Towards efficiency improvement of multifuel grate-fired boilers

PGE 2014

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Our expertise at your service
Motivation

• The most common technology for small and medium size utility generation

• In the past:
  - Environmental regulations could be met with minimal efforts
  - Relative low cost of fuel
  - Little interest from ICI market for optimization of boiler operations
    • ICI market not convinced software optimization works
    • High costs
    • High level of maintenance to keep operating
    • Difficult to integrate with existing DCS

• Now:
  - New fuels entering the market (biomass, industrial and municipal solid waste) resulting in increased interest in grate firing (the cheapest technology available)
  - New combustion and environment protection rules enacted
Current situation
fuels

- Historically grate boiler were mostly used with coal
- As the new fuels came into perspective it appeared that the grate firing enables their firing in the easiest way
- New combustion aspects:
  - Biomass firing in the grate-boilers
  - Alternative fuels (waste-to-energy) including industrial and municipal solid waste
  - Co-firing of the new fuels with coal
- Both biomass and waste constitutes of the large variety of different fuels with different characteristics, i.e. calorific value, composition and properties variations, granularity, chemical composition
- Combustion brings more and more challenges:
  - combustion stability and safety is no more the only important aspect
  - Combustion is connected with economical, environmental, political, societal goals and drivers resulting with the need for high efficiency and low pollutant residues
Current situation
emissions and pollutants

• Major emissions from the classical coal combustion
  - particulate matter
  - unburned coal, CO, CO₂
  - NOₓ
  - SOₓ

• Once using alternative fuels we have to add to the above list:
  - Hydrocarbons (CₓHᵧ) and poly aromatic hydrocarbons (PAH)
  - Cl, S and K compounds (i.e. HCl/Cl₂, KCl, …)
  - PCDD (polychlorinated dibenzo-dioxins) and PCDF (polychlorinated dibenzofurans)
  - Metals and heavy metals

• Deposits formation and corrosion
  - Ash drivers (P, Ca, Mg, …)

• many new other constraints might appear
Grate fired boiler technology

different technologies and sub-processes

• Fuel preprocessing and preparation
• Fuel-feeding system
• Grate assembly
• Primary air and traditional mechanism in the fuel bed on the grate
• Advanced secondary air supply
• Possible fuel reburning
• Flue gas recirculation
• Scrubbers and precipitators
Control System Improvements

A common sense approach

1. Control System Review – how good is the design?
2. Tuning – make it work the best it can and find problems to be solved

10% to 35% of Control Loops run in Manual
30% of Control Loops - Tuning is completely wrong
85% of Control Loops have Sub-Optimal Tuning

3. Make improvements – there is always room for improvement
4. Measure control system performance (KPIs)
5. Apply optimization solutions
Combustion Control Optimization

• Optimization objectives must be well defined

- CO Emissions
- NOx Emissions
- Increase % Biomass and Alternative Fuels
- Limestone and/or other Additives consumption
- Stabilize Steam Pressure / Common Header Operation
- Improve Temperature Profile
- Controls in Automatic for more consistent operation

• Technology must be proven and practical
• Many solutions on the market – choose carefully!
Research and analysis background
14 different grate boiler analyzed

• Different grate type: travelling, reverse-acting, oscillating, hybrid
• Different air arrangements
• Different fuels: coal, wood, sugarcane bagasse, TDF, domestic solid waste
• Different I&C systems and control philosophies
• Different operational goals: electricity production, steam delivery, waste incineration
• Different pollution control and gas cleaning equipment
• Different business environment: Europe, North and South America, Africa
Research and analysis background

similarities

- Similar fuel delivery devices and their control (several gate sections) giving possibility for different grate transportation speeds between the sides
- Mostly multifuel operation with high variations of the fuel type and/or properties
- Similar approach of air control with undergrate primary air control (however the dampers number and control availability varies) and over-grate secondary/OFA air control
- Standard boiler draft pressure control, drum level, steam pressure and temperature control philosophy

All of them share similar behavior and operational issues
How do we do it?

Assessing benefits of improved control with statistical analysis

![Normal (Gaussian) distributions](image)

**Predicted with improved control**

Original plant

**Rule of “same limit”**

**M2 – M1 = 3(σ₁ - σ₂)**

σ₂ = α•σ₁
Combustion Optimization Example #1
100 t/h w2e grate boiler
Combustion Optimization Example #2
6 Grate Fired Boilers 80 t/h each

- Boilers have different combustion characteristics
- Saturation of the ID fans
- Uneven and unknown amount of fuel mixture delivered
Combustion Optimization Example #2
6 Grate Fired Boilers 80 t/h each

There is visible observation that grate speed has a correlation with boiler emissions (CO and O2) and on boiler efficiency.

Nonetheless the grate speed is not used in control.
Combustion Optimization Example #2
6 Grate Fired Boilers 80 t/h each

Assymmetric temperature distribution over the grate ➔ right side has a much lower temperature
Combustion Optimization Example #1

100 t/h w2e grate boiler

HISTOGRAM - asymmetry in spray flows

Asymmetry [dirty]   Asymmetry [clean]
Combustion Optimization Example #3
90 t/h biomass grate boiler

Another example of poor quality of excess air control $\text{air} = f(\text{fuel})$ characteristics.

Plot is highly scattered.

There are clearly visible vertical strands of points meaning MANUAL air control.
Combustion Optimization Example #4
Sugarcane bagasse 60 t/h

Potential improvement space = 0.65 %
Combustion Optimization Example #3
90 t/h biomass grate boiler

BOILER LOSSES (exhaust gas + CO incomplete combustion)

Potential improvement space = 0.64 %

Optimal O₂ 6.90
Optimal loss 10.66 ± 0.15

Actual O₂ 9.39
Actual loss 11.65 ± 0.20
Observations

• The boilers operate in a non-stationary environment and are subject to various disturbances
• Limited instrumentation infrastructure
• Most of the controls are in MANUAL resulting in day-to-day operating problems for operators, non-repetitive operation, lowered safety levels and inhibiting the possibility to implement supervisory level operation
• It is frequent situation that equipment operates on its limitation and MVs are saturated
• No automatic combustion optimization nor supervision
• Most of the investigated sites reveal quite significant space for efficiency improvement through optimal control
The engine: Fuzzy Controller

Adaptation and nonlinearities

- Method to handle human like reasoning into machine processing
- Extension of the standard sets theory into non crisp ‘world’
- ‘Possibility’ versus ‘Probability’
- Incorporate heuristics into control strategy
- Define nonlinearities in an intuitive way
- Terminology: *if temperature is low then flow is big*
- Premises are characterized by sets, *fuzzy sets*
- Sets are specified by linguistic function
The engine: Model Predictive Controller

Real time dynamic optimization

• Multivariable
  - All devices are controlled simultaneously
  - No pressure scheduling

• Predictive
  - Based on both pressure and steam balance
  - Major disturbances
  - Slow boilers
  - Machine start-up’s or batches

• Optimal
  - Cost functions are minimized
  - Generation is maximized
  - Against physical constrains
Summary

• Leverage Automation to improve the performance of boilers
• Use a common sense, layered approach to improve the control system
• Do your homework – testing, analysis, evaluate options
• Utilize available expertise and participate in the solutions