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JMP Engineering

Boiler Tune-ups
Tips, Traps & Opportunities

Real Life Examples of Boiler Tuning Issues

Chris Henderson

AAI/JMP Engineering

Exton, Pennsylvania

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AAI NEWS

- Automation Applications Inc, LLC (AAI) has joined JMP Engineering, Inc.
- AAI is operating as JMP Engineering - Philadelphia
- 7 North American branches
- 100+ employees
- Additional Engineering Capabilities
  - MES Solutions
  - Water and Waste Treatment

AAI-JMP Engineering

- Independent Full Service Turnkey Solutions Provider in Process Control, Manufacturing & Information Systems
- Consumer Products, Food & Beverage, Petrochemical, Pharmaceutical, and Pulp & Paper Market Solutions
- Boiler Combustion Controls and Industrial Energy Management is Core Application Expertise
- Successfully Completed over 300 Powerhouse Projects
- Industrial Energy Solutions Team Comprised of Individuals with Hands-On Background in Boiler Control Design, Start-Up and Operation

Introduction

While there are differences between tune-ups to minimize emissions and tune-ups for energy efficiency, they both rely on precise accurate control of fuel, air, and fuel/air ratio.

Boiler System Energy Losses

Significant energy losses associated with boilers fall into two categories:

- Radiation and Convection Losses
- Stack Losses

Stack Losses typically account for 95% of all boiler energy losses.

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Stack losses represent the heat in the flue gas that is lost to the atmosphere upon entering the stack and are greatly affected by maintenance and operations.

Stack Heat Losses

There are two types of Stack Heat losses:

•Dry Flue Gas Losses – the (sensible) heat energy in the flue gas due to the flue gas temperature

•Flue Gas Loss Due to Moisture – the (latent) energy in the steam in the flue gas stream due to the water produced by the combustion reaction being vaporized from the high flue gas temperature.

These losses are primarily a function of three variables:

•Moisture/Hydrogen Content of the Fuel

•Quantity of Excess Air

•Stack Exit Temperature

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These losses are primarily a function of three variables:

- Moisture/Hydrogen Content of the Fuel
- **Quantity of Excess Air**
- **Stack Exit Temperature**

Excess Air

Lowering Excess Air decreases the amount of air not needed for combustion. This air goes along for the ride, entering the unit at ambient temperatures, exiting with millions of BTU, robbing your unit of efficiency.

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Excess Air

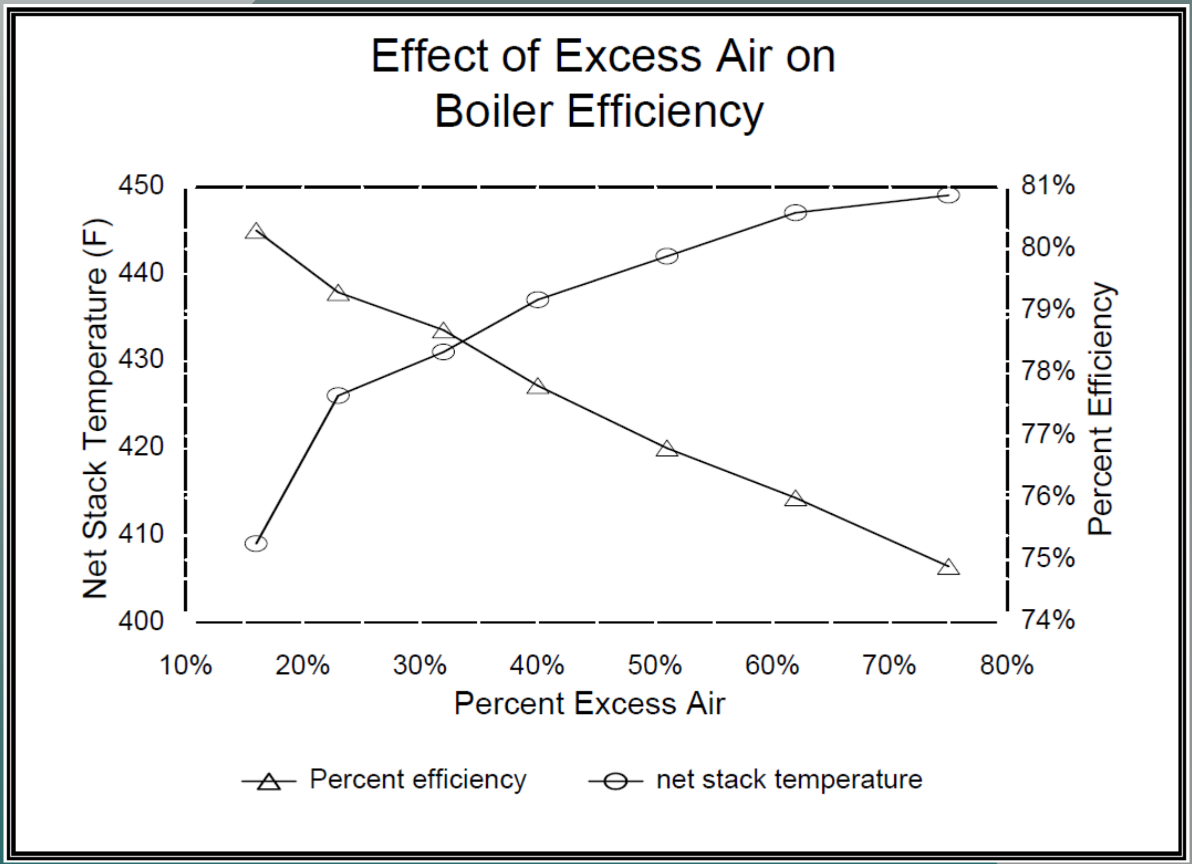
Lowering Excess Air, resulting in less volume of flue-gas, increases heat transfer in the convection section resulting in significantly lower stack exit temperatures.

In other words, it improves...

2 of the 3 factors Effecting Stack Losses

- Moisture/Hydrogen Content of the Fuel
- **Quantity of Excess Air**
- **Stack Exit Temperature**

Excess Air and Boiler Efficiency



Lowering Excess Air Has a Significant Effect on Stack Temperature

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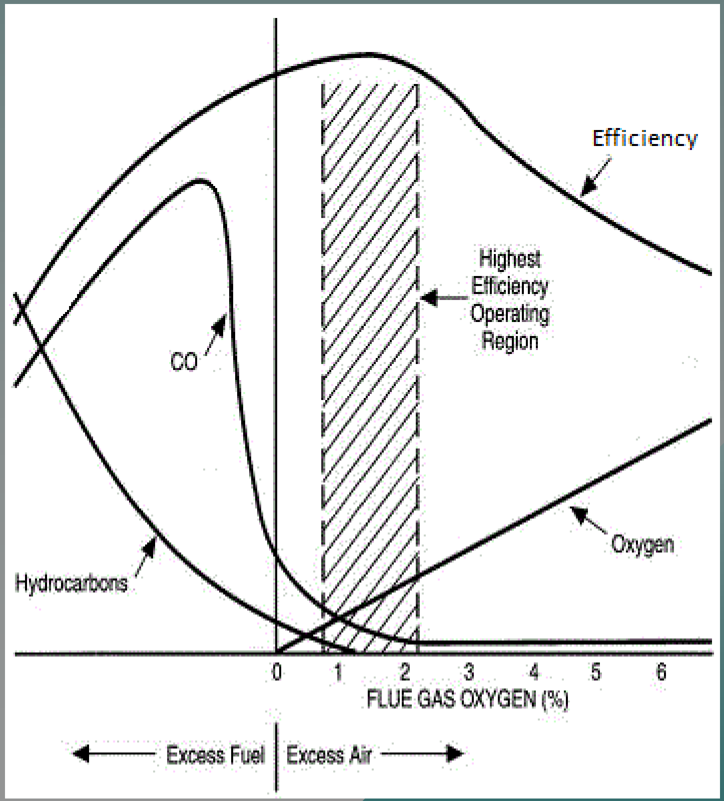
Minimum Excess Air

A Chart We've all Seen Before

Reduce O2 until the point where you start to make CO, however...

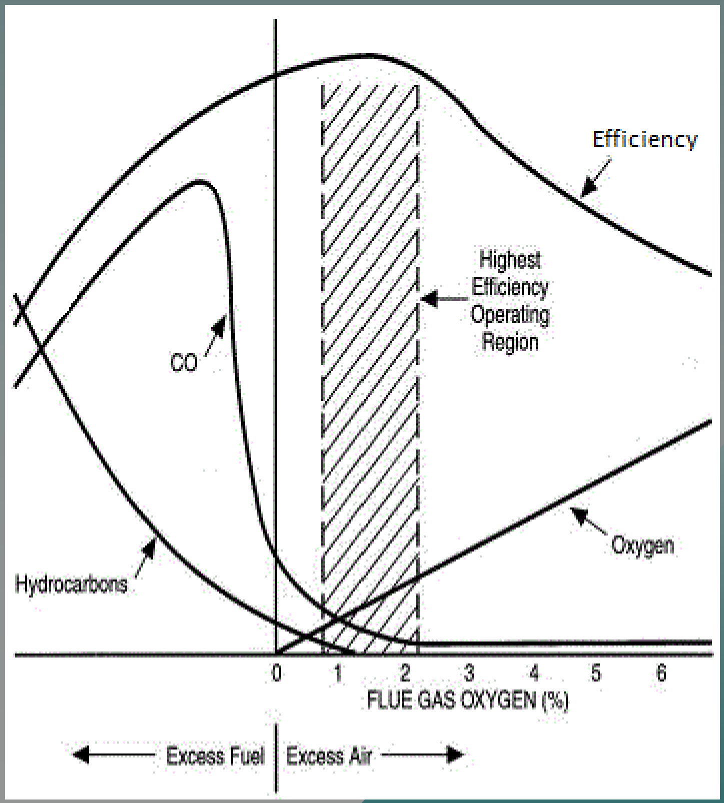


Minimum Excess Air

A Chart We've all Seen Before

Reduce O2 until the point where you start to make CO, however...

The Relationship between Excess Air and CO Is Not Fixed!



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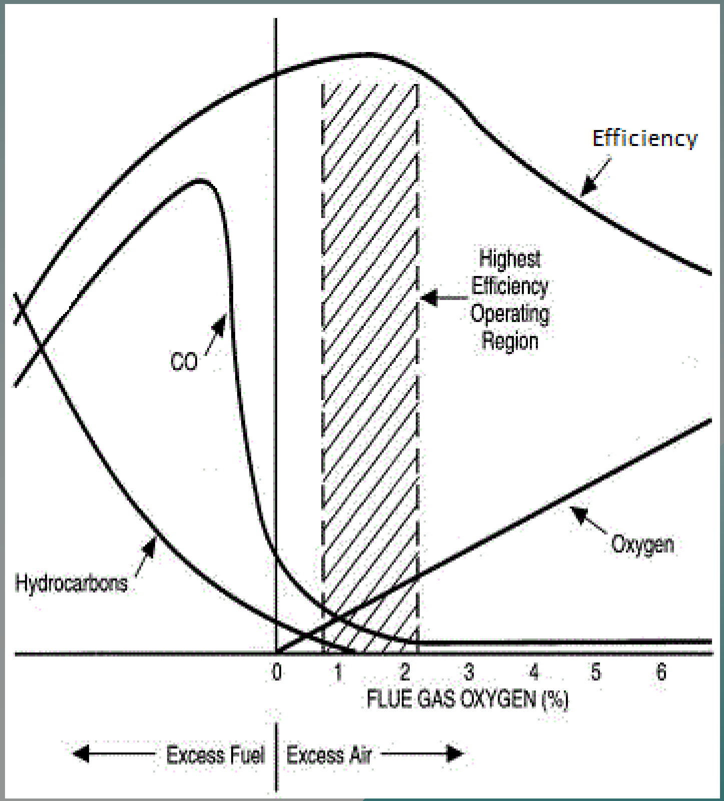
Minimum Excess Air

Increase the effectiveness of mixing, and the CO line slides to the left.

