

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

Power-Gen Europe 2010

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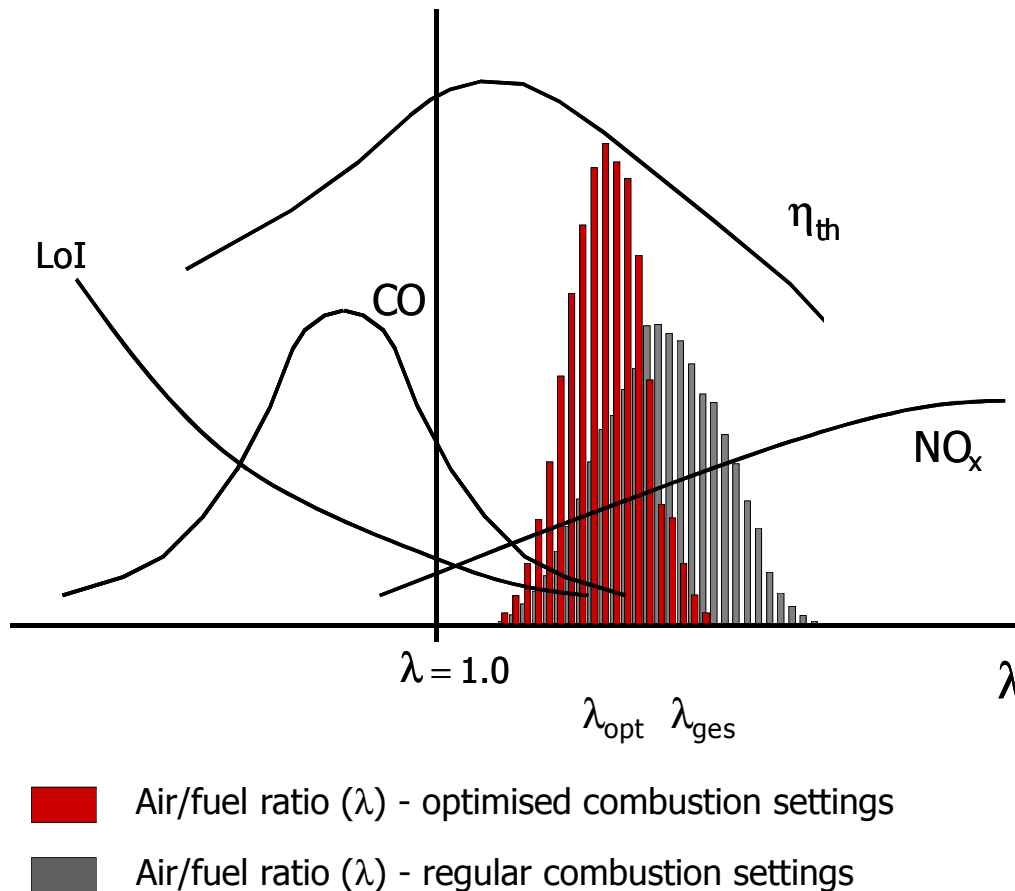
- Introduction
- Measuring – Controlling - Optimising
- Results
- Summary

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

Air/fuel ratio and performance



Strategy

- 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

Why is coal and air flow control so important?

Controllable O&M variable	$\Delta\eta_{th}$
Coal fineness	0.1 - 0.3%
Primary air-flow	0.1 - 0.2%
Fuel line balance	0.1 - 0.3%
Particulate-air ratio	0.1 - 0.3%
Carbon-in-ash (LoI)	0.1 - 0.3%
Excess oxygen	0.1 - 0.3%
Total*	0.6 – 1.7%

*** 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
O ₂ excess	4.0 %
LoI _{ref}	2.9 %
T _{BoilerExit, ref}	199 °C
η _{Boiler, ref}	86.66 %

Optimisation	
Coal flow	655 - 657 t/h
O ₂ excess	3.2 %
LoI _{opt}	1.8 %
T _{BoilerExit, opt}	191 °C
η _{Boiler, opt}	87.10 %

Boiler Efficiency Calculation via ASME PTC 4.1 Method			
Data Input Sheet			
Test Description:			
Fuel Data:			
Carbon	C	61.80	(%)
Hydrogen	H ₂	4.30	(%)
Sulfur	S	3.80	(%)
Oxygen	O ₂	7.90	(%)
Nitrogen	N ₂	1.20	(%)
Moisture	H ₂ O	12.00	(%)
Ash		9.00	(%)
Other		0.00	(%)
Total:		100.00	(%)
HHV		11,265	(Btu/lb)
Ash Data:			
Ash Location		Ash Split (%)	LOI (%)
Bottom Ash		80	3.00
Economizer Ash		5	5.00
Precipitator or Baghouse Ash		15	5.00
Total Ash		100	
Economizer Exit Gas Data:			
Excess O ₂ (% by Vol) OR Excess Air (% by Weight)		3.00	
Carbon Monoxide		0	(ppm)
O ₂ Measurement Basis: 1 = Wet, 0 = Dry		0	
Air Heater Exit Gas Data:			
Excess O ₂ (% by Vol)		4.00	
O ₂ Measurement Basis: 1 = Wet, 0 = Dry		0	
Air, Gas & Fuel Temperatures:			
Calculation Reference Temp		80	(°F)
FD Fan Inlet Air Temp		80	(°F)
Boiler Gas Exit Temp Corrected (Measured)		510	(°F)
Fuel Temperature (Default = T _{ref})		80	(°F)
To correct the efficiency for "Unconnected AH Gas Outlet Temperature", enter "1" at right. If not, leave blank.			
Boiler Efficiency Losses, Manual Input:			
Radiation and convection (Default = 17)		0.17	(%)
Unaccounted for Losses (Default = 50)		0.50	(%)
Manufacturers margin (Default = 1.00)		1.00	(%)

