Continuous measurement of coal flow and air-fuel ratio for closed-loop control

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Contents

- Introduction
- Measuring – Controlling - Optimising
- Results
- Summary
Introduction
Introduction

Why is coal and air flow control so important?

- Fuel and air flow parameters determine the quality of combustion
- Area in which the overall generation process is least perfect
- Process not directly monitored and controlled
- Increasing variability of coal quality
- Renewable energies impose increasingly dynamic load adaptation
- Boiler are usually not operated at their design point
**Introduction**

**Air/fuel ratio and performance**

- Reduce process variability and shift operating point closer to the limits
- Individual adjustment of air and fuel flow at burner level
- Identify and utilize the intricate interplay of combustion parameters
- Continuous optimization
- Instantaneous adaptation to load changes

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**Strategy**

- 
  \[ \lambda \]
  
  \[ \eta_{th} \]
  
  \[ NO_x \]
  
  \[ CO \]
  
  \[ LoI \]
  
  \[ \lambda_{opt} \]
  
  \[ \lambda_{ges} \]

---

Air/fuel ratio (\( \lambda \)) - optimised combustion settings

Air/fuel ratio (\( \lambda \)) - regular combustion settings
### Why is coal and air flow control so important?

<table>
<thead>
<tr>
<th>Controllable O&amp;M variable</th>
<th>$\Delta \eta_{th}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal fineness</td>
<td>0.1 - 0.3%</td>
</tr>
<tr>
<td>Primary air-flow</td>
<td>0.1 - 0.2%</td>
</tr>
<tr>
<td>Fuel line balance</td>
<td>0.1 - 0.3%</td>
</tr>
<tr>
<td>Particulate-air ratio</td>
<td>0.1 - 0.3%</td>
</tr>
<tr>
<td>Carbon-in-ash (LoI)</td>
<td>0.1 - 0.3%</td>
</tr>
<tr>
<td>Excess oxygen</td>
<td>0.1 - 0.3%</td>
</tr>
<tr>
<td>*<em>Total</em></td>
<td><strong>0.6 – 1.7%</strong></td>
</tr>
</tbody>
</table>

*These benefits do not add up synergistically. Typically, an overall improvement in net efficiency will be around 0.3 – 1.0%*
# Benefits quantified

**Plant**
- **Unit size**: 630 MW
- **Lignite LHV**: 10,300 kJ/kg
- **PLF**: 88.5 %

**Reference**
- **Coal flow**: 660 t/h
- **O₂ excess**: 4.0 %
- **LoI**: 2.9 %
- **T Boiler Exit, ref**: 199 °C
- **η Boiler, ref**: 86.66 %

**Optimisation**
- **Coal flow**: 655 - 657 t/h
- **O₂ excess**: 3.2 %
- **LoI opt**: 1.8 %
- **T Boiler Exit, opt**: 191 °C
- **η Boiler, opt**: 87.10 %

### Savings
- **Δ Coal p.a.**: > 23,000 t
- **Cost per tonne**: 26 EUR
- **Annual savings**: ~ 600,000 EUR
- **Δ CO₂ p.a.**: > 27,300 t
- **CO₂ Certificate**: 20 EUR/t
- **‘Carbon benefit’**: ~ 550,000 EUR
- **Total benefit p.a.**: 1,150,000 EUR

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Monitoring – Controlling - Optimizing
The Basic Idea

Measure
If you can’t measure, you can’t control.
Monitoring – Controlling - Optimizing

The Basic Idea

Measure
If you can’t measure, you can’t control.

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EUcoalflow sensors
Control unit
Orificing valve
Coal Flow Control
Monitoring – Controlling - Optimizing

The Basic Idea

Measure
If you can’t measure, you can’t control.

Control
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The Basic Idea

Measure
If you can’t measure, you can’t control.

Control
If you can’t control, you can’t optimize.

Optimize
If you don’t optimize, you waste money.
Monitoring – Controlling - Optimizing

**System structure**

**EUcoalflow Sensor**
- Coal mass flow
- 2 – 3 Sensors per pipe

**Orificing valve**
- Basic adjustment
- Pipe-to-pipe balancing
- Manual or motor driven

**SA-Damper Control**
- Automatic adjustment of SA
- AFR at prescribed level

**Optimisation (EUcontrol)**
- Optimal air/coal distribution and biasing
EUcoalflow – Closed-loop Control

Strategy

1. Measure the coal flow and PA flow in each pipe

2. Adjust coal flows to acceptable reference limits (manual or by motor)

3. Determine SA flow in each pipe from damper position and pressure differential (soft sensing)

4. Adjust SA dampers to balance AFR ratio at each burner while maintaining overall SA intake

5. Use excess O2 as control variable to fine-tune SA-damper position (adaptive, corrective loop)

6. Optimize (emissions, heat rate, LoI, slagging, ...)

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EUcoalflow Sensor

**Specifications**

- Sensor type: Microwave
- Measuring range: 0 - 400 mm
- Operating temp.: < 200 °C
- Flow density: < 1000 g/m³
- Sensor diameter: 20 mm
- Power supply: 110/240 V AC
- Sensor set-up: 2 or 3 per pipe