Narrow the controllability range with tight responsive coordinated control, and Excess O2 Setpoint can be lowered.



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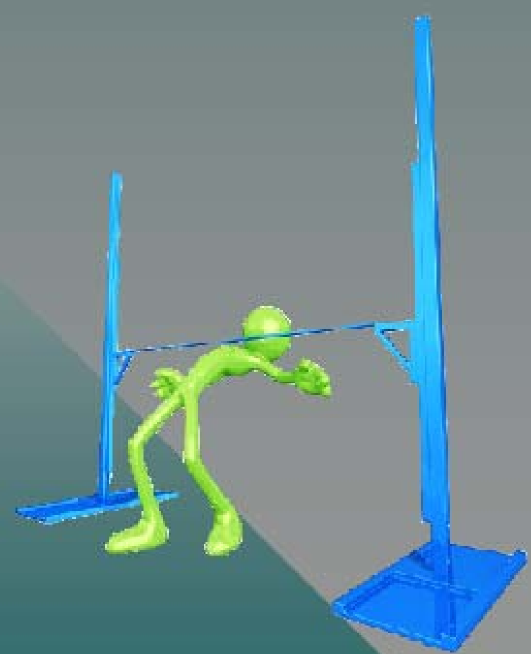
Excess O2

How Low, Can You Go?



Excess O2

How Low, Can You Go?

With most boilers in good condition, significant improvements can be made if you have...

- Tight, Responsive, Coordinated Control
- Optimized Mixing of Fuel and Air

Excess O2

How Low, Can You Go?

Stoker 3.0 – 3.5%

Excess O2

How Low, Can You Go?

Stoker	3.0 – 3.5%
Pulverized Coal	2.5 %

Excess O2

How Low, Can You Go?

Stoker	3.0 – 3.5%
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Oil	< 2.0%

Excess O2

How Low, Can You Go?

Stoker	3.0 – 3.5%
Pulverized Coal	2.5 %
Oil	< 2.0%
Natural Gas	< 1.5%

Significant Savings

Attractive Payback

Typical Improvement of 2% - 5%

Typical 100,000 klb/hr. Boiler running at 80% Capacity
2.5% Energy Efficiency Improvement

		Savings	
Fuel		**Daily**	**Annual**
Natural Gas	=	$ 345	$ 125,852
#2 Oil	=	$ 1,507	$ 550,128
#6 Oil	=	$ 1,018	$ 371,424
Coal	=	$ 470	$ 171,696

Based on the following fuel cost;

Natural Gas = $4.40/MMBtu, #2 Oil = 2.76/gallon, #6 Oil = $2.00/Gallon and Coal = $100/Ton.

Tune-ups for Boiler Efficiency

An overview of the process used to tune-up boilers for efficiency.

Examples of real field experiences over the last 25 years will be utilized to illustrate typical “gotchas”, which conversely are opportunities for improvement.

Tune-up Procedure

- Physical Inspection
- Maintenance Procedures & Signal Accuracy
- Review of Control Configuration and Design
- Output Characterization
- PID Tuning
- Load Tests and Loop Tuning
- Mixing and Air Distribution

Physical Inspection

Proper Location of Transmitters

Lines plumbed correctly

Appropriate Location for Flue Gas Analyzers

Proper Alignment of Actuator/Damper Linkage

Physical Condition of Boiler and Instrumentation

Physical Inspection

- Proper Location of Transmitters
- **Lines plumbed correctly**
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- Physical Condition of Boiler and Instrumentation

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- Appropriate Location for Flue Gas Analyzers
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- **Physical Condition of Boiler and Instrumentation**

O2 Probe Mystery

One O2 probe consistently read greater than the other.

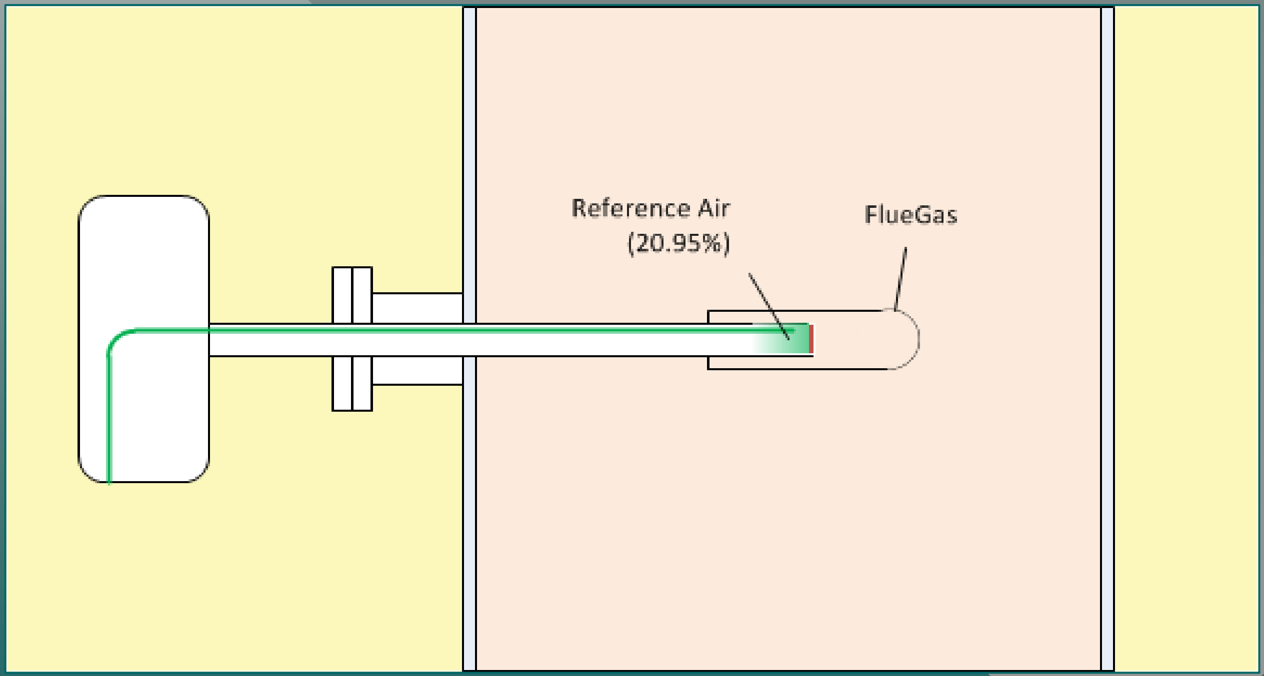
Repeated Calibrations indicated the probe was reading correctly.

Tramp air infiltration along with stratification was suspected.

A portable flue gas analyzer was used to take transverse readings, and showed little stratification.

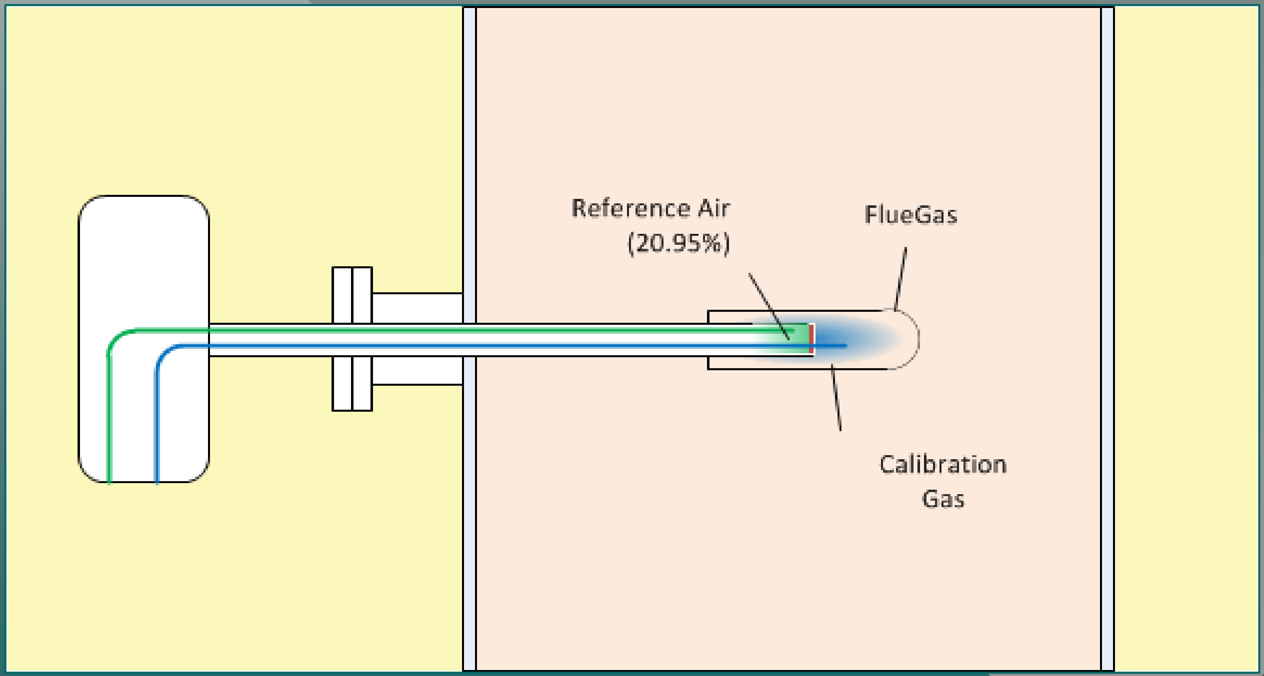
O2 Probe Condition

Heated Zirconium Oxide Sensors generate a voltage proportional to the difference in oxygen partial pressures on the two sides of the sensor.