Table 13A Combustion Calculations - Btu Method									
TONS - BY TEST OR		FUEL DATA - Coal		Theor. Air, Btu/100b		17 H ₂ O, Btu/100 b fuel			
N									
coarsest, % by weight	16.26	15 Ultimate Analysis		16		17			
ash, %	80	constituent	% by wt.	K1	[1.5] x K1	K2	[1.5] x K2		
moisture, %	80	A C		61.80	11.51	71.19			
dry	80	B S		4.30	4.31	16.38			
avg AH (including leakage), °F	510	C H ₂		34.28	147.42	8.94	38.43		
avg AH (excluding leakage), °F	534	D H ₂ O		12.00		1.00	12.00		
dry air	0.0135	E H ₂		1.20					
air Btu/100 b fuel	0.0000	F O ₂		7.90	-34.13				
		G Ash		9.00					
		H Total		100.00		840.86			
		I Higher heating value (HHV), Btu/lb fuel					11200		
		J Unburned carbon loss, % fuel input					0.41		
		K Theoretical air, Btu/10,000 Btu			[1.68] x 100 / [15]		7.51		
		L Unburned carbon, % of fuel			[1.9] x [15] / 14,500		0.32		
5 CALCULATIONS, Quantity / 10,000 Btu Fuel Input									
corrected, Btu/10,000 Btu	[26] - [21] x [15] / [15]						7.48		
in fuel, Btu/10,000 Btu	[1.50] + [21] x 100 / [15]						0.08		
A [At Burners] B [Leakage] C [Leaving Furnace] D [Leaving Air Heater]									
weight				16.2642/1007926436	6.701	16.26	22.97		
1 Btu	[1 + [25] / 100] x [23]					8.69			
0.000 Btu	[26] x [2]				0.12	0.12	0.12		
un, Btu/10,000 Btu	[30] x 100 / [15]				0.00	0.00	0.00		
0.000 Btu	[1.78] x 100 / [15]				0.45		0.45		
1 Btu/10,000 Btu	[100 - [1.50] - [21] x 100 / [15]					0.81			
10,000 Btu	Summation [26] through [30]					9.62	10.13		
Btu/10,000 Btu	Summation [27] + [28] + [29]				0.57	0.57	0.57		
2 Btu	[33] - [34]					9.05			
weight	[100] x [34] / [33]					5.90	5.67		
right	100 x [24] / [33]					0.86	0.82		
ULATIONS, % Input from Fuel									
Losses									
38 Dry Gas, %	0.0024 x [33] x [3] - [3]						9.86		
39 Water from	Enthalpy of steam at 1 psi, T = [6]						1,295.27		
40 Fuel,	Enthalpy of water at T = [3]						48.00		
41 as-fired %	[29] x [39] - [40] / 100						5.61		
42 Moisture in air, %	0.0045 x [27] x [3] - [3]						0.24		
43 Unburned carbon, %	[1.9] or [21] x 14,500 / [15]						0.41		
44 Radiation and convection, %	ABMA curve						0.17		
45 Unaccounted for and manufacturers margin, %							1.50		
46							17.78		
47							0.00		
48							0.00		
49							0.00		
50							0.00		
51							0.00		
52							82.22		

Savings	
Δ Coal p.a.	> 23,000 t
Cost per tonne*	26 EUR
Annual savings	~ 600,000 EUR
Δ CO ₂ p.a.	> 27,300 t
CO2 Certificate	20 EUR/t
'Carbon benefit'	~ 550,000 EUR
Total benefit p.a.	1,150,000 EUR

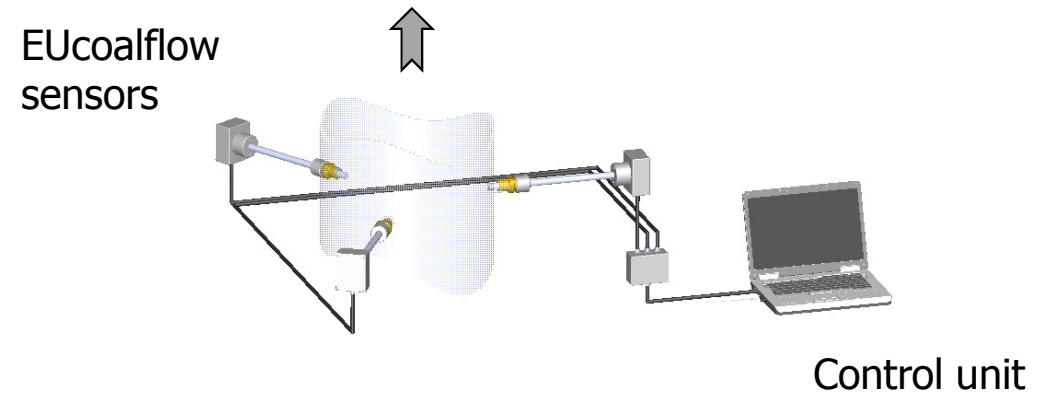
Monitoring – Controlling - Optimizing

Monitoring – Controlling - Optimizing

The Basic Idea

Measure

If you can't measure,
you can't control.



