This study presents dynamic modelling experiences of a 30 MWth CIUDEN CFB test plant in oxy-mode. The modelled results of the CIUDEN CFB test plant have been compared with the measurements. Schematic of the CIUDEN CFB test plant is showed at the Figure 1.

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2. Description of 1-D dynamic CFB model

The studied CFB process consists of a fast fluidised bed riser and solids return system after the furnace with external Intrex™ unit. The different process modules are divided into 1-D elements in the vertical direction. Time dependent balance equations for mass and energy are written for each element. Each element has been treated as an ideally mixed control volume. Solid and gas phases are calculated separately using the same average temperature for both of the phases. Modules can be either adiabatic or the prescribed insulation thickness and surface temperature can be determined. There is also an option for additional internal heat exchangers. The set of time dependent balance equations are solved using ordinary differential equation solver (ODE) in the Simulink/Matlab system. The detailed modelling approach is presented by Ritvanen et al. [1]

3. Modelling of CIUDEN TDP

The object of the studies is the CIUDEN’s Technology Development Plant in El Bierzo, Spain [2]. The test campaign, which has been carried out at CIUDEN TDP, includes numerous tests with different fuel mixtures and operating conditions. This study present one dynamic example of fuel feed step change. Figure 2. demonstrates the fuel feed test experiment in the oxy mode. Within this test the oxygen feed and flue gas recirculation were kept constant and steps down and up was applied for the fuel feed. The used fuel in this study is anthracite and the fuel analysis data is presented at the table 1.

![Figure 2. Relative fuel feed at the test.](image)

During the simulation experiments, the collected process input variables – fuel, primary/secondary oxidant flows and flue gas recirculation – were supplied as inputs for the model. The main variable to test the performance of the hot-loop was the flue gas O₂ content. The flue gas responses at the fuel step change test are shown in Figure 3. The flue gas O₂ content was around 3.5% at the beginning of the fuel step change test. The model could successfully mimic the real process behaviour in dynamic sense.

<table>
<thead>
<tr>
<th>Components</th>
<th>Anthracite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultimate analysis (wt%, dry)</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>62.9</td>
</tr>
<tr>
<td>H</td>
<td>1.9</td>
</tr>
<tr>
<td>N</td>
<td>0.75</td>
</tr>
<tr>
<td>O</td>
<td>2.52</td>
</tr>
<tr>
<td>S</td>
<td>1.01</td>
</tr>
<tr>
<td>Proximate analysis (wt%)</td>
<td></td>
</tr>
<tr>
<td>Moisture</td>
<td>6.7</td>
</tr>
<tr>
<td>Ash (dry basis)</td>
<td>31.02</td>
</tr>
<tr>
<td>Volatiles (dry basis)</td>
<td>6.2</td>
</tr>
<tr>
<td>Heat value (MJ/kg)</td>
<td></td>
</tr>
<tr>
<td>LHV (as received)</td>
<td>21.3</td>
</tr>
</tbody>
</table>

Table 1. Fuel analysis data.
4. Conclusions

A simulation model for a CIUDEN CFB test unit has been built using general transient mass and energy balances with empirical correlations. The empirical correlations and the simulation model have been validated using previous experience and plant scale measurements. CIUDEN oxy-combustion reference case has been studied, and a comparison of the numerical simulation with the measurements has been introduced with high correspondence. Building up a dynamic simulation model has shown its value in the analyses of experimental results. When investigating physical phenomena such as combustion or heat transfer process more deeply, the validation of physical models by a dynamic simulation tool has provided valuable information and understanding of the dynamic characteristics and relationships between the dynamic phenomena. In addition, the analyses of dynamic tests can reveal important behaviour patterns of the process which can be utilised also in stationary design models.

As a result of this study, oxy-fuel CFB system dynamics can be further studied and optimal control systems can be developed for oxy-combustion. Different control system approaches can be tested using the simulator to achieve higher efficiencies also in transient situations.

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References
