Ein modulares Messtechnik- und Prozesssteuerungssystem zur Optimierung der Betriebsführung von Großdampferzeugern

An advanced boiler monitoring and optimisation system
Modular, closed loop boiler optimisation

- Which optimisation goals can be achieved with EUcontrol-boiler?
- What are the advantages of the modular approach?
- Which components can be integrated?
The plant behaviour is predicted with an (identified) process model. An optimiser calculates the best possible combination of inputs.

Hard and soft constraints can be equally considered. Preferential adjustment of set-points is possible if the degree of freedom is sufficient.
System identification

Systematic reduction of input data

Remaining input data
- Primary air setting
- Coal feeder setting
- Burn-out air 2 setting

Input data
- Emissions measurements
- Steam parameters
- Power consumption
- Efficiency

Dependence

Simplification

Little variance

Fouling
Mill speed
### Data structure

#### Plant model

**INPUT (u)**

1. **Manipulated variables**
   - Primary air (1...8)
   - Coal hopper (1...8)
   - $\Sigma$ Secondary air
   - OFA 1
   - OFA 2
   - $O_2$ Excess

2. **Measured (dist.)**
   - Output power
   - Sooth blowers

3. **Unmeasured (dist.)**
   - Coal quality

**OUTPUT (y)**

- $NO_x$
- $T_{BK}$
- $CO$
- $\sigma_T$
- $T_{Mill}$ (1...8)

**4. Constraints**

- FD fan pressure drop
- Mill temperature
- Mill arrangement
Main features

- Multi criteria optimisation
- Adaptive model predictive control
- Set-point optimisation
- Advisory and closed-loop mode
- Fully customisable
- Flexible interfacing (OPC)
Seamless integration of tools

- EUvis insitu
- EUcoalsizer
- EUflame
- EUcontrol-boiler
- EUtools

Control room

Combustion process

Set-point adjustment

Measurement data
Seamless integration of tools

- EUvis insitu
  - Condition monitoring
  - Slagging and fouling
  - Erosion detection
  - On-demand cleaning

Control room

Set-point adjustment

Combustion process
Seamless integration of tools

**EUcontrol-boiler**

- Control room
- Measurement data
- **EUcoalsizer**
  - Inline and online measuring:
    - fineness (size)
    - velocity
    - mass density
  - No by-passing, no sieving
  - Mill and separator optimisation
  - Control loop integration
- Set-point adjustment

---

© 2005 EUtech Scientific Engineering GmbH
Dennewartstraße 25-27, 52068 Aachen, Germany
www.eutech-scientific.de
Phone: +49/241/963-23-80
Fax: +49/241/963-23-81
**EUcontrol-boiler**

**Seamless integration of tools**

- Measurement data
- EUflame
  - 2D temperature distribution
  - Flame ball balancing
  - Particle and gas temperature
  - Flame thickness (particle load)

**Control room**

**Set-point adjustment**
Seamless integration of tools

- Control room
- Set-point adjustment
- Closed loop optimisation
- Emissions control
- Combustion optimisation
- Efficiency improvement
Seamless integration of tools

EUtools
- Web-based report system
- Benchmarking
- Archiving
- Data viewer
- ...
Snapshots ...
### Optimisation objectives and parameter settings

#### EUcontrol-boiler Parameter

**NOx Optimisation**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Minimum</th>
<th>Ziel</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOx</td>
<td>80</td>
<td>180</td>
<td>195</td>
</tr>
<tr>
<td>Zeitdauer für NOx-Betrachtung [min]</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Breite NOx Band 1 [mg/m³]</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Breite NOx Band 2 [mg/m³]</td>
<td>9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**CO Optimisation**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Minimum</th>
<th>Ziel</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO Max</td>
<td>170</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zeitdauer für CO-Betrachtung [min]</td>
<td>5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**O2 Optimisation**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Minimum</th>
<th>Ziel</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>O2</td>
<td>30</td>
<td>32</td>
<td>60</td>
</tr>
<tr>
<td>Zeitdauer für O2-Betrachtung [Vol.%]</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Breite O2 Band [Vol.%]</td>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**EUcontrol Boiler – Snapshots**
Defining damper and set-point constraints
Constraint definitions – pulveriser settings
Concept of combustion optimisation....
Optimising Combustion

- Combustion takes place at locally distributed microscopic scales
- Manipulated variables only adjust macroscopic parameters (e.g. overall excess air, mean temperature)
- Identify and utilise the intricate interplay of combustion parameters

Air/fuel ratio ($\lambda$) - range at optimised combustion settings
Air/fuel ratio ($\lambda$) - range at regular combustion settings

Find the optimal trade-off for adjusting combustion parameters
Controlling NO$_x$, CO and fouling simultaneously

**Strategy**

- Possibility to reduce NO$_x$ but often with a negative impact on CO, carbon-in ash (CIA) or fouling – multiobjective optimisation

- Countless possible settings of mill combinations, fuel distribution, O$_2$ levels and damper settings – each with different NO$_x$, CO and fouling gradient