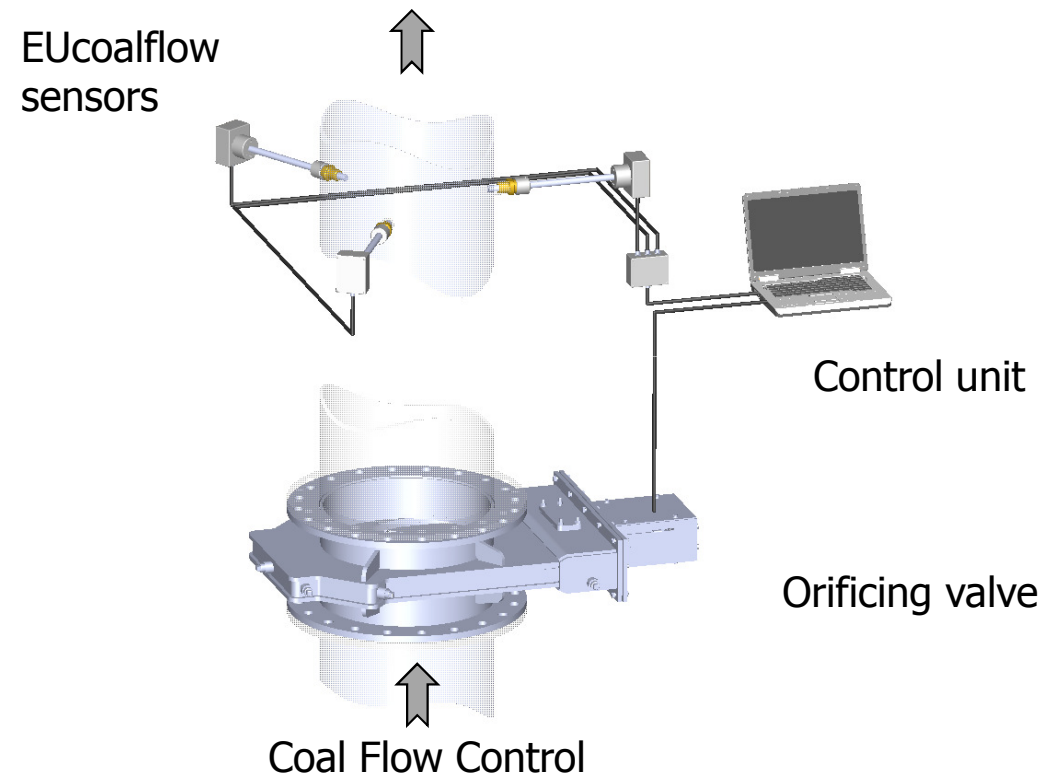
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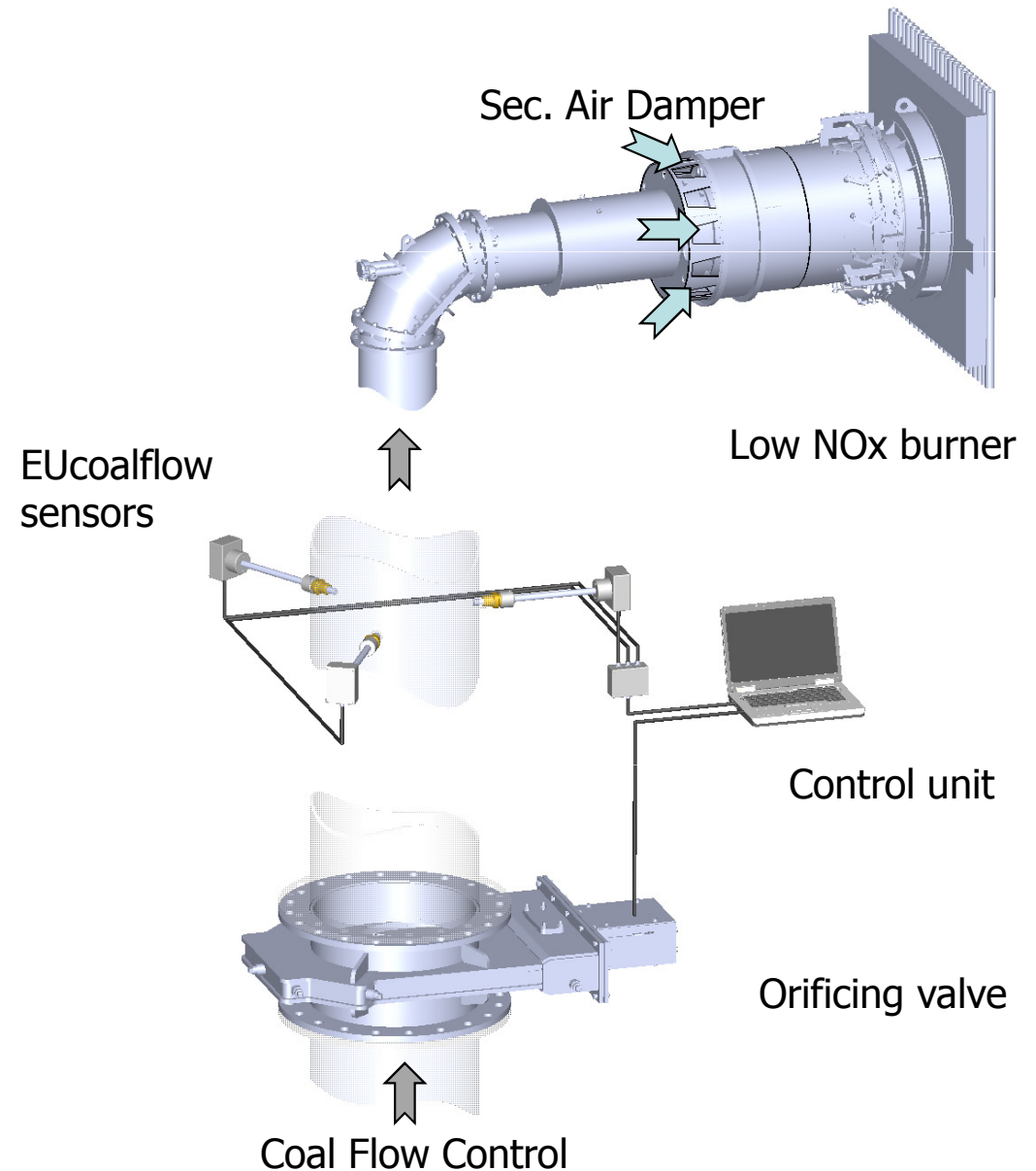
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The Basic Idea

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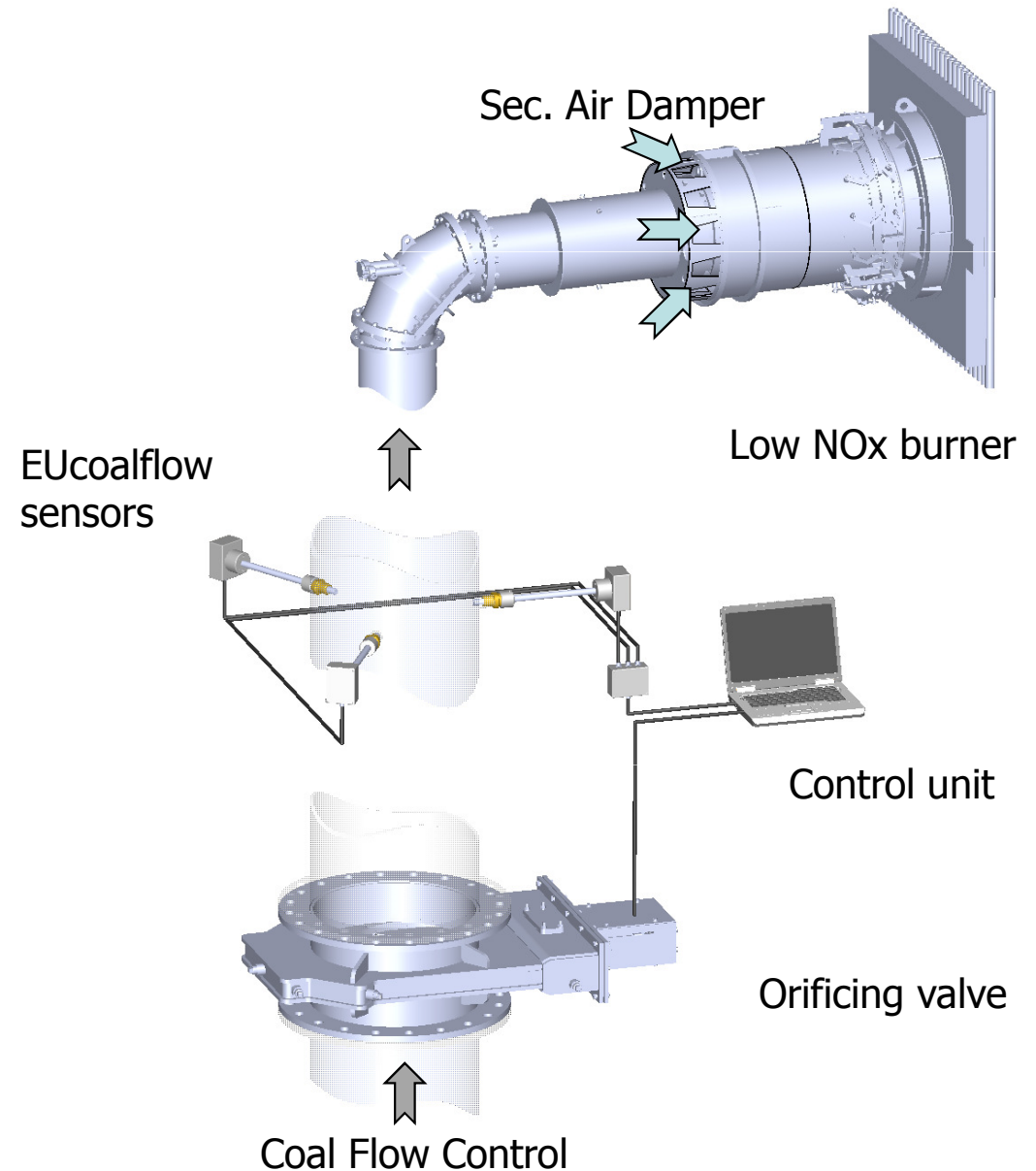
If you can't measure,
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Control