O2 Probe Condition

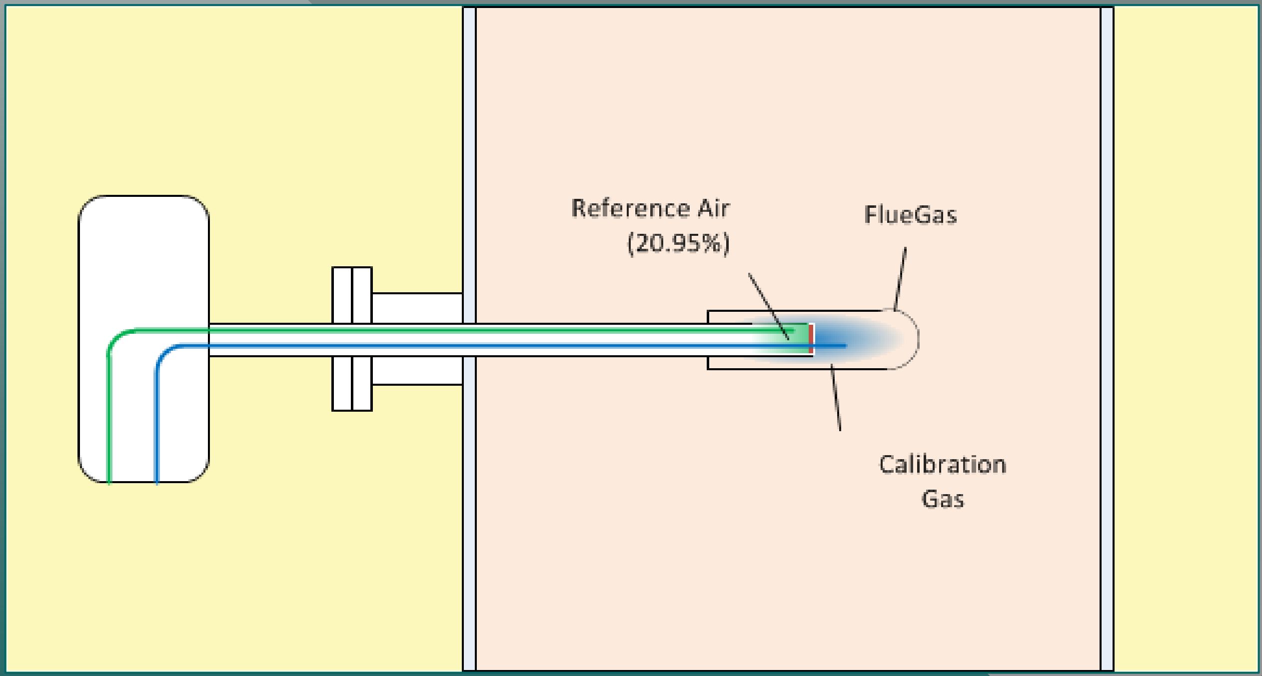
Calibration Gas is introduced, displacing the flue gas in the probe's sensing chamber.



O2 Probe Condition

Calibration Gas is introduced, displacing the flue gas in the probe's sensing chamber.

Missing Cap on Cal Gas Sensing Port!



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Maintenance Procedures & Signal Accuracy

O2 Analyzer Calibration Frequency and Records

O2 Calibration Gas Selection

Transmitter Selection

Transmitter Calibration Records

Air Flow Accuracy

Maintenance Procedures & Signal Accuracy

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Air Flow Accuracy

Maintenance Procedures & Signal Accuracy

- O2 Analyzer Calibration Frequency and Records
- O2 Calibration Gas Selection
- **Transmitter Selection**
- Transmitter Calibration Records
- Air Flow Accuracy

Transmitter Selection

Symptoms:

- Excessive Noise at Low Flows
- Fuel/Air curve Irregular at Low End

CE Boiler
Pulverized Coal
240 klb/hr

Transmitter Selection

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Differential Transmitter Specification

Maximum Span: 40.0” H_2O
Minimum Span: 0.4” H_2O
Accuracy: ± 0.04% of Calibrated Span*

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Transmitter Selection

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Maximum Span: 40.0” H2O
Minimum Span: 0.4” H2O
(Resolution)Accuracy: ± 0.04% of Calibrated Span*

** for turndowns of 1:1 to 5:1*

Accuracy for turndowns of 5:1 to 100:1
± (0.0105 + 0.0059 x TD) % of Calibrated Span

CE Boiler
Pulverized Coal
240 klb/hr

Ultra Low Range Transmitters

Calibrated Scan: 0.87” H2O

Turndown of 44:1

Accuracy = ± (0.0105 + 0.0059 x 44)% of Calibrated Span

Accuracy = 0.27% of Calibrated Span

(Resolution) Accuracy = ± 0.0023” H2O

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CE Boiler
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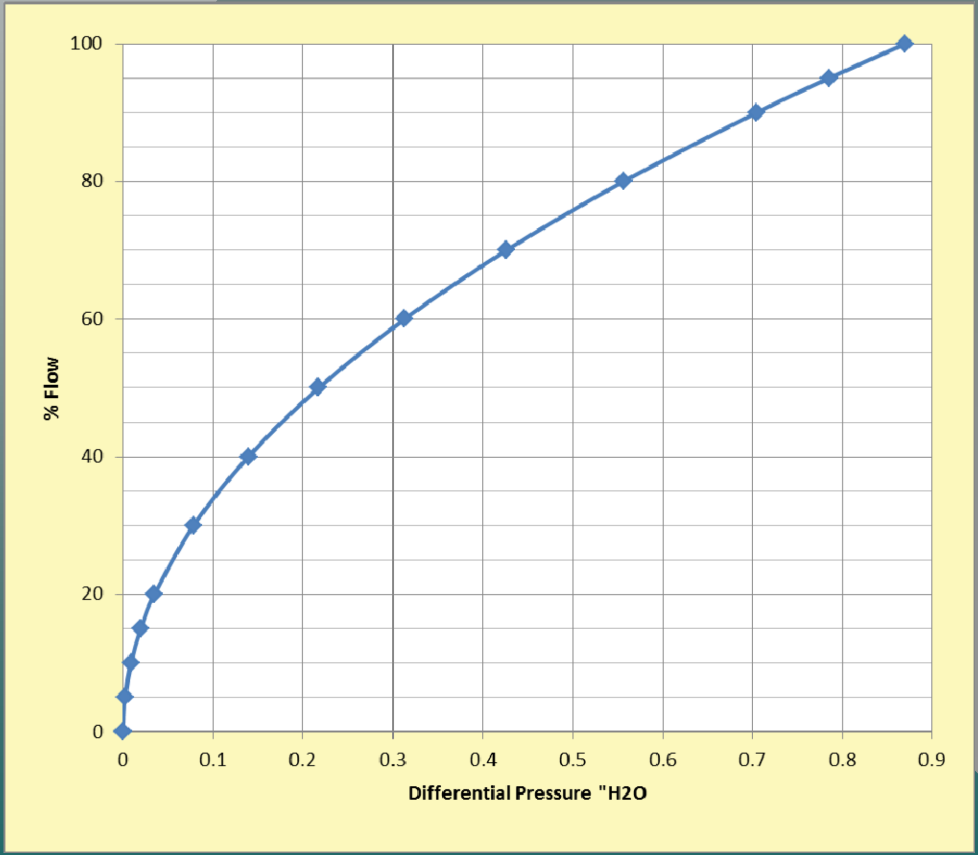
Ultra Low Range Transmitters

(Resolution) Accuracy = ± 0.0023" H2O



@ 10% Airflow

DP is 0.0087" H2O

± 0.0023" H2O

Equates To:

8.5% - 11.3% Airflow

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Maintenance Procedures & Signal Accuracy

- O2 Analyzer Calibration Frequency and Records
- O2 Calibration Gas Selection
- Transmitter Selection
- **Transmitter Calibration Records**
- Air Flow Accuracy

Maintenance Procedures & Signal Accuracy

- O2 Analyzer Calibration Frequency and Records
- O2 Calibration Gas Selection
- Transmitter Selection
- Transmitter Calibration Records
- **Air Flow Accuracy**

Air Flow Accuracy

Boilers using characterization curves to set air demand, with only one level of air, do not necessarily need absolutely accurate air flow readings so long as they are repeatable.

Boilers with more than one level of air, need both air flows to be accurate relative to each other.

If accuracy of an airflow measurement is in doubt, it can be checked by various methods.

Traditional transverse velocity measurements can be used to calculate airflow, or if O2 readings are trusted, airflow can be checked empirically.

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Air Flow Accuracy Testing

Boiler load is held steady.

Furnace Pressure is quadrupled and the resulting increase in O2 noted.

Various Air Flows are changed, and the measured change in flow compared against the calculated change in air as indicated stoichiometricly by changes in excess air.

Stoichimetric Constants

Net MMBtu/KPPH of Steam	1.201	**Boiler Efficiency**	79%	**KPPH Air/ MMBtu Coal**	0.755

Combustion Air Calculation

				MMBtu Steam		MMBtu Coal	Theoretical Air	
Steam Flow	156	KKPH	=	187.356	/ Eff =	237.159	179.055	Klb

Tramp Air Estimation

Initial O2 Reading	4.6	is	25.24%	Excess Air, which should be	224.256	Klb
O2 after Quadrupling Furn Press	5	is	28.13%	Excess Air, which should be	229.415	Klb
			5.16	Klbs, Estimated Tramp air at original Furnace Pressure		

Airflow Verification

O2	4				**Measured**	**Theoretical**
Plenum Airflow	147			**Total Airflow**	213.96	216.97
Overfire Airflow	42.26			**Excess Air**	19.49%	21.18%
FGR Flow	101.6	***Equiv Air***	19.54			
Estimated Tramp Air	5.16					

Determine which airflow measurements are off by making a significant change in one air level, and entering before and after O2 below.

Calculated Change in Air using the resulting change in O2

O2 Reading Before Change	5	is	30.31%	Excess Air, which should be	233.332	Klb
O2 Reading After Change	5.8	is	37.01%	Excess Air, which should be	245.329	Klb
			12.00	Klbs, Change In Total Airflow between Two Test Points		

Control Configuration & Design

Cross Limits

Implementation Method of Excess Air Trim

Implementation Method of Fuel/Air Characterization

Implementation of Air Splits (if applicable)

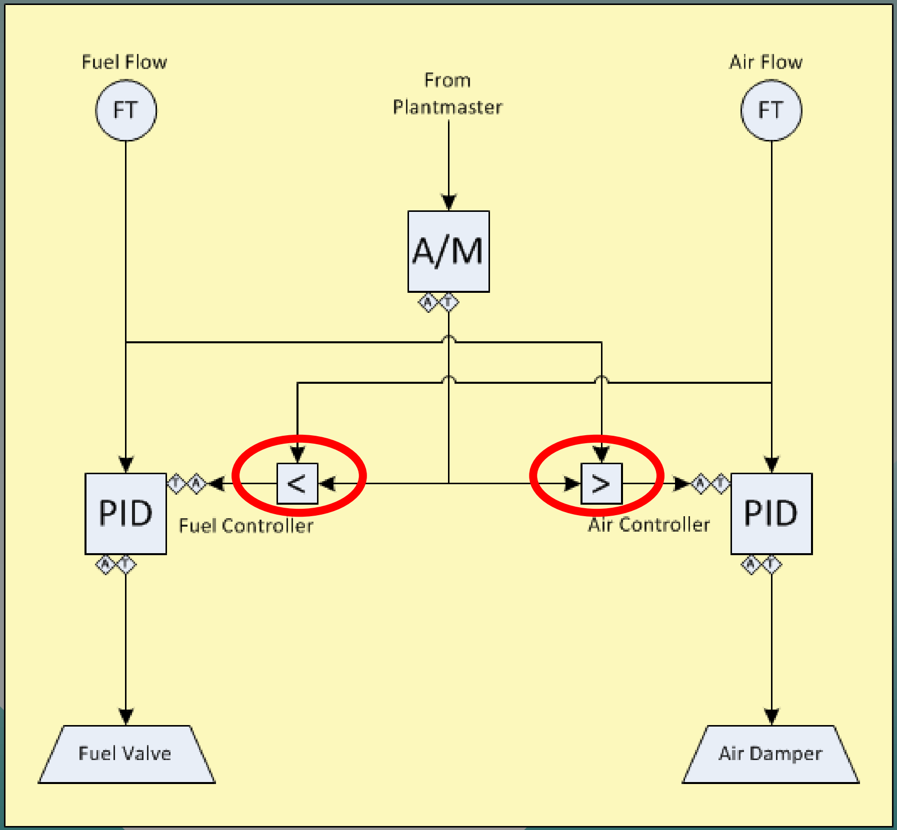
Output Characterization Capabilities

Configuration of Feedforwards

Cross Limits

Check that cross-limits are implemented correctly.

This ensures that there is always enough air for fuel entering the boiler.



