Unburned Carbon In Flyash Measurement
System Application for Boiler Optimization

- Steam generator
- Burners
- Secondary air
- Air preheater
- Primary air
- MECONTROL
- Electrostatic precipitator
- Flue gas
- Coal bunker
- Pulverized fuel
- Coal mill
- FD Fans
- MECONTROL
- UBC
- Combustion Air
- Fly ash Silo
- Fly ash
 Targets in Boiler Optimization

- Efficiency
  Optimization of coal flow distribution, excess air and unburned carbon,
  Reduction of flue gas losses and ignition losses----

- O2 Distribution
  Equalization of the both O2 levels at the flue gas duct

- Unburned Carbon (UBC) Reduction
  Increase combustion efficiency, maximize fly ash quality

- NOx
  Reduction of NOx emission / ammonia use in DeNOx system (SCR)

- CO
  Prevention of boiler wall corrosion/slagging
Unburnt carbon in fly ash

- Main indicator for combustion quality
- Determination of further fly ash usage
# Fly ash can cost or bring benefits

Table 1-2
Annual Costs of Fly Ash Disposal Less Fly Ash Sales

<table>
<thead>
<tr>
<th>Unit Capacity</th>
<th>Percent Fly Ash Disposal / Percent Fly Ash Sales</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0/100</td>
</tr>
<tr>
<td>200</td>
<td>-99,000</td>
</tr>
<tr>
<td>400</td>
<td>-198,000</td>
</tr>
<tr>
<td>600</td>
<td>-298,000</td>
</tr>
<tr>
<td>800</td>
<td>-397,000</td>
</tr>
<tr>
<td>1,000</td>
<td>-496,000</td>
</tr>
</tbody>
</table>

**ASSUMPTIONS:**
- 65% Capacity Factor
- 10% of the coal is fly ash
- $2 per ton sales price for fly ash
- $4 per ton disposal cost for fly ash
- 23 MBtu per ton coal
Internal Quality Assessment
Europe: According to EN-450 (DIN 18 990)
- Internal QA and coordination with customer

- Quality has to be traceable at any stage of the fly ash production. Sampling > 2 /day

- Clearance of "ready to ship" ash according to DIN EN 450
- 3 Qualities
  - Category A < 5%
  - Category B > 2 % and < 7 %
  - Category C > 4% and < 9%
- Sampling locations to be coordinated with the external auditor (LOI, Particle Size, CaO)
Internal Quality Assessment
North America: ASTM C 618
- Internal QA and coordination with customer

- Quality has to be traceable at any stage of the fly ash production. Sampling > 2 /day

- Clearance of "ready to ship" ash according to DIN EN 450

- Qualities
  - Category C < 6%

- Sampling locations to be coordinated with the external auditor (LOI, Particle Size, CaO)
Internal Quality control according to DIN 18 990

- Online-C-Measurement
- wet chemistry
  (Calibration of Online measurement and accuracy check)
- LOI
- Particle Size
- Free Lime
- Chlorine; Sulfur Trioxide

Frequent Checking: Internal QA (this internal QA needs to be trackable. It does not need to comply with formal procedures of EN 450)

Less frequent Checking: Internal Self Auditing
(Self Auditing: has to comply with formal procedure of - DIN EN 450)
Proof of compliance

Internal QA Auditor

Internal Quality Control
Power station

Process control

Measurement and accuracy check

Checking of fly ash quality

Take action in case of deviations

Storage, Bulk handling

Checking of equipment accuracy

Supervision of compliance status

External Auditor

Internal Quality assessment
Producer

Sampling and QA procedures

Corrective Action

Assessment of QA supervision tools

QA Historical Data

Source: Draft VGB-AK Werksqualitätshandbuch DIN 18990
Internal QA of Fly Ash

Unburned Carbon / LOI

UBC (TOC) [wt%]

LOI [wt-%]

Analytik und Betriebsüberwachung ANA
Classification of Loss On Ignition measurement

- **LOI Measurement**
  - On-Line Carbon-in-Ash Monitors
    - Extractive
      - Isokinetic
      - Non-Isokinetic
    - Non-Extractive
  - Manual Sampling
    - Gas Stream
    - Hoppers

Sampling/ Instrumentation  Laboratory
Classification of Loss On Ignition measurement

- On-Line Carbon-in-Ash Monitors
- Extractive
  - Isokinetic
  - Non-Isokinetic
- Non-Extractive

Sampling required

In-situ = no sampling
Optimization Principle

Correlation between UBC, flue gas and excess air as a function of the losses
# MECONTROL Boiler Optimization