If you can't control,
you can't optimize.

Optimize

If you don't optimize,
you waste money.



System structure

EUcoalflow Sensor

- Coal mass flow
- 2 – 3 Sensors per pipe

Orificing valve

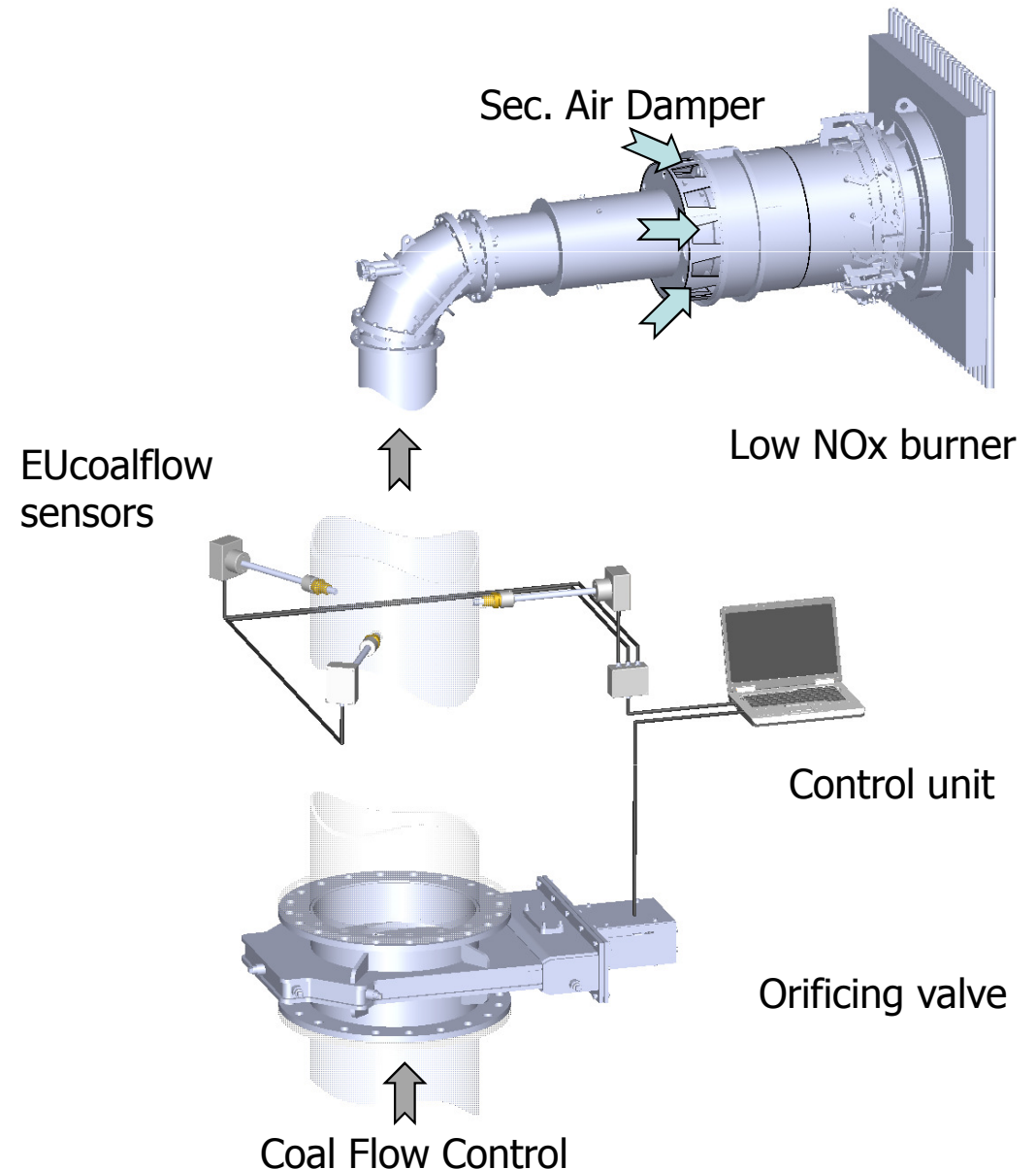
- Basic adjustment
- Pipe-to-pipe balancing
- Manual or motor driven

SA-Damper Control

- Automatic adjustment of SA
- AFR at prescribed level

Optimisation (EUcontrol)

- Optimal air/coal distribution and biasing



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, ...)