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Control Configuration & Design

- Cross Limits
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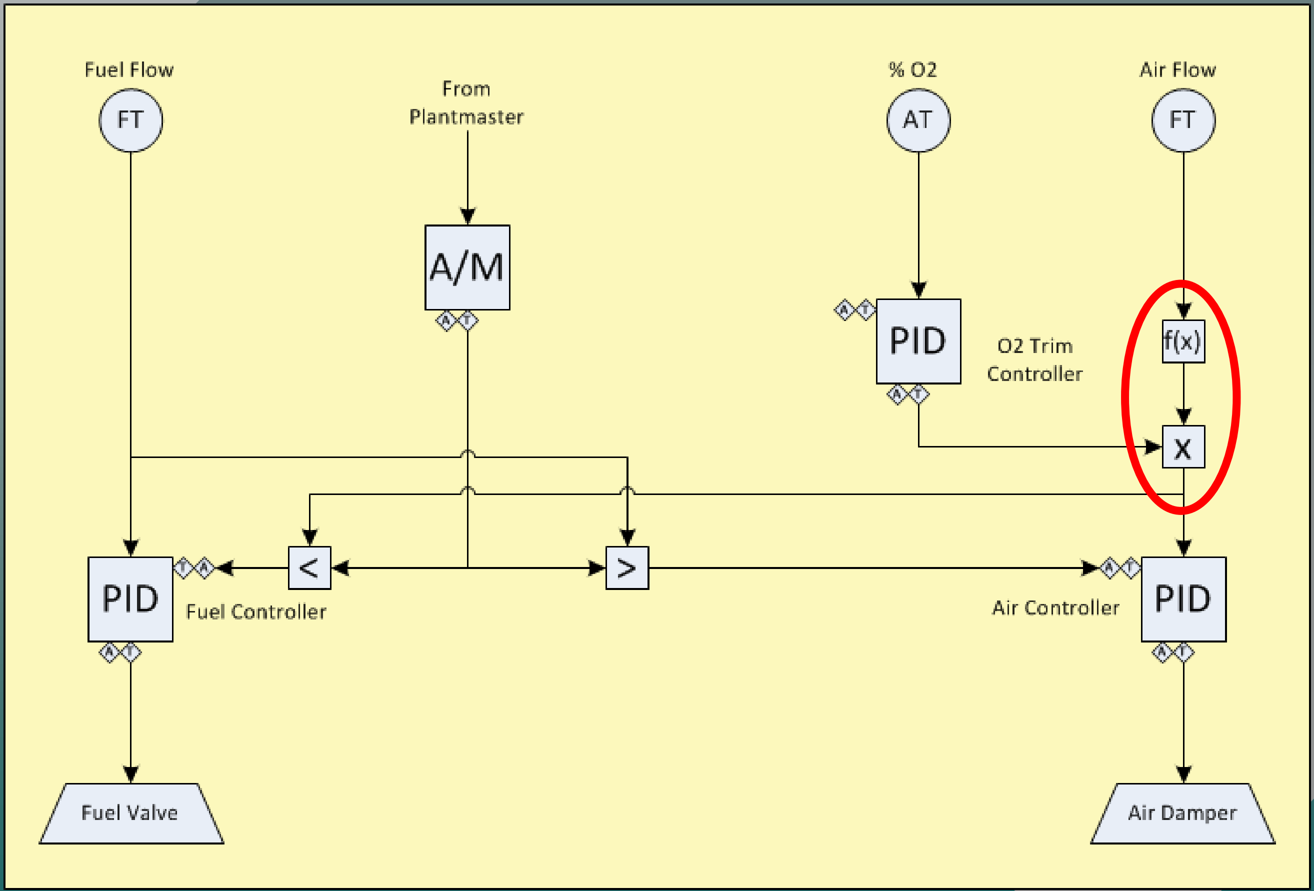
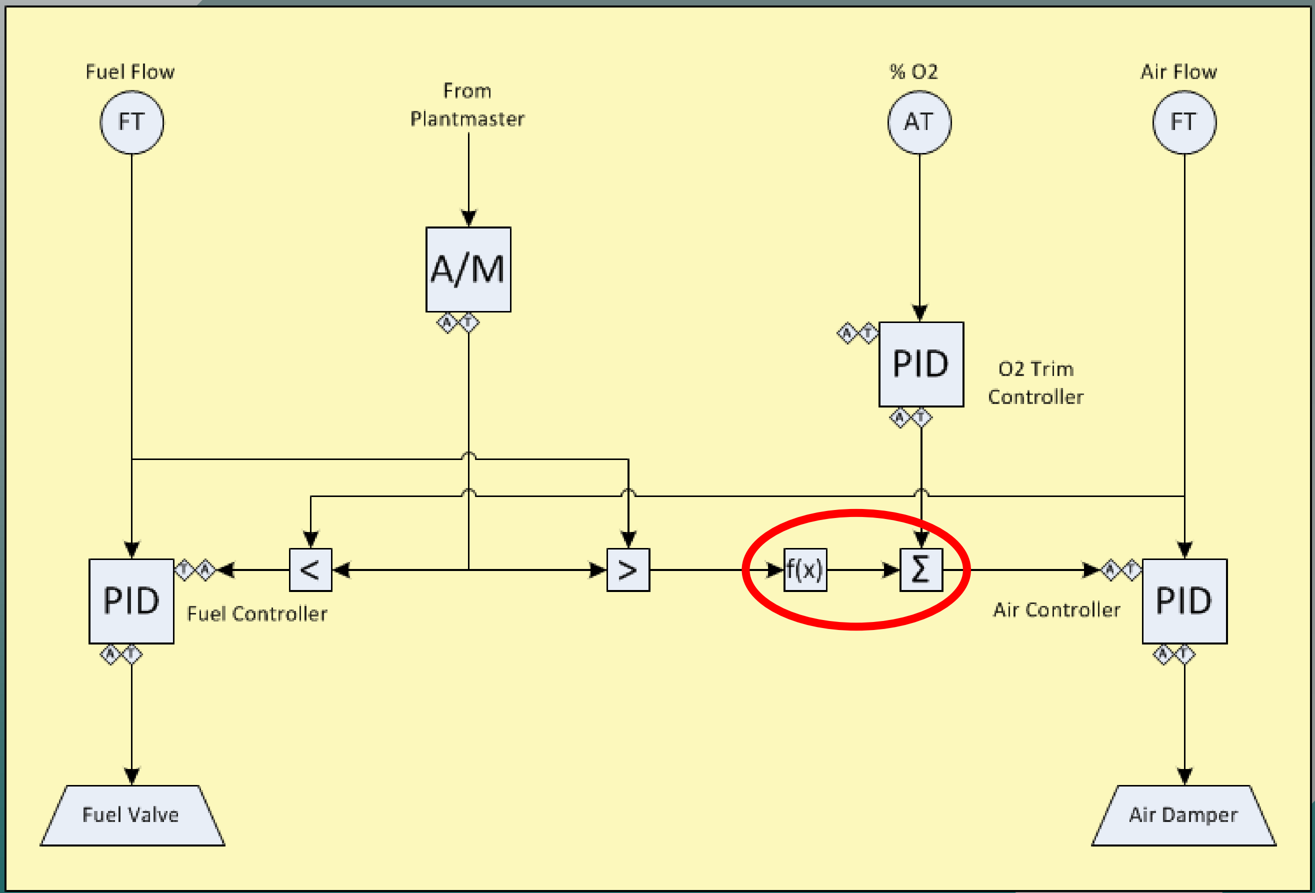
Air Characterization And Trim

Are Characterization and Trim done on the PV side...



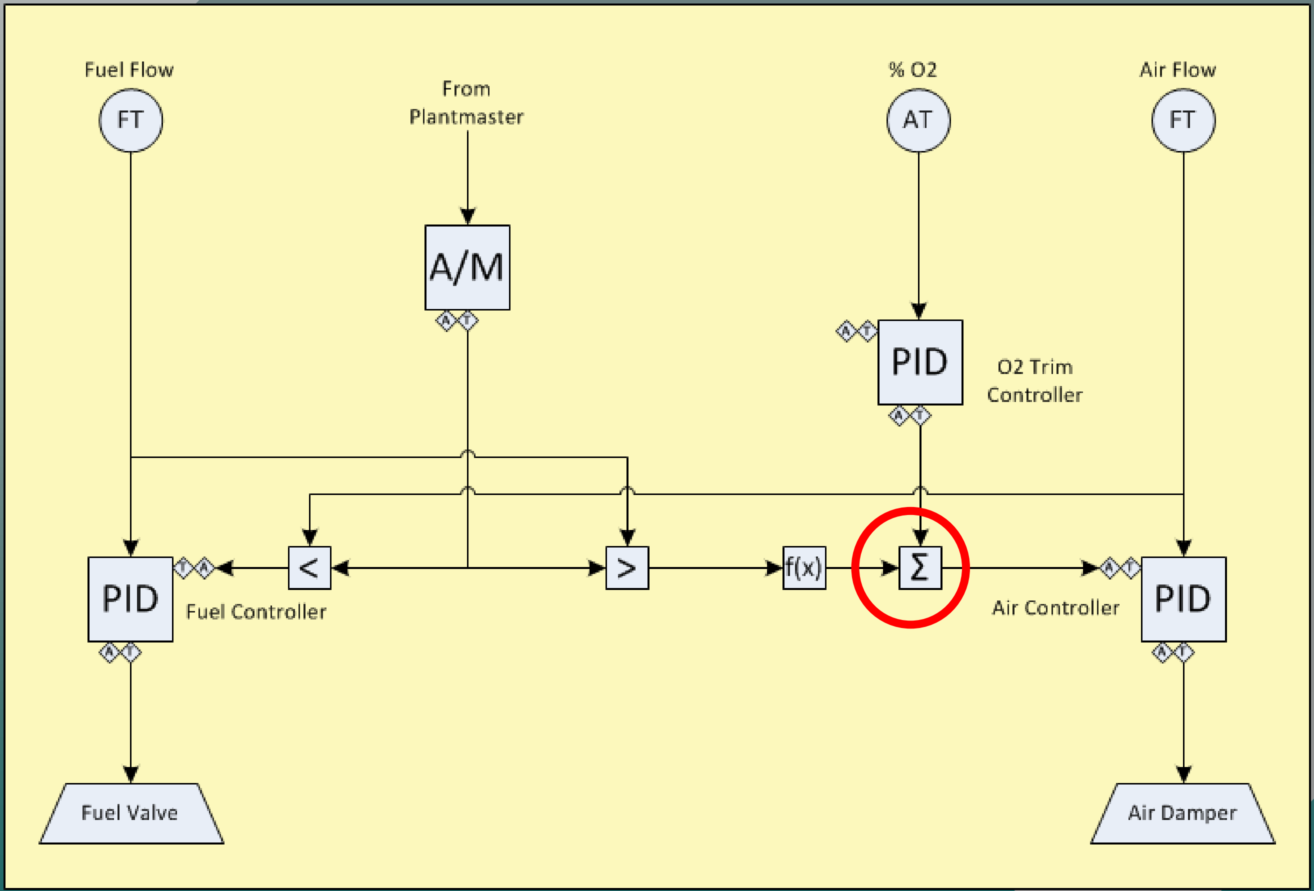
Air Characterization And Trim

... or on the Setpoint?