- Main objective is to identify the unit specific outcomes for different settings and advise on the optimal, overall set-up

- No major modification of plant DCS as only (independent) setpoints are adjusted

- Open loop operation provides advice for operation strategy, in closed loop biases are directly controlled

- Individual adaptation to a wide range of objective functions, plant types and constraints
Case study I: Avoiding slagging and increasing efficiency ...
Avoiding slagging and increasing efficiency

- Investigations show that an increase of surplus O2 at burner level reduces slagging
- Low temperatures at the end of the combustion chamber avoid melting of ash and glassification
- The homogenisation of combustion conditions (air-fuel ratio) at burner level improves burn-out and reduces slag formation
- Reducing excess O2 while simultaneously reducing CO improves efficiency

Simultaneous optimisation of a multitude of combustion objectives (NOx, TBK, CO, O2) -> multi-criterial optimisation!
Optimising combustion

**Air fuel balancing at individual burners**

- The combustion is homogenised in the “horizontal” burner plane for every time step
- Primary air damper influences the mill temperatures and the air pressure drop
- Coal feeder RPM has an effect on mill temperatures, too
- Intelligent control required

**Air-fuel ratio without EUcontrol-boiler**

Large variation between burners

**Air-fuel ratio with EUcontrol-boiler**

Narrow air-fuel variation
The mill temperature is controlled through primary air settings, coal feeder and mill speed. In this case it should be between 120°C - 200°C.

Primary air affects the air-fuel ratio and the pressure distribution in the boiler.

The speed of the coal feeder affects the air-fuel ratio.
Combustion and burn-out are improved by opening primary and secondary dampers.

As more oxygen enters at the burner level NOX is increased to an adaptive set-point well below the emission allowance (200 mg/m³) → NOx level becomes an indicator for good burn-out.

Simultaneously the excess air was reduced!
Many operational constraints must be considered while optimising combustion.

The air pressure drop is influenced by damper interaction: primary, secondary and over-fire air and ID fan setting.

The pressure limits can be parameterised.
Optimising Combustion

**Result**

- Slagging and fouling of boiler walls significantly reduced
- Forced outages due to excessive on-load cleaning are at a minimum
- CO emissions reduced indicating improved burn-out
- NOx level reliably below allowance level
- Mills operated close to optimal conditions
- Balanced temperature profile reducing material stress
- Reduced level of excess O2 improves efficiency
- Operator can select combustion strategy according to situation
Case study II: Minimising furnace temperature imbalances
Situation/Problem

Minimising furnace temperature imbalances

- Asymmetric mill or burner arrangement, unequal burner loads or damper settings may bias temperature profile at furnace exit
- Non-centred flame ball leads to material stress and can cause slagging problem
- Asymmetric temperature profile at furnace exit leads to steam temperature differences in boiler sections that have to be compensated by spray water
- Spray water reduces boiler thermodynamic efficiency

Definition of task

- Reduction of the temperature difference of four given temperature measurements (4 "AGAM zones ") in a large scale utility boiler (> 900 Mwel)
- Additional optimisation tasks (partly correlated):
  - CO (minimise)
  - Average O2-level at at the end of boiler (minimise)
  - O2- deviation at the end of boiler (minimise)
  - Overall boiler efficiency (maximise)
Solution – Measuring temperature distribution

**EUflame-2D**

- Direct measurement of furnace exit gas temperature (FEGT) distribution
- Flame characterisation via mean value and standard deviation (max/min) of temperature and flame ball position (centre of flame)
Minimising temperature variation

**Primary optimisation goal**

Minimisation of FEGT temperature variation ("Agam" zones)

Relative temperatures

\[ T_{\text{AGAM \ rel},i} = T_{\text{AGAM},i} - T_{\text{AGAM}} \]

Temperature "quality"

\[ T_{\text{AGAM \ qual}} = \sum |T_{\text{AGAM \ rel},i}| \]
System identification – direct parameters

Model of temperature variation

- **Input data:** Relative inputs
- **Output data:** Relative temp.
- **Properties:** Prognosis model of all available data sets
- **Conclusion:** Good model quality. Model can be directly use for optimisation.
- **Quality:** 92 %

![Graphs showing temperature variation over time](image)

- Original temperature
- Temperature during model generation
- Temperature during model validation
Optimisation - results

Result of optimised settings (optimisation goal)

- Temperature quality = \( \Sigma |T_{AGAM \text{ rel},i}| \)
- Significant improvement of temperature quality through optimisation
Summary....
Benefits and deliverables

Benefits ...

- EUcontrol-boiler is an optimal cost-value ratio option for producing sustained boiler operation under desired conditions (low NOx, reduced slagging, high efficiency)
- No modification of plant DCS system required
- Highly adaptive, automatically adjusting to changing situations
- Multivariate target optimisation (low NOx AND low fouling AND high efficiency)
- Customisable to individual plant requirements

... leading to a new value proposition

- Consideration of different operational objectives (technical, commercial, environmental)
- Offering an attractive means to upgrade older boilers at low cost
- Straightforward implementation at lowest risk (model based)