## Focus/Conditions

<table>
<thead>
<tr>
<th>Focus/Conditions</th>
<th>Flue gas losses</th>
<th>Optimization Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Excess Air and Low UBC</td>
<td>Reduction of the excess air (OFA or burner air, SA)</td>
<td>Base line testing and optimization</td>
</tr>
<tr>
<td>Low Excess Air and High UBC</td>
<td>Operating feedback on effectiveness of air registers</td>
<td>Base line testing and optimization</td>
</tr>
<tr>
<td>High Excess Air and High UBC</td>
<td>Feedback on effectiveness of mills and classifier settings and PA velocities</td>
<td>Base line testing and optimization</td>
</tr>
</tbody>
</table>

## Optimization

- Optimization using DCS & Optimizers
- Advice on control scheme modification
How to measure?
Methods to estimate unburnt carbon in fly ash

Loss on ignition (LOI)

- **Laboratory**
  - Simple to conduct at laboratory without special analyzers. (Only furnace and scale required)
  - Most common laboratory analysis method for UBC estimation in power plants
  - Readings differ approximately 0,3 % to 1% wt UBC due to other reactands

- **Process**
  - Complicated to apply for online measurement (Sample extraction, piping, clogging problems)
  - Other reductants than carbon e.g. sulphur influence result
Methods to estimate unburnt carbon in fly ash

TOC

- **Laboratory:**
  - Sample is evacuated and then incinerated with pure oxygen
  - CO$_2$ concentration is measured by NDIR gas analyzer
  - → very accurate (typically better than 0.1% wt UBC)
  - Expensive laboratory analyzer

- **Process:**
  - Complicated to apply for online measurement (Sample extraction, piping, clogging problems)
  - Maintenance & Cost intense
  - Limited reliability
  - Consumables, disposals
Methods to estimate unburnt carbon in fly ash

Infra Red reflectance

- **Process:**
  - Sample is taken from process and exposed to infra red light
  - The reflectance is a measure for the unburnt carbon content
  - Complicated to apply for online measurement (Sample extraction, piping, clogging problems)
  - Dirt sensitive
  - Strong influence by particle size, raw coal type and other elements contained in the coal (Fe etc)
Principle: Light Reflection

- Reflection only in surface zone
- Ash color (Fe2O3) has influence
- Smaller carbon particles overrepresented!
- Change in particle size spectrum between carbon and ash brings change in light reflection

Typical size: 100µm
The UBC particles are larger than the average of the ash particles.
same ash, same UBC content, different particle size

- grinding ash especially makes carbon particles smaller
- so the black particles get a larger surface
- so the ash turns darker, even with the same UBC content
Extractive Microwave System
Extractive Microwave System

Microwave resonance/ Microwave absorption

- Laboratory
  - Microwave resonant frequency/ Microwave absorption depending on unburnt carbons

- Process (extractive methods)
  - Complicated to apply for online measurement (Sample extraction, piping, clogging problems)
  - Undefined bulk density
  - Maintenance & Cost intense
In-Situ Microwave Resonance solution
Methods to estimate unburnt carbon in fly ash

MECON TROL UBC

- In-Situ Microwave Resonance
  - Internationally patented In situ measurement
  - Fast accurate and reliable
  - Virtually no maintenance required
  - Fully self contained unit
Dielectric constant of fly ash is a function of the carbon content. Measuring the shift of frequency in a resonator ($\Delta f$) the carbon content can be calculated.

\[ UBC = A + B \cdot \Delta f \]

A and B are the calibration coefficients
Principle: Microwave Resonance

- no light quanta but classical microwaves
- penetration through all material and inside the particles
- no impact of ash colour
- no impact of particle size

Frequency $f_0$, wavelength $\lambda_1$

- low UBC

Frequency $f_0$, wavelength $\lambda_2$

- high UBC
Oscillating circuit

Relation: \( f_{\text{res}} \approx \frac{1}{\sqrt{\varepsilon \cdot C}} \)

- Resonance frequency depends on capacity \( C \) and dielectricity \( \varepsilon \)

- Air: \( \varepsilon = 1 \),
  Ash with no carbon: e.g. \( \varepsilon = 2.25 \)
Sample will be compressed by a defined force in measurement chamber
- Large sample volume (500 ml)
- Simple mechanical design
- International patents
Main Panel

- Touch Panel controlled
- Protection up to IP66
- Can handle up to 4 independent UBC sensors
- 4-20mA I/Os to DCS
- Profibus/Modbus/Ethernet capability
- Remote maintenance access
MECONTROL UBC System - Design

Measurement Cabinet

Local control box

Sensor(s)

Up to 8 Sensors
Local control box

1: Power indicator
2: Error indicator
3: Release signal indicator
4: Filling indicator and button
5: Emptying indicator and button
6: Sampling indicator and button
7: Automatic/manual mode switch
8: Automatic mode indicator
9: Main switch
MECON TROL UBC In field applications