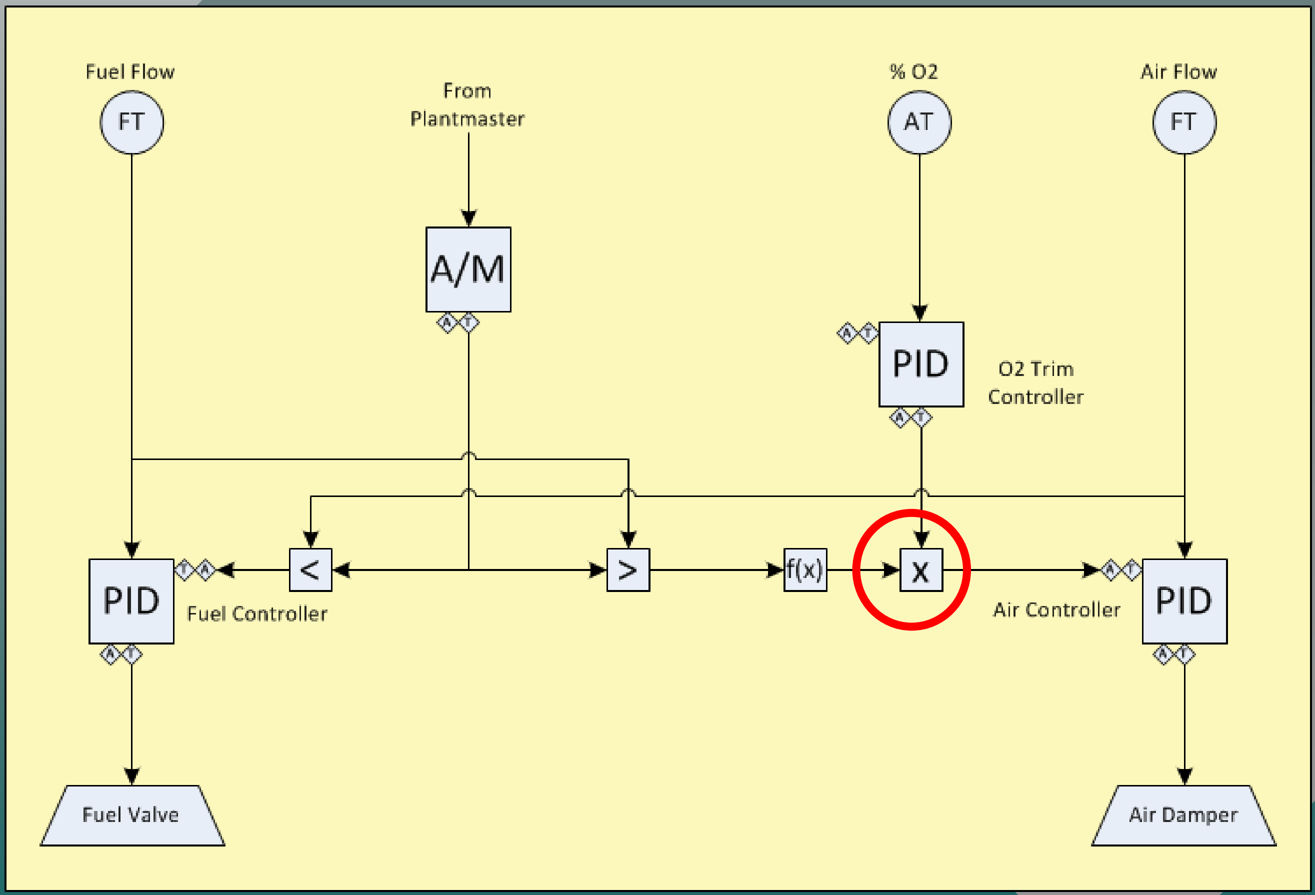
Air Characterization And Trim

Is O2 Trim implemented additive...



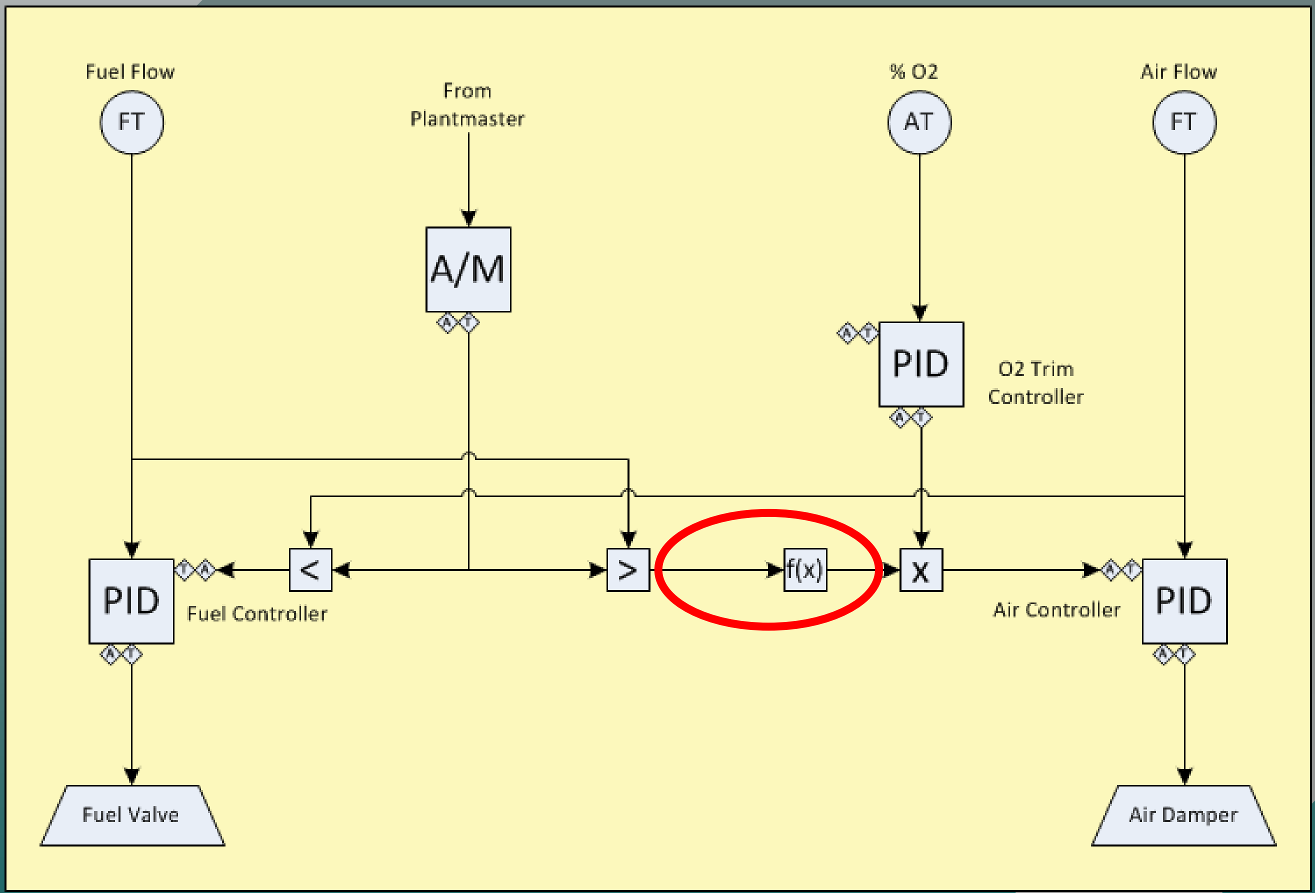
Air Characterization And Trim

... or multiplicative?



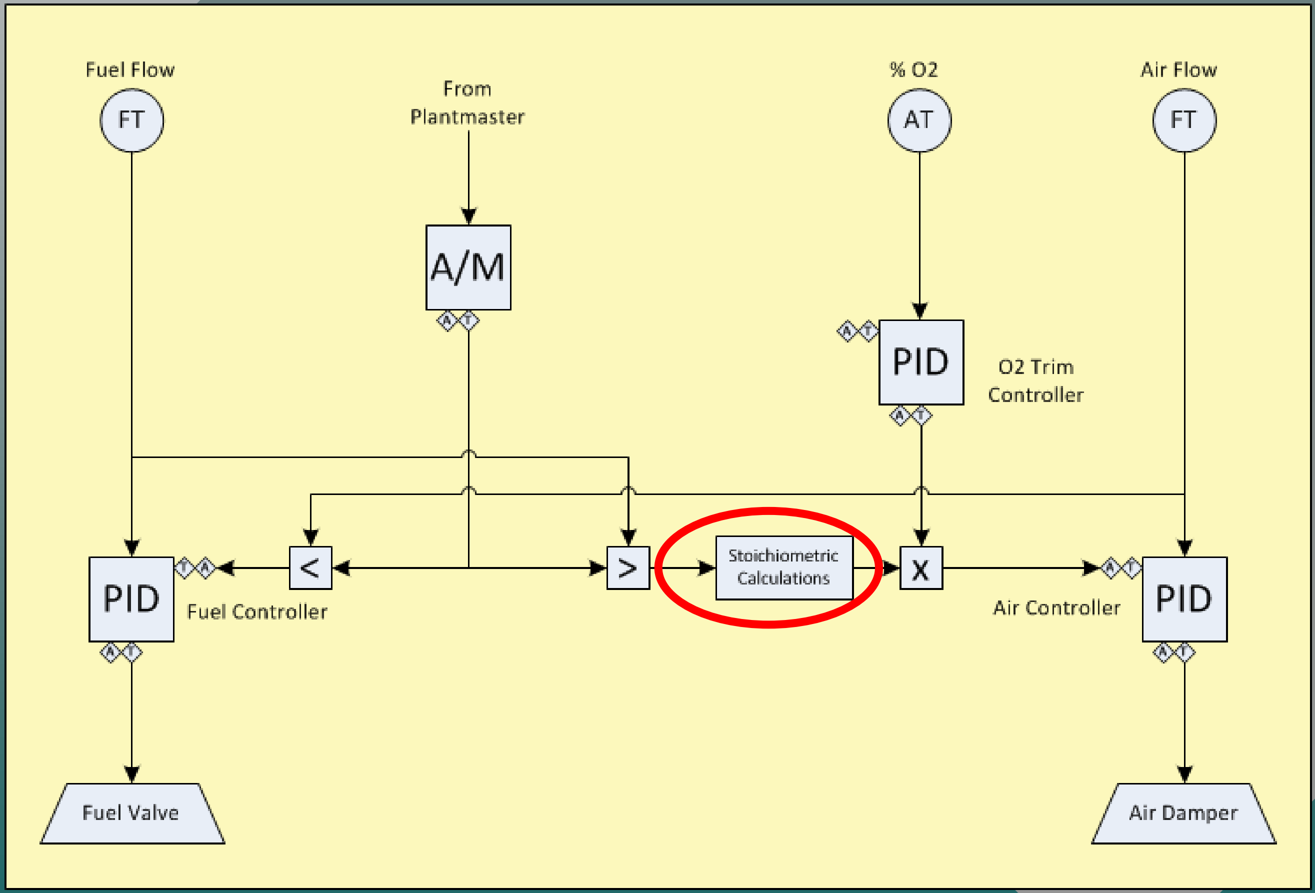
Air Characterization And Trim

Is Air Demand set by a characterization curve...



Air Characterization And Trim

...or Stoichiometric Calculations?