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

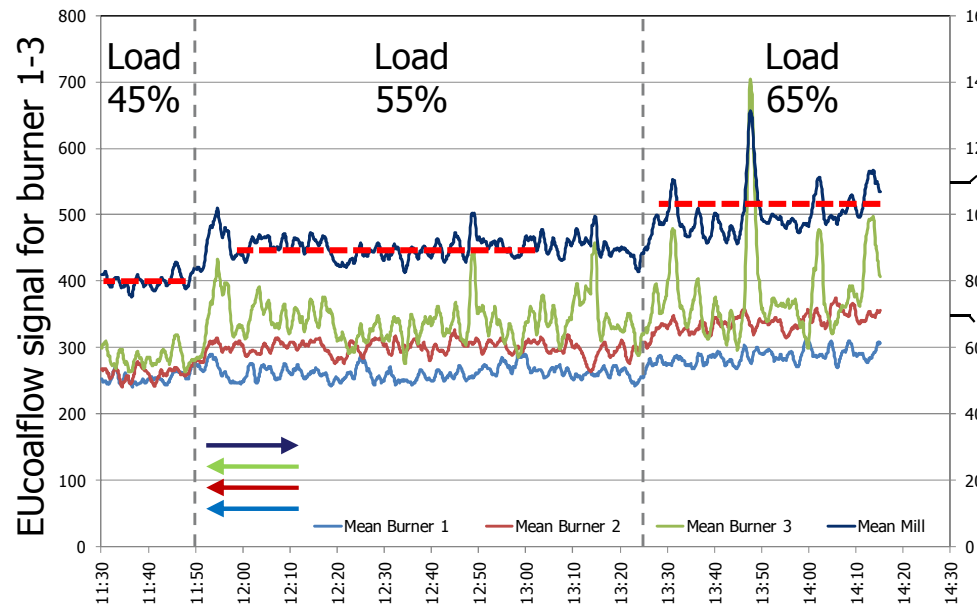


Control unit

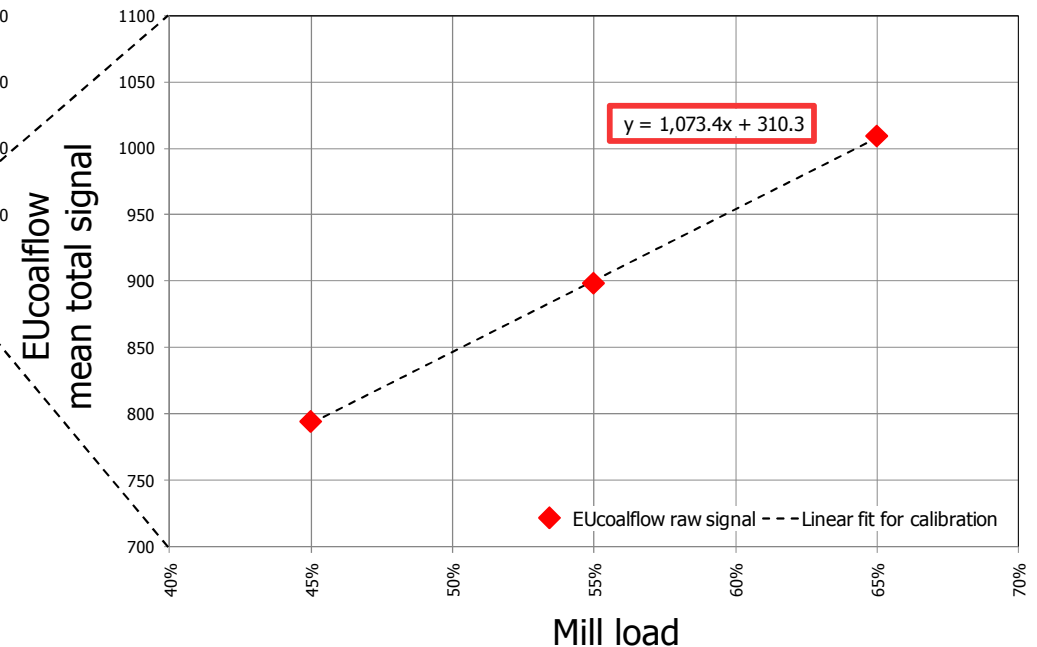
- Online determination of
 - Coal mass flow
 - Gas velocity & volume flow
- Pipe to pipe distribution
- Statistic functions



Application – lignite fired plant



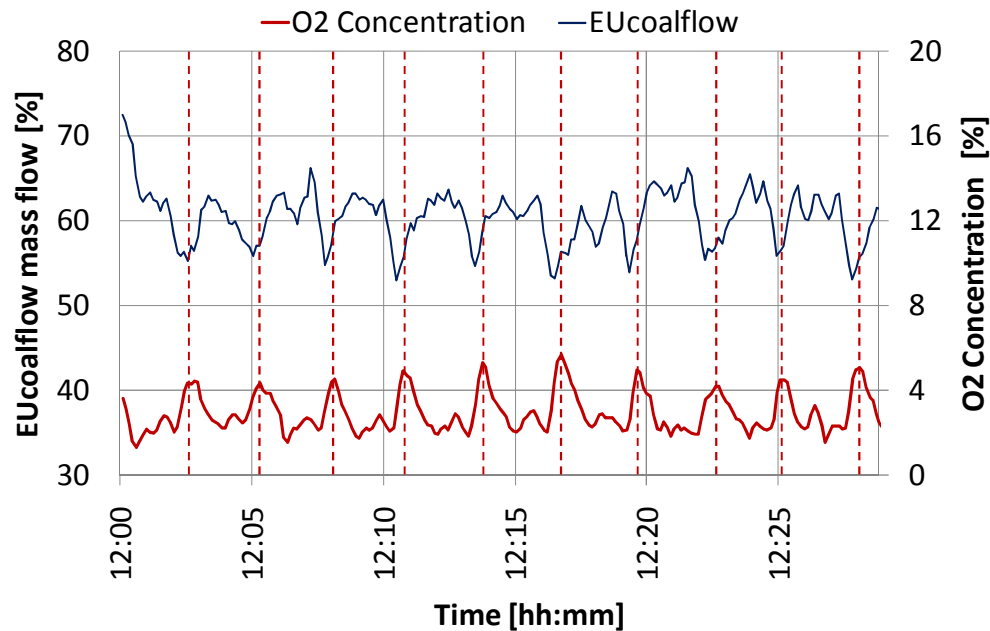
Sensor accuracy



Conclusion

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

Application – dense phase



Signal analysis

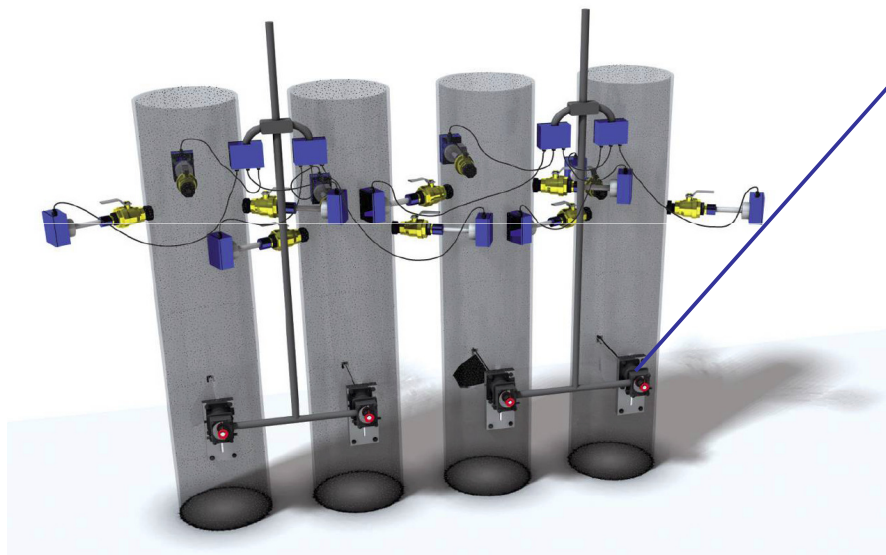
- High fluctuation in the mass flow signal causes
- fluctuating excess oxygen (DCS signal)
- at constant load set point

