47th International Energy Agency
Workshop on Large Scale CFB and Technical Meeting

Turow Power Station, Zlotniki, Poland October 13th and 14th 2003

Testing and Simulation in Turow Unit 3 and the Application of the Results on the Lagisza 460 Mw_e OT CFB

Arto Hotta and Rafal Psik
Foster Wheeler
Background for CFB Models

• Trends for CFB boiler industry:
  – Larger unit sizes and higher steam parameters.
  – Higher efficiency.
  – Tighter emission standards.

• More detailed, fast and reliable models required.
• Valid model – optimised CFB design and process performance.
PROCESS MEASUREMENTS IN TUROW UNIT 3

EU PROJECT: Processes In Large-scale Circulating Fluidized Bed Combustors

- gas concentration
- solids distribution
- temperature distribution
- solids flow
- solids segregation
Gas concentrations

- L4R (TUHH, 19.06.01, 14:00-15:30)
- L4F (TUO, 19.06.01, 09:30-14:00)

- $\frac{O_2}{O_2}$, measured / $\frac{O_2}{O_2}$, stack

- $\frac{CO}{CO}$, measured / $\frac{CO}{CO}$, stack

- $\frac{NO}{NO}$, measured / $\frac{NO}{NO}$, stack

- $\frac{SO_2}{SO_2}$, measured / $\frac{SO_2}{SO_2}$, stack

penetration depth [m]
DESIGN MODEL FOR THE CFB HOT LOOP

CFB DATABASE
- Field tests and analyses

CHARACTERIZATION
- Fuel & Limestone
- Reactivity

PARAMETERS
- Solids loading
- Heat transfer
- Emissions
- ...

BOILER DESIGN PERFORMANCE

NEW FUEL
Model Description

• Steady-state combustion model for CFB furnace.

• 0-D fractional material balances.

• 3-D modeling of solid and gaseous species.

• 3-D modeling of energy balance.

• Empirical suspension density profile.
Calculation Results
Oxygen
Simulation Tools
The Dynamic CFB Model of Foster Wheeler

• A dynamic simulation tool to model dynamic behavior of the CFB system.

• Separate submodels have been developed for different parts of the CFB loop
  – Furnace
  – Solids separator
  – Return channel
  – INTREX™ heat exchangers.

• Each model component is based on the fundamental laws of conservation of mass, energy and momentum and on empirical correlations.
Analysis of Process Dynamics

- Dynamic Process Tests
  - Dynamic process tests have been carried out in a 235 MW_e CFB boiler.

- Process Modeling
  - A tailored dynamic simulator was built for the 235 MW_e CFB boiler.

- Model Validation and Simulation Analysis
  - Measured data on the dynamic process tests were used to determine and to verify the model parameters and modeling principles.
Analysis of Process Dynamics

Dynamic Process Tests

Matrix of the Dynamic Process Tests

<table>
<thead>
<tr>
<th>Test</th>
<th>Load 100 %</th>
<th>Load 80 %</th>
<th>Load 60 %</th>
<th>Load 40 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open loop load change</td>
<td>100 ⇒ 90 ⇒ 80</td>
<td>80 ⇒ 70 ⇒ 60</td>
<td>60 ⇒ 50 ⇒ 40</td>
<td>40 ⇒ 50 ⇒ 60</td>
</tr>
<tr>
<td>closed loop load change</td>
<td>100 ⇒ 80</td>
<td>80 ⇒ 60</td>
<td>60 ⇒ 40</td>
<td>40 ⇒ 60</td>
</tr>
<tr>
<td></td>
<td>4 %/min</td>
<td>4 %/min</td>
<td>4 %/min</td>
<td>4 %/min</td>
</tr>
<tr>
<td>Fuel reactivity</td>
<td>+/- 10 %</td>
<td>+/- 10 %</td>
<td>+/- 10 %</td>
<td>+/- 10 %</td>
</tr>
<tr>
<td></td>
<td>step change</td>
<td>step change</td>
<td>step change</td>
<td>step change</td>
</tr>
<tr>
<td>Primary air</td>
<td>+/- 10 %</td>
<td>+/- 10 %</td>
<td>+/- 10 %</td>
<td>+/- 10 %</td>
</tr>
<tr>
<td></td>
<td>step change</td>
<td>step change</td>
<td>step change</td>
<td>step change</td>
</tr>
<tr>
<td>Secondary air</td>
<td>+/- 10 %</td>
<td>+/- 10 %</td>
<td>+/- 10 %</td>
<td>+/- 10 %</td>
</tr>
<tr>
<td></td>
<td>step change</td>
<td>step change</td>
<td>step change</td>
<td>step change</td>
</tr>
<tr>
<td>Prim/sec air ratio</td>
<td>60/40 ⇒ 65/35 ⇒ 70/30 ⇒ 60/40 ⇒ 55/45 ⇒ 50/50 ⇒ 60/40</td>
<td>60/40 ⇒ 65/35 ⇒ 70/30 ⇒ 60/40 ⇒ 55/45 ⇒ 50/50 ⇒ 60/40</td>
<td>60/40 ⇒ 65/35 ⇒ 70/30 ⇒ 60/40 ⇒ 55/45 ⇒ 50/50 ⇒ 60/40</td>
<td>60/40 ⇒ 65/35 ⇒ 70/30 ⇒ 60/40 ⇒ 55/45 ⇒ 50/50 ⇒ 60/40</td>
</tr>
</tbody>
</table>
Analysis of Process Dynamics
Dynamic Process Tests