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Output Characterization Capabilities

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Damper Actuators and Output Characterization

Actuator Characterization – Position vs. Flow

Hysteresis

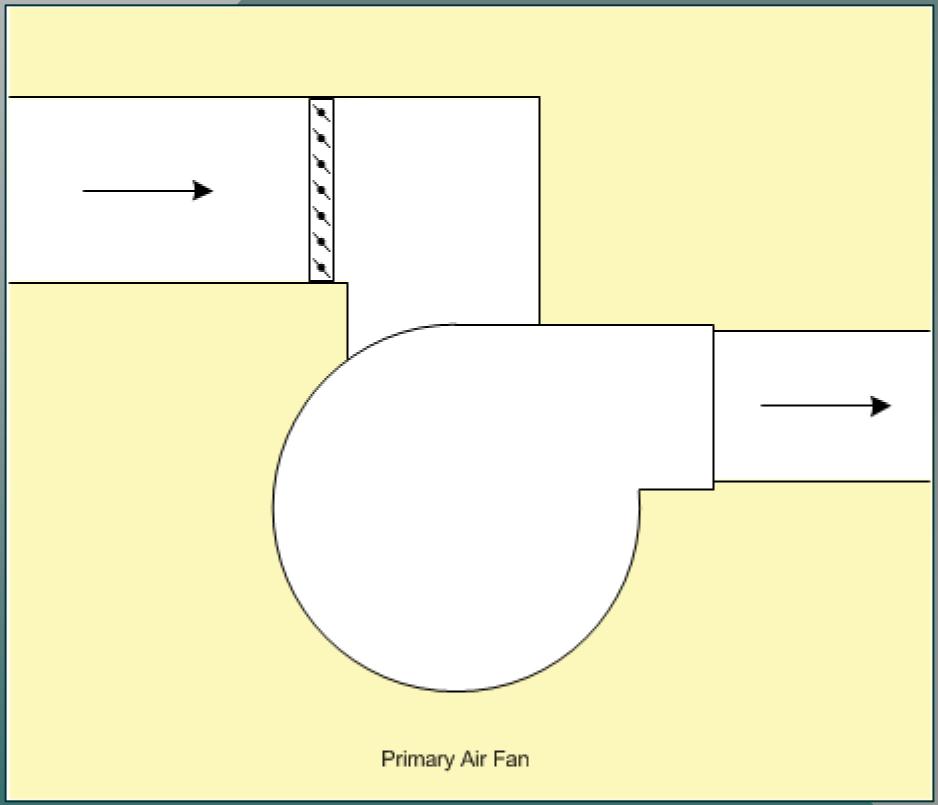
“Sticktion”

Damper Position vs. Flow

Characterizing controller outputs so that a given change in output results in a consistent change in flow throughout its range allows the PID controller to be tuned tightly rather than then the loose tuning needed to accommodate different effective gains.

Occasionally this can be a challenge...

Actuator / Damper Linkage



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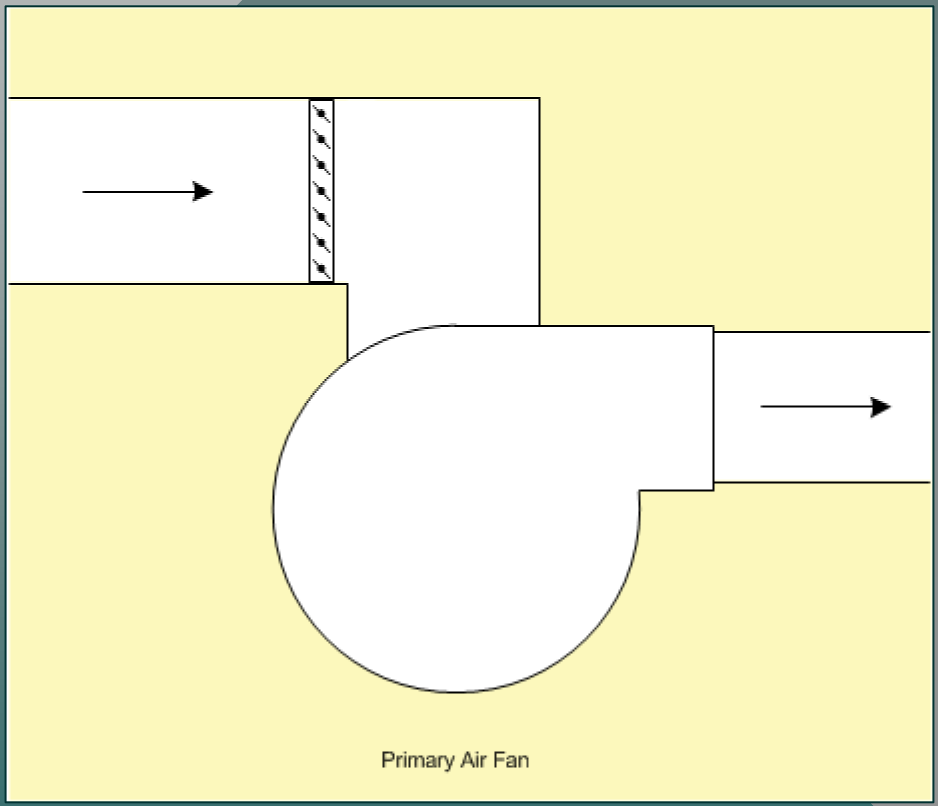
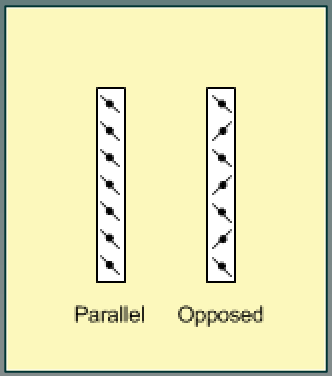
B&W Sterling Boiler
Pulverized Coal
200 klb/hr @ 180 psi (Saturated Steam)

Actuator / Damper Linkage





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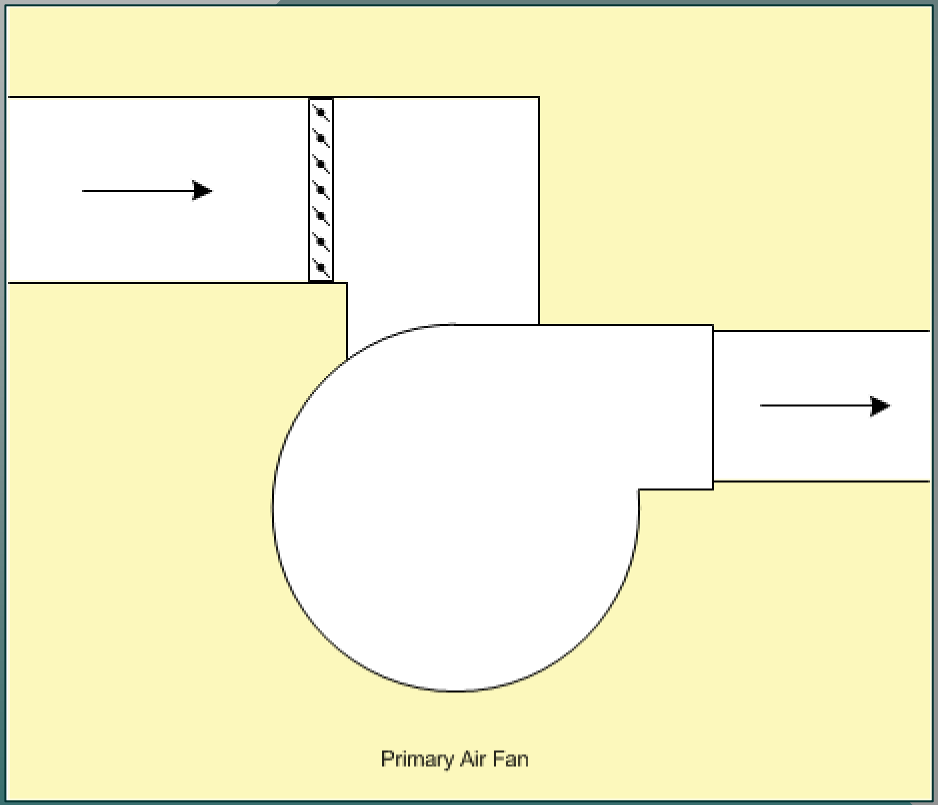
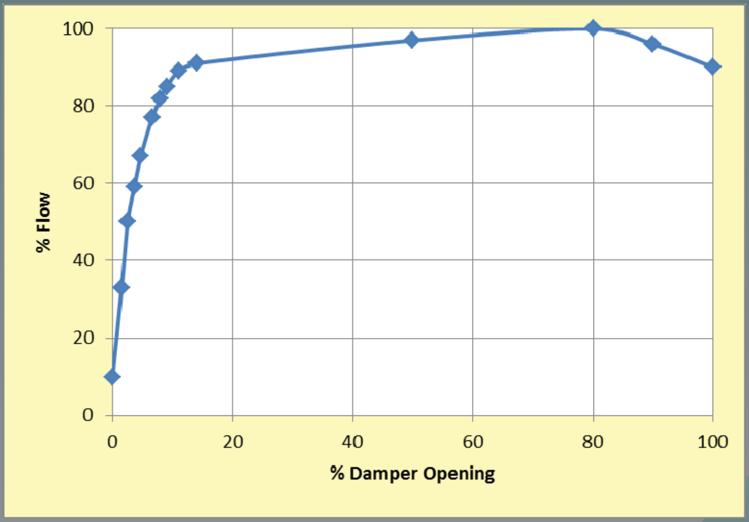
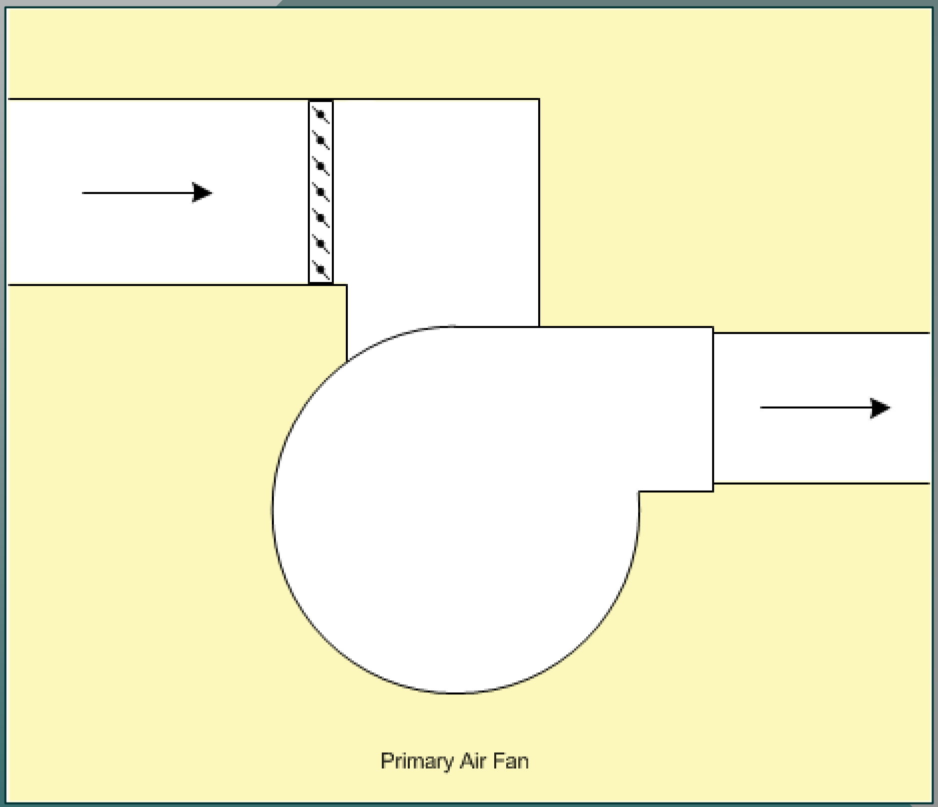
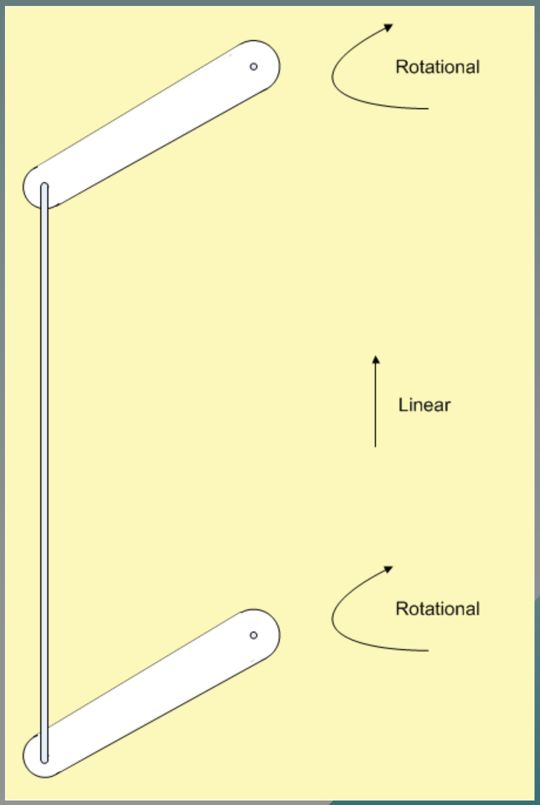




90% of Full Flow @ 12.1% Damper Opening!