Conclusion

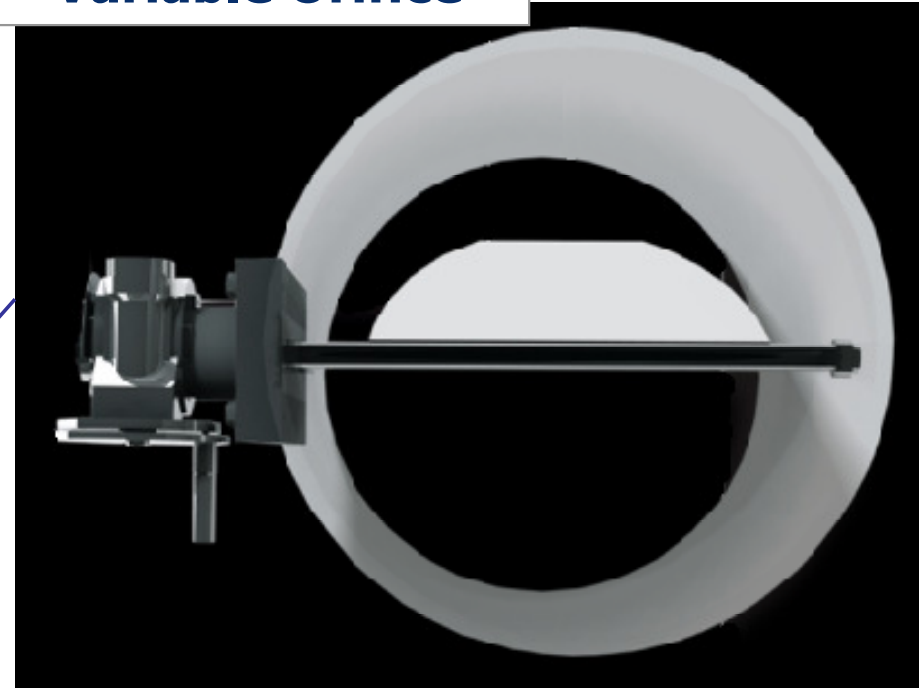
- High correlation of excess oxygen signal with coal mass flow
- Direct visualisation of feeding and milling malfunctions
- Control of secondary air flow