Measurement point with UBC Sensor type 300

Measurement point situated over a vessel
MECONTROL UBC Design UBC Sensor Type 300

Sensor Flange Mounting

Measurement Chamber

Ash Auger
SCADA Screen for sampling location
System Data Flow: Single Cabinet

Knepper
MST-05

FP10SH5
IP: ___________
COM: ___

TCP/IP

RS232

CH00
Becherwerk

CH01
Ferti-Verladung
Multiple Cabinets
Recommended measurement locations

A

- 90% separation
- 90% separation
- 90% separation
- 90% separation
- 90% separation
- 90% of the total fly ash

B

- 0.09%
- 0.9%
- 9.0%
- 90% of the total fly ash

Digital Input Signals
Release signals per channel (if necessary)

Measurement Cabinet
4 Sensors

Control Room

Microwave Receiver
PLC Unit
Power Supply
Signal Converter
Touch Screen Operator Interface
Fault Messages

4-20 mA Signals (UBC)
Measurement Location

Not representative 〇  Representative

Air Preheater

Flue gas sampler

Spot sampling

Weak Correlation to Silos

Strong Correlation to Silos

90%  9%  0.9%

100%

Silos

Flue gas

Fly ash

MECON TROL UBC
Sampling of the Ash Flow

Ash and gas not homogenized

Ash discharged in dense quantities

Cross sectional coverage: 0.000005%

Fly ash concentration: 5g/m³

Cross sectional coverage: 2-8%

Fly ash concentration: 200,000 g/m³
Measurement Response Time

- ash travel time from burner to DUCT sampler: 3 secs
- ash collection time: 5 minutes

An adequate response time in the flue gas duct is only achievable by a very small sample size.

Fly Ash Collection Rate

<table>
<thead>
<tr>
<th>Flue Gas Duct</th>
<th>ESP Hopper</th>
</tr>
</thead>
<tbody>
<tr>
<td>1g/minute</td>
<td>100 g/minute</td>
</tr>
</tbody>
</table>

Sampling can achieve both:
- Large, representative sample size
- fast response measurement
Sample Size

5 g out of flue gas duct

500 g out of precipitator
Extractive Measurement

In-Situ Measurement

Flue gas duct

Ambient Temperature

160°C

cyclone separation classification?

Transport through heated pipes

MW measurement of Air/Ash mixture

Static weighing of 5g sample

Measurement Panel

Sampling and measurement in the hopper:

- no Extraction,
- no cyclone separation
- no static weighing
- no heating elements

ESP Hopper

60°C

Fly Ash to the Silo
Mechanical: Less moving parts are better

Mechanical sampling system

All-in-one sensor

- non extractive sampling!
- no pneumatic transport
- 1 moving part
- simple/robust design
- no weighing
Unequal particle size distribution

- Bigger particles drop faster than small particles
  - Unqual particle size distribution in horizontal conveyor pipes
  - Unequal UBC content depending on particle size
  - Inaccurate measurement since sample is not representative
Measurement Location

Representative ↔ Not representative

Air Preheater

90% 9% 0.9%

Electric precipitator

MECONTROL UBC

Fly ash

Flue gas

Silos

Sampling from conveyor pipe
Conclusion measurement location

- No particle size classification/ fractionating
- Representative averaged sample
- Short response time
Basic

Accuracy comparison with Laboratory TOC Analyzer
Typical Measurement Data

UBC
Promecon

Unit 1 Sensor 1
Unit 1 Sensor 2
Unit 2 Sensor 1
Unit 2 Sensor 2

-0,60%
+0,60%
Measurement Basics / Measurement Analysis

Accuracy of the system

Performance guarantee of 0.6% accuracy based on a single standard deviation

Difference of two measurement values

\[ \Delta_i = R_C(\text{Lab})_i - R_C(\text{PROMECON})_i \]

Gaussian distribution

- 68% of values: \(-\sigma < 0 < +\sigma\)
- 95.5% of values: \(-2\sigma < 0 < +2\sigma\)
Measurement Data of MECONTROL UBC

Wedel
Trial Run at "Reuter West" Plant, dated 2001-11-12

Remark: Listed values of secondary air amount are only for one burner plane.