**System set-up**

**Control unit**

- Online determination of
  - Coal mass flow
  - Gas velocity & volume flow
- Pipe to pipe distribution
- Statistic functions
EUcoalflo Flow Sensor

Application – lignite fired plant

Sensor accuracy

Graph showing EUcoalflo flow sensor signal for burners 1-3 with load percentages of 45%, 55%, and 65%.

Conclusion

- Tests with three mill settings
  - Precise, stable and reproducible signal
  - Direct monitoring of load changes in each burner pipe
  - Very good correlation between EUcoalflo mass flow signal and mill load
- Linear fit can be used for absolute signal calibration

EUcoalflo raw signal - - - Linear fit for calibration
EUcoalflow Sensor

Application – dense phase

Signal analysis

- High fluctuation in the mass flow signal causes
- Fluctuating excess oxygen (DCS signal)
- At constant load set point

Conclusion

- High correlation of excess oxygen signal with coal mass flow
- Direct visualisation of feeding and milling malfunctions
- Control of secondary air flow
EUcoalflow – Actuators

Required Features

- Easily adjustable (no “freeze up”)
- Linear valve characteristics
- Abrasion resistant (flow & material)
- Easy installation
- Manual or motored versions
EUcoalflow – Actuators

**Required Features**

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**Variable Orifice**
**Material and Design**

- Innovative adjustable orifice valve technology (V-valves) with chromium-carbide coating (patent pending)
- The below shown valve was installed in May of 2007 and pulled out for inspection in March of 2009. The chromium-carbide coating shows no signs of wear.
Flow Characteristics

- Innovative adjustable orifice valve technology (V-valves) with chromium-carbide coating (patent pending)
- The below figure shows a CFD calculation of the particle flow through the valve. Determination of pressure drop and valve characteristics.
### Steps to success

<table>
<thead>
<tr>
<th>Feasibility</th>
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<tbody>
<tr>
<td>- Site familiarisation and review of existing plant equipment</td>
</tr>
<tr>
<td>- Test with EUcoalflow mobile</td>
</tr>
<tr>
<td>- Identify additional equipment requirements</td>
</tr>
<tr>
<td>- Review of available data and data quality</td>
</tr>
<tr>
<td>- System identification using available data</td>
</tr>
<tr>
<td>- Parametric testing using Design of Experiments</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Prediction models for control/optimisation</td>
</tr>
<tr>
<td>- Process/plant model for model-in-the loop testing (hardware-in-the-loop)</td>
</tr>
<tr>
<td>- Smart sensoring</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Operate in advisory mode</td>
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<tr>
<td>- Extend to closed loop</td>
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</tbody>
</table>

**Typical project time is 2 – 3 months**
Implementation, Installation and Commissioning

**Steps 1 – Advisory Mode**

- The ECF coal flow sensors are installed and connected to the ECF control module.
- Variable orificing valves are installed (static coal flow adjustment).
- A “soft sensor” module for the determination of SA flow is installed on the ECF. It calculates optimal SA flows according to the measured coal mass flow in the pipe and translates these into damper settings.
- The SA damper set points are manually adjusted by the operator via DCS interface at reasonable intervals (e.g. 15 min).

**Steps 2 – Closed-loop Control**

- Interface to plant DCS via OPC or generic interface protocol.
- Controller adjustment and test using model based design approach.
- Commissioning of closed loop system.

**Steps 3 – Online Optimization**

- Use coal and air flow control for combustion optimization.
Results – Reduced excess O2

Enhanced boiler operation - O₂ and air-fuel ratio

- EUcontrol activ 29/4/2010 - 12/5/2010
- EUcontrol not activ 2/2/2010 - 15/2/2010
- standard deviation EUcontrol aktiv
- standard deviation EUcontrol not activ
Results - AFR

Process stabilization

- Air/fuel ratio 'lambda'
  - Range of all active mills
  - Average
  - Difference Max. Min

- Hopper speed
  - Range of all active mills
  - Targeted area
  - Average

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Summary

Benefits

- Improved heat rate (1 to 3 %)
- Reduced LoI
- Reduced NOx and CO emissions (- 5 to - 15%)
- Avoid material stresses and abrasion in pipes
- Reduce slagging and fouling, limit soot blower operation
- Less material stress in furnace due to more even temperature distribution
Thank you for your attention!

For more information you can find us at booth G100