Execution of the Dynamic Process Tests
Analysis of Process Dynamics
Basics of the CFB Dynamics

- Air flow to the boiler
- Fluidization velocity
- Solids flow pattern
- Convective heat transfer
- Total heat transfer
- Heat flux to the surfaces
- Fuel burning
- Fuel feed
- Furnace temperature level
- Mass of the bed material (inertia)
- Mass of the steel material (inertia)
- Mass of the working fluid (inertia)
- Fuel
- Limestone
- Separator
- Make up
- Steam flow
- Flue gas oxygen

Control variable
Dynamic response
Inertia
HIPE CFB
High Performance Multifuel CFB with Advanced Steam Cycle

• EU – funded research program (2001 – 2003)
  – Total volume 3.6 M€ (1.7 M€ from EU)

• Objective
  – Development of Supercritical Once Through Design for Circulating Fluidized Bed (CFB) Boiler

• Partners
  – Foster Wheeler Energia OY
  – Siemens AG
  – Energoproject Katowice
  – Technical Research Center of Finland
Lagisza Power Station, 460 MW<sub>e</sub>, Poland

**CFB BOILER DESIGN DATA**

<table>
<thead>
<tr>
<th>Output</th>
<th>MW&lt;sub&gt;e&lt;/sub&gt;</th>
<th>460</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steam Flow</td>
<td>kg/s (SH/RH)</td>
<td>360/313</td>
</tr>
<tr>
<td>Steam Pressure</td>
<td>bar (SH/RH)</td>
<td>275/50</td>
</tr>
<tr>
<td>Steam Temperature</td>
<td>°C (SH/RH)</td>
<td>565/580</td>
</tr>
</tbody>
</table>

**SCHEDULE**

- Contract Signing: December 30, 2002
- Engineering Release: March 1, 2003
- Mechanical Completion: February 28, 2006
- Commercial Operation: September 30, 2006

**FUELS (as received)**

<table>
<thead>
<tr>
<th></th>
<th>Coal</th>
<th>Coal Slurry (max. 30 %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulphur % wt</td>
<td>1.2</td>
<td>0.6 – 1.4</td>
</tr>
<tr>
<td>Ash % wt</td>
<td>23</td>
<td>10-25</td>
</tr>
<tr>
<td>Moisture % wt</td>
<td>12</td>
<td>6-23</td>
</tr>
<tr>
<td>LHV MJ/kg</td>
<td>20</td>
<td>18-23</td>
</tr>
<tr>
<td>LHV % wt</td>
<td>18</td>
<td>7-17</td>
</tr>
</tbody>
</table>
ŁAGISZA 460 MW$_e$ CFB
Lagisza: Evaporator Studies

- Furnace calculated with Foster Wheeler’s modern 3D furnace model
- Different design conditions evaluated
  - Furnace conditions
  - Evaporator water/steam side conditions
  - Example: Coal feeder disturbance
- Low and uniform heat fluxes in a CFB furnace
- Lower mass flow rates (“natural circulation characteristics”)
<table>
<thead>
<tr>
<th>Case 1– Basic case. Uniform fuel feeding to all the feeding points.</th>
<th>Case 2– Fuel feed stopped to feeding point at front-right corner. Feed rate to other feeders increased equally.</th>
<th>Scale [kW/m²]</th>
<th>Difference Case 2 – Case 1 [kW/m²]</th>
<th>Percentual change [%]</th>
</tr>
</thead>
</table>

**Furnace Heat Flux – Comparison of Two Cases**
Furnace Combustion Temperature – Comparison of Two Cases

Case 1 – Basic case. Uniform fuel feeding to all the feeding points.

Case 2 – Fuel feed stopped to feeding point at front-right corner. Feed rate to other feeders increased equally.

Scale [°C]

Difference Case 2 – Case 1 [°C]
Fuel feed stopped to feeding point at front-right corner. Feed rate to other feeders increased equally.
Lagisza: Dynamic Simulations
Boiler run-back: Secondary air fan trip

- Fuel feed
- Primary air feed
- Secondary air feed
- Main steam flow
- Flue gas oxygen
Lagisza: Dynamic Simulations
Step load changes +5% MCR

Time (s)

Mass flow rate (kg/s)

- Main steam flow
- Set point
SUMMARY

Process tests in Turow produced valuable data for the modelling of large scale furnaces

The valid models are essential tools in further development of OT CFB (Lagisza)

The models are tools for the further optimisation of Turow units