Actuator / Damper Linkage





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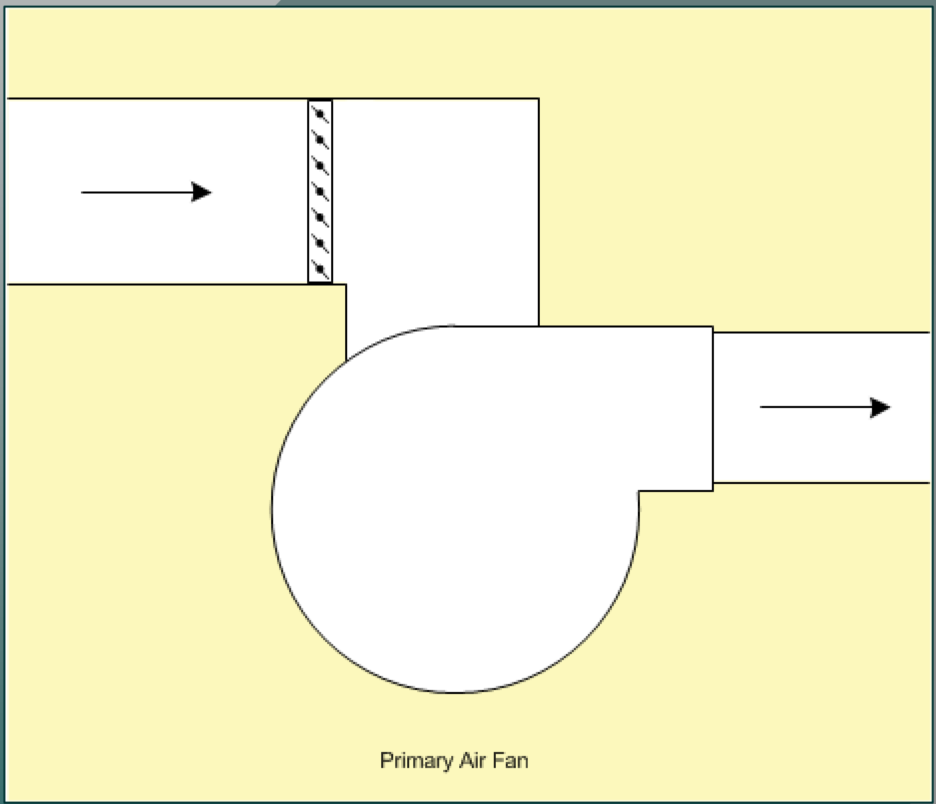

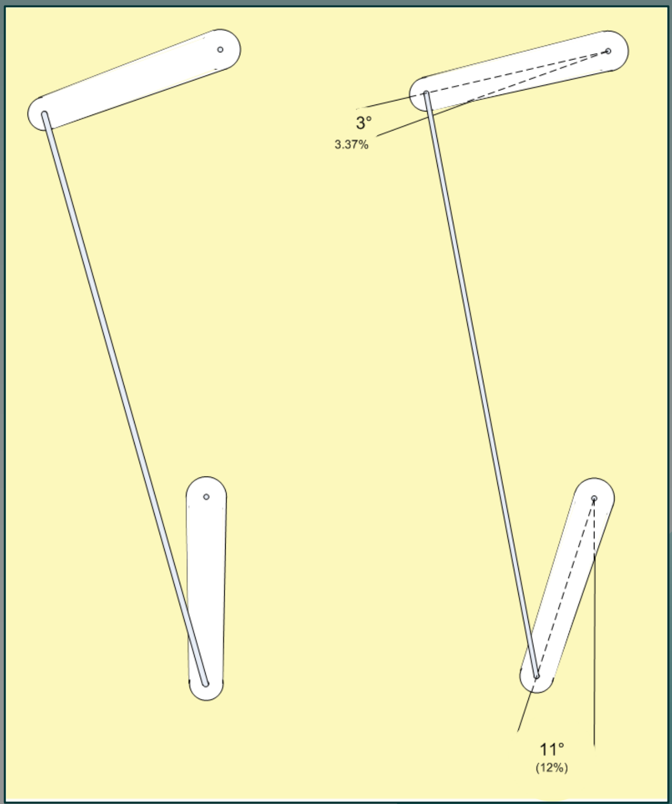

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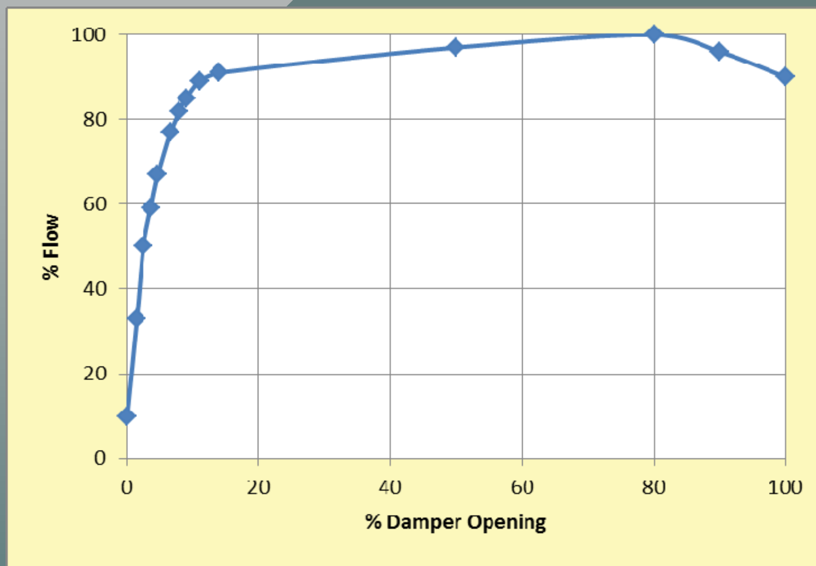
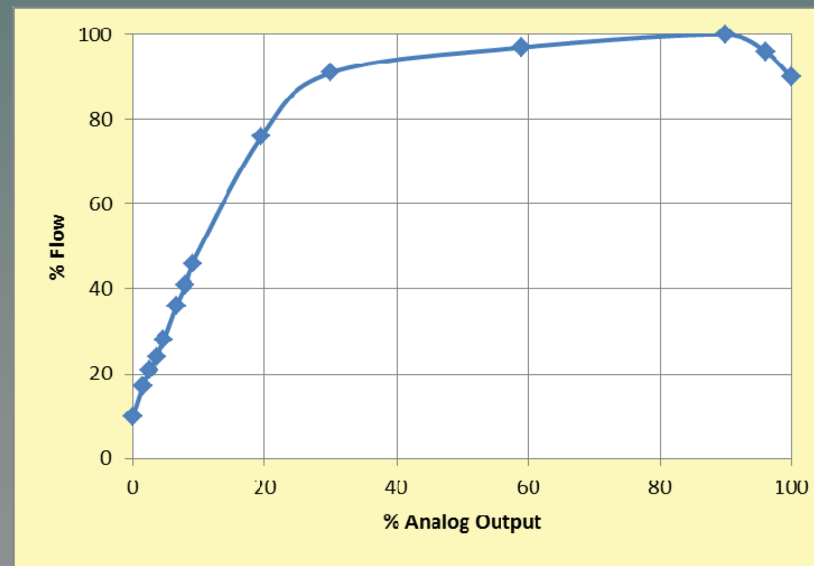




90% of Full Flow @ 30.2%

Damper Opening

Damper Actuators and Output Characterization

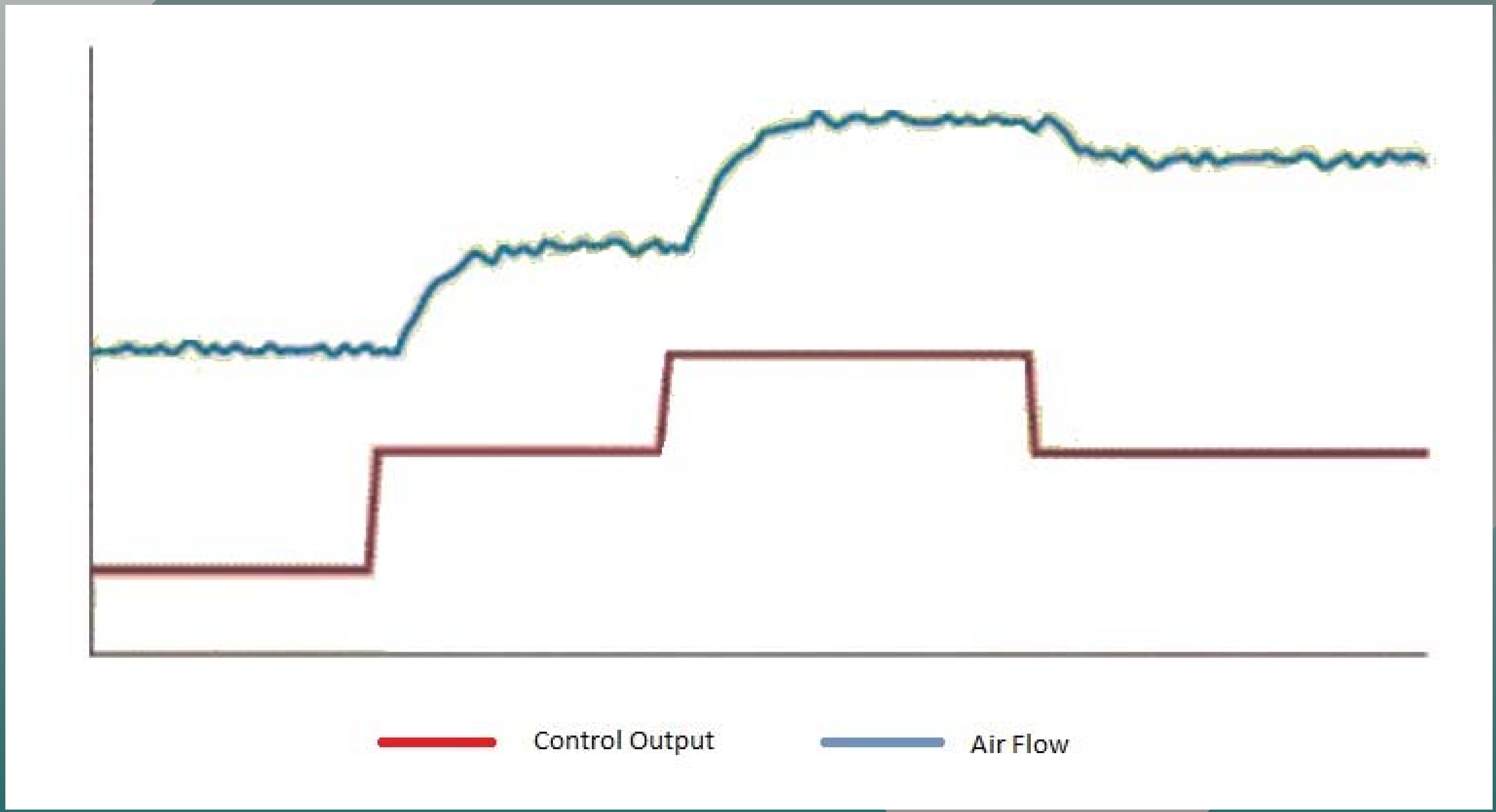
Actuator Characterization – Position vs. Flow