Required Features

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

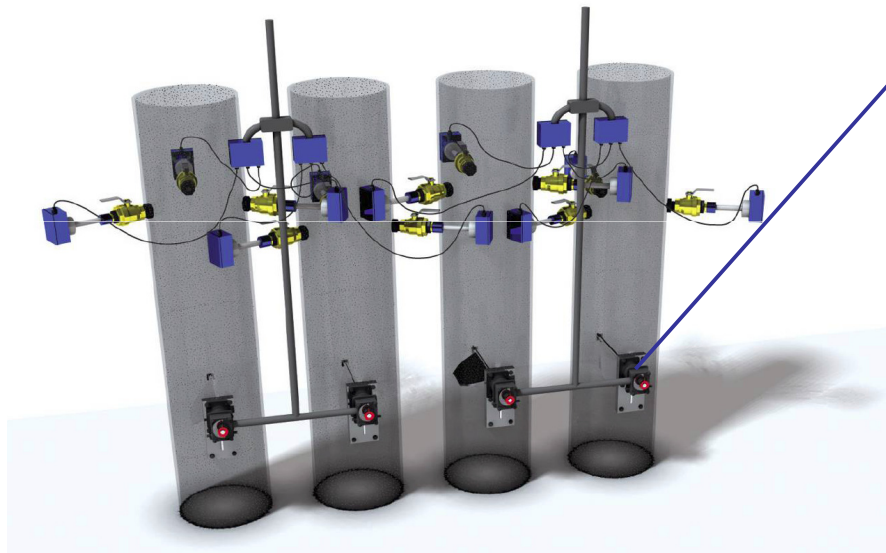


Variable Orifice



Required Features

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Variable Orifice



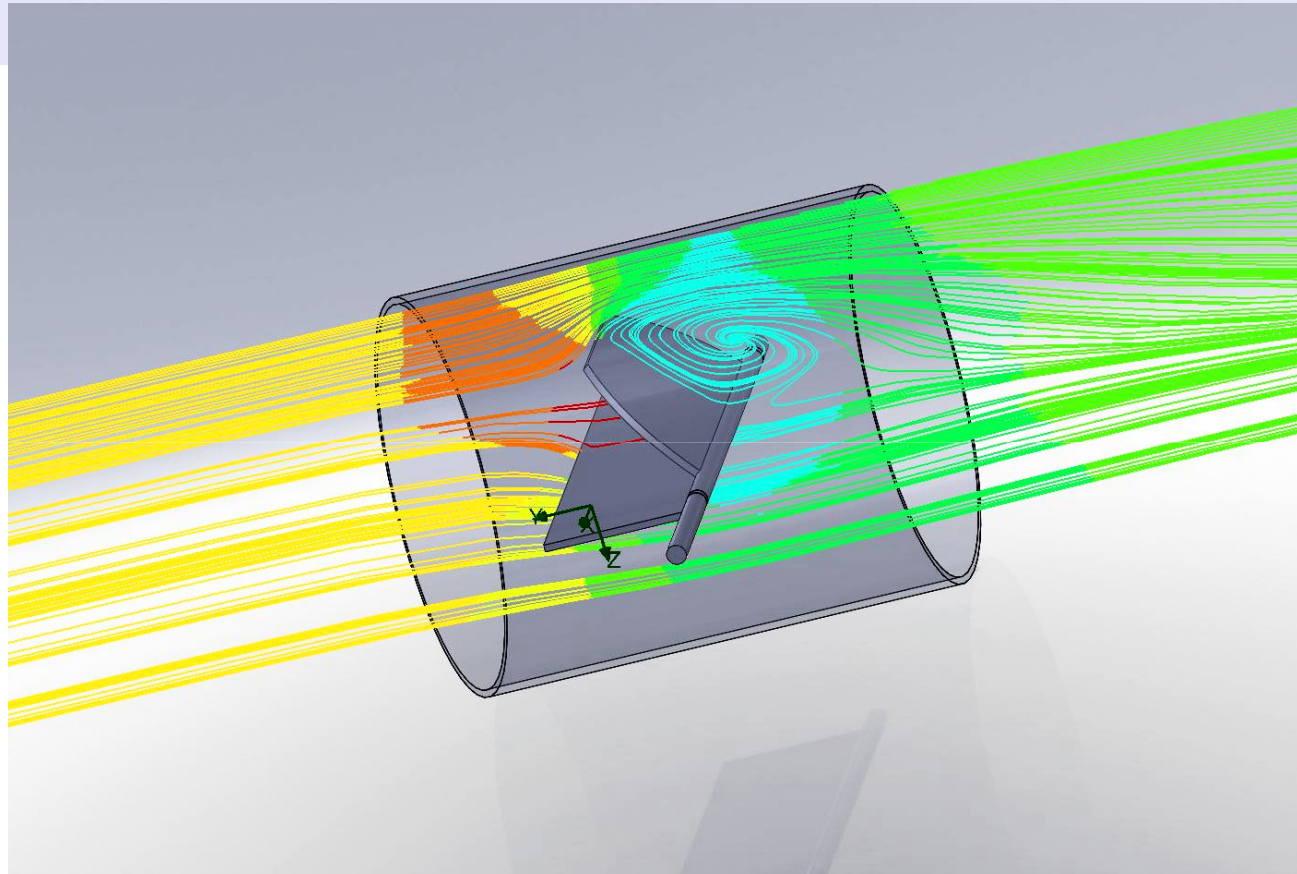
Material and Design

- 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.

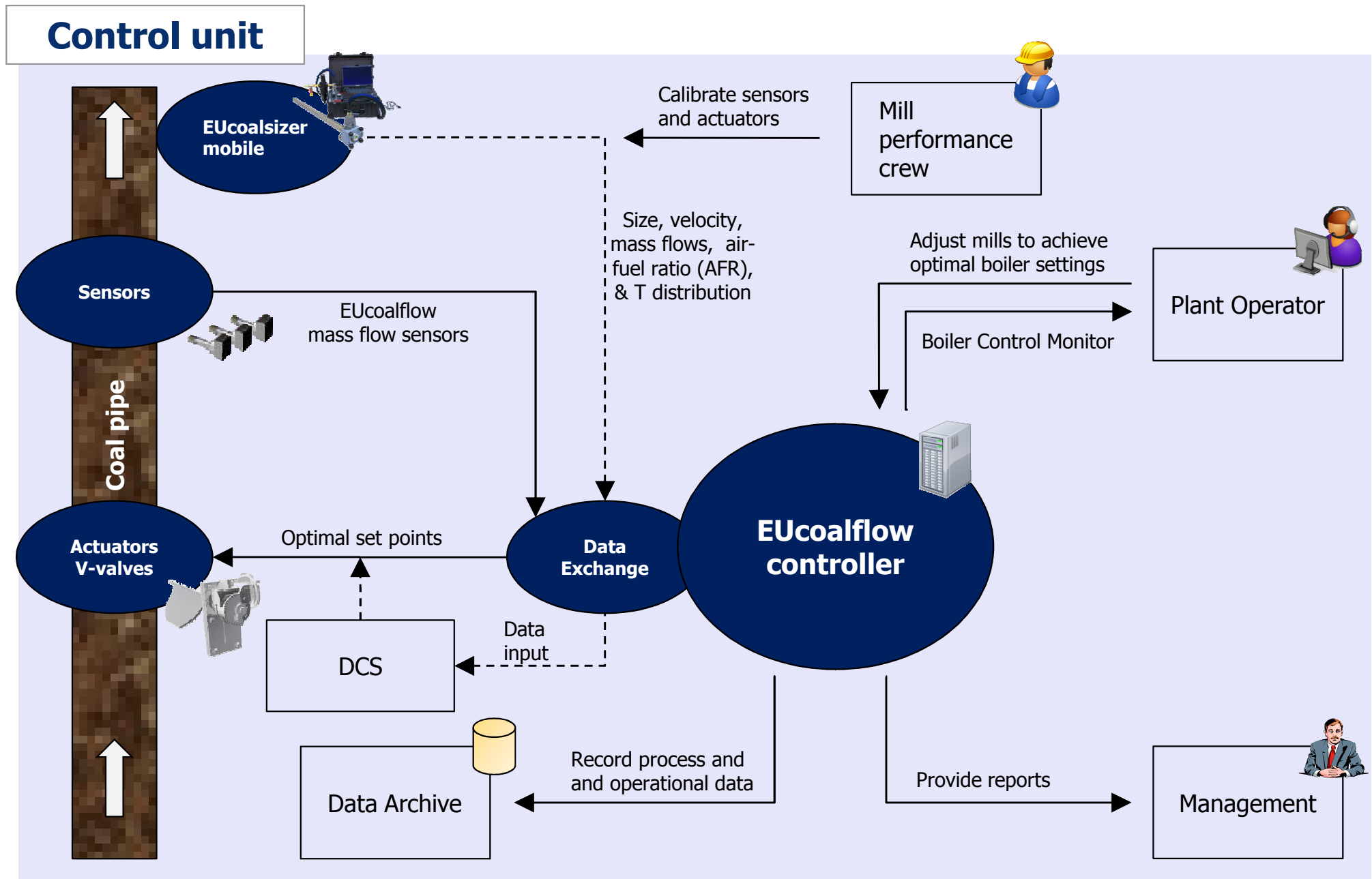


Flow Characteristics

- 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.



EUcoalflow – Closed-loop Control



Steps to success

- Feasibility
 - Site familiarisation and review of existing plant equipment
 - Test with EUcoalfow mobile
 - Identify additional equipment requirements
 - Review of available data and data quality
 - System identification using available data
 - Parametric testing using Design of Experiments
- Control
 - Prediction models for control/optimisation
 - Process/plant model for model-in-the loop testing (hardware-in-the loop)
 - Smart sensing
- Implementation
 - Operate in advisory mode
 - Extend to closed loop

Typical project time is 2 – 3 months

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).