≈ 1% O₂
MECONTROL UBC Optimization Results

Trial run at "Reuter West" power plant, dated 2001-11-12

- UBC Fly ash (MECONTROL UBC)
- UBC Fly ash (Lab analysis)
- \(O_2\) Boiler / DeNOx outlet

Excess Air Reduction
Power Station Farge, Power Utility E-on

\[\text{NOx [mg/m}^3\text{]}\]

\[\text{O}_2 \ [\text{Vol.-%}]\]

- SA1+CA
- SA2
- TA

\[\text{O}_2 \text{ boiler out} \]
\[\text{NOx before SCR} \]

Stefan Kranz
Page: 56
MECONTROL UBC$^{\rho}$

- Integrated density correction by nucleonic source
- Enhanced online accuracy
- Independent of ash quality variation
- Easy upgrade of existing systems
Sensor arrangement

Quelle (Cs137 185 MBq)

radiometrischer Sensor

4-20 mA

SPS
Nucleonic Source

Don‘t fear about radioactivity:

- Very small source 185 MBq
- Savely sealed, Stainless steel shell, lead & steel protector
- Typically used in Power stations for
  - Density measurement of lime milk (FGD)
  - Level switch for coal bunker exit
  - Belt scale measurements for feeder
Typical accuracy

Accuracy process versus laboratory < 0.2% wt
we focus on your process

Real world examples without $\rho$ correction

<table>
<thead>
<tr>
<th>No.</th>
<th>Labor</th>
<th>UBC</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10,49</td>
<td>7,12</td>
<td>3,37</td>
</tr>
<tr>
<td>2</td>
<td>1,65</td>
<td>2,36</td>
<td>-0,71</td>
</tr>
<tr>
<td>3</td>
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<td>2,53</td>
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<tr>
<td>5</td>
<td>1,35</td>
<td>0,91</td>
<td>0,43</td>
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<tr>
<td>6</td>
<td>4,44</td>
<td>4,37</td>
<td>0,07</td>
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<tr>
<td>7</td>
<td>4,97</td>
<td>4,13</td>
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<td>8</td>
<td>5,00</td>
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<td>9</td>
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<td>11</td>
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<td>3,16</td>
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<td>0,80</td>
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<td>13</td>
<td>3,00</td>
<td>2,10</td>
<td>0,90</td>
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<td>14</td>
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<td>15</td>
<td>2,85</td>
<td>2,31</td>
<td>0,54</td>
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<tr>
<td>16</td>
<td>3,40</td>
<td>4,53</td>
<td>-1,13</td>
</tr>
<tr>
<td>17</td>
<td>3,30</td>
<td>4,50</td>
<td>-1,20</td>
</tr>
<tr>
<td>18</td>
<td>2,70</td>
<td>3,10</td>
<td>-0,40</td>
</tr>
</tbody>
</table>

$\sigma = 1,10\%$
Real world examples with $\rho$ correction

Accuracy process versus laboratory $\sim 0.2\%$
Gain of the effective accuracy

Accuracy Laboratory
0,1%
2 samples/ day

\[ \sigma_{\text{ExpectedMeanValue}} = \frac{0,1\%}{\sqrt{2}} = 0,07\% \]

Accuracy MECONTROL UBC
0,6%
50 samples/ day
(situation Altbach)

\[ \sigma_{\text{ExpectedMeanValue}} = \frac{0,6\%}{\sqrt{50}} = 0,08\% \]

\[ \sigma_{\text{ExpectedMeanValue}} = \frac{\sigma_{\text{System}}}{\sqrt{n}} \]

→ Gain of effective accuracy due to frequent measurements
Comparison Laboratory vs. Online

Altbach HKW2

UBC (%)

Channel 1

Lab
Conclusions

- On-line in situ measurement of UBC
- Fully self contained unit, no extractive sampling, simple mechanical design
- High accuracy and absolute measurement of UBC
- Virtually no maintenance, low LTCO
- Independent of ash density
- Large international installed basis > 200 Sensors at > 100 boilers

MECON\textsuperscript{CONTROL} UBC\textsuperscript{ρ}

- Enhanced accuracy version 0.2% online vs. lab
- Easy upgrade of existing installations
Benefits to the Power Plant

- Accurate measurement of the key combustion parameter
- Optimization of mill & boiler performance
- Improvement of NOx, CO, O2 and UBC
- High cost savings by reduction of primary losses
- Cost efficient fly ash disposal
- Recommendations by Babcock Borsig Power (BBP) and current utility users
Benefits with PROMECON systems

PROMECON is the world leader with MECONTROL UBC installations in more than 90 Power Plants worldwide. At several international utilities PROMECON has achieved improvements of several $100,000 US per year by its systems.

Recent investigation at reference Power Stations

Optimization of the boiler efficiency: 0.4 – 1.0 %
Reduction of the unburned carbon: 10 - 30 %
Reduction of CO: 50 - 80 %
Saving coal consumption: $300,000 /y
PROMECON estimates $150,000 – $500,000 US with NOx optimization and boiler wear reduction.
Thank you very much!
we focus on your process