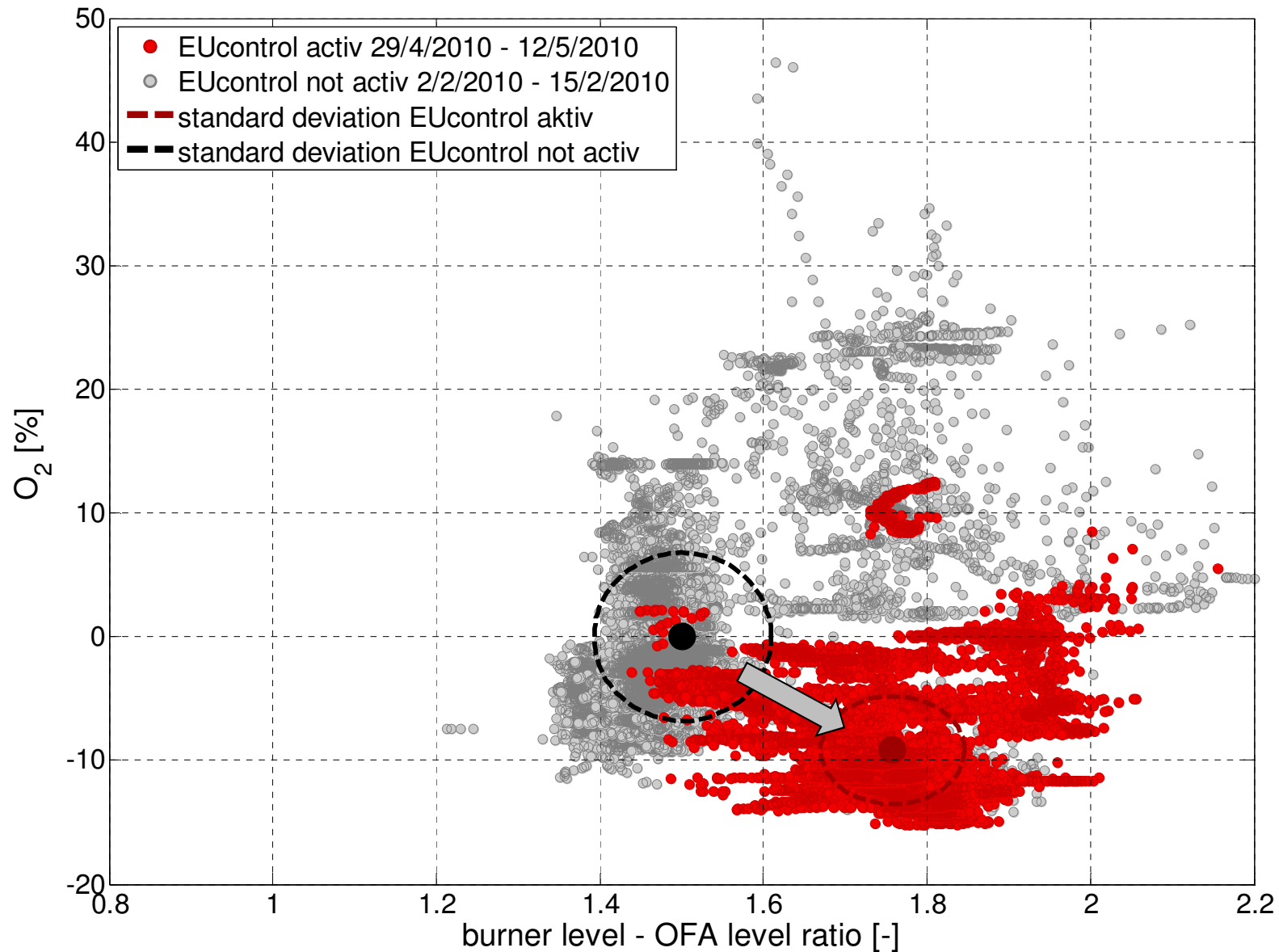
Steps 2 – Closed-loop Control

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

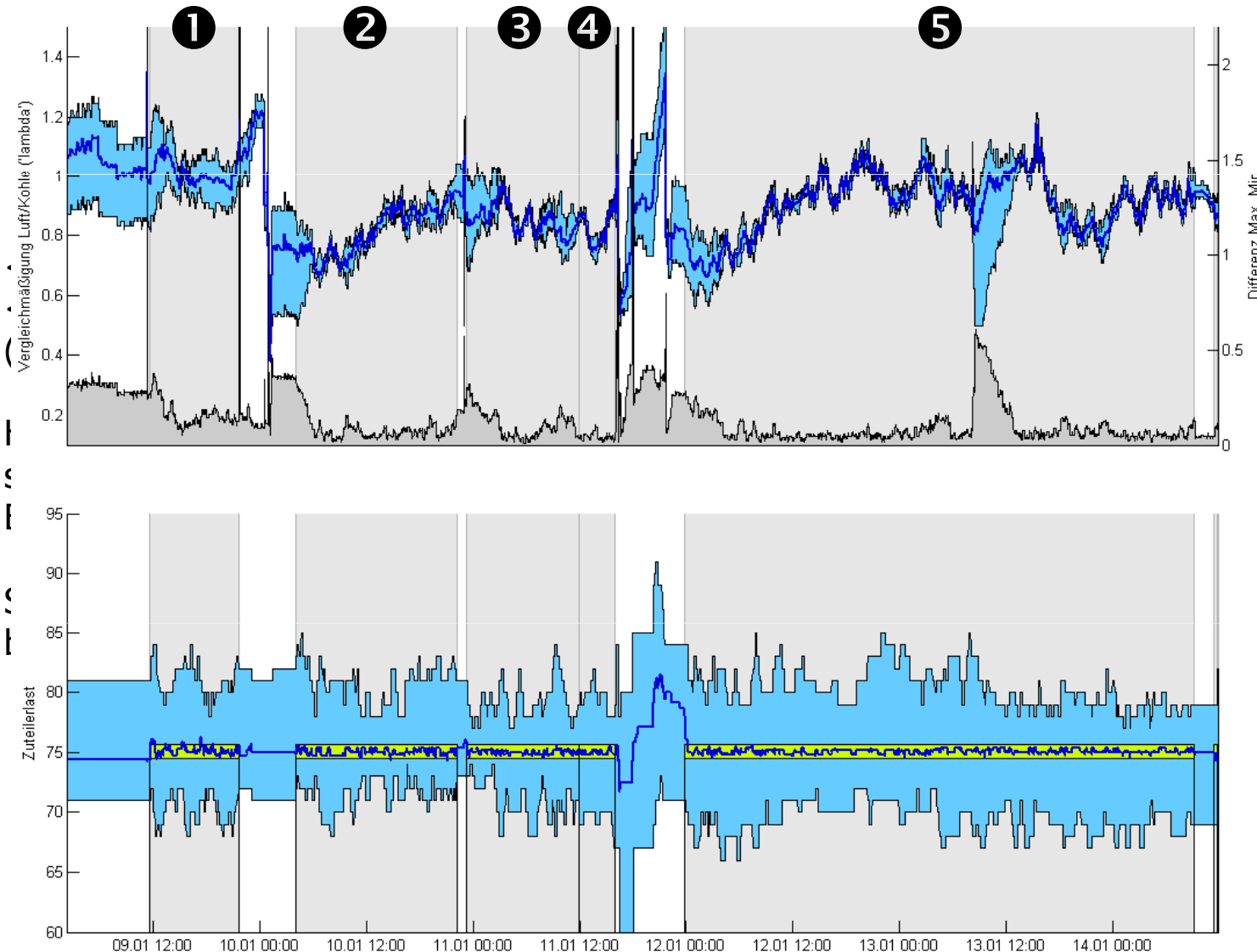
Steps 3 – Online Optimization

- Use coal and air flow control for combustion optimization

Enhanced boiler operation - O₂ and air-fuel ratio



Process stabilization



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