Hysteresis

“Sticktion”

Hysteresis

Also called "Backlash" and "Deadband"



Damper Actuators and Output Characterization

Actuator Characterization – Position vs. Flow

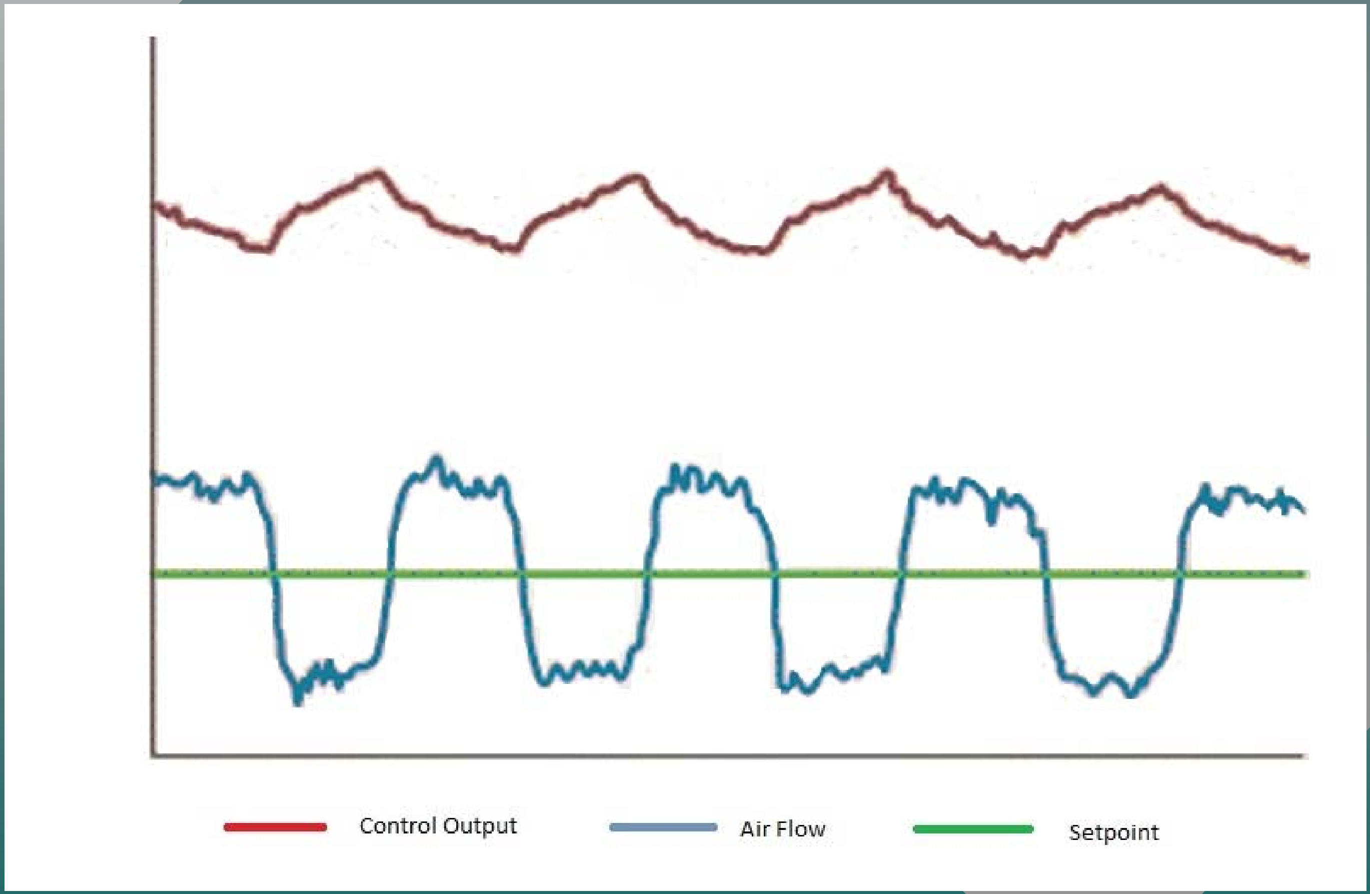
Hysteresis

“Sticktion”

3 - Natural Gas Field Erected Boilers
180 klb/hr @ 150 psi (Saturated Steam)

"Sticktion"

Also called "Stick-Slip"



Load Tests and Characterization

Fuel/Air Curves

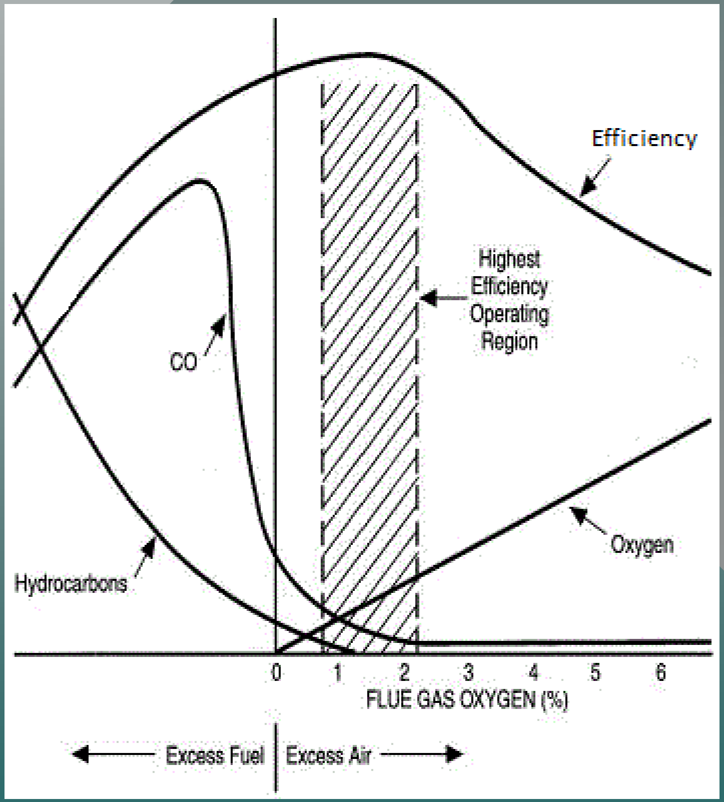
Air Split Curves

O2 SP Curve

Maximize Mixing Effectiveness

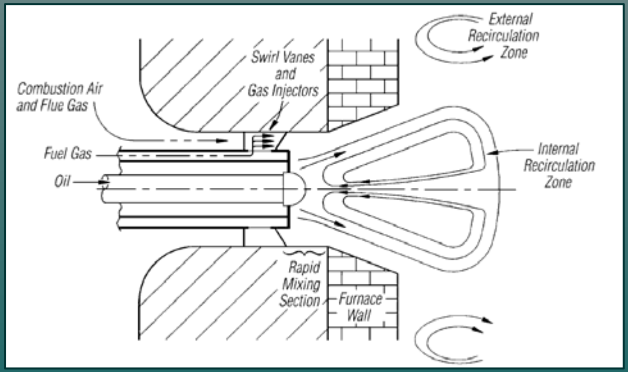
The primary factor determining how low you can go on excess air, is how effectively you can mix air and fuel in the combustion zone.

Maximize Fuel-Air Mixing



During the load tests, lower excess air until CO begins to rise. Then try to improve mixing to slide the CO and Opacity curves to reduce CO.

Air Fuel Mixing on Gas/Oil Burners



Spin or Swirl vane adjustments have traditionally been made primarily by eye, adjusting the mixing pattern by visually observing the flame.

Excess Air is lowered until CO starts to rise.   The swirl adjustment can then be tweaked to improve mixing.

Settings that give the best results at higher loads, are frequently not optimum for lower loads

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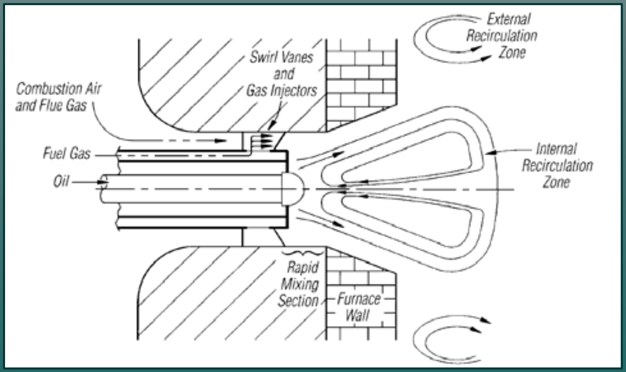
Air Fuel Mixing on Gas/Oil Burners



A Food/Beverage manufacturer had a bank of 5 package boilers supplying steam to batch processes. It was not unusual for the boilers to have extended periods at 20% to 30% load, as well as above 80%

Utilizing a small electric actuator to move the register to different settings at different loads based on a characterization curve, enabled these boilers to run below 1.5% Excess O2 at loads down to 25%!

cibo

Air Fuel Mixing with Oil and PC

As fuels become more complex, so do the considerations necessary to maximize fuel air mixing and combustion.

With Oil Burners, in addition to swirl vanes, you have the interstation point of the gun, type of gun tip, and atomization steam or air pressure.

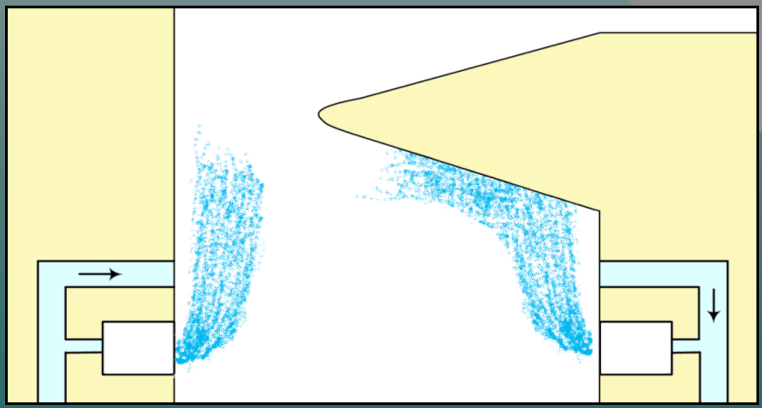
With Pulverized Coal, you have classification size, primary air ratio and mill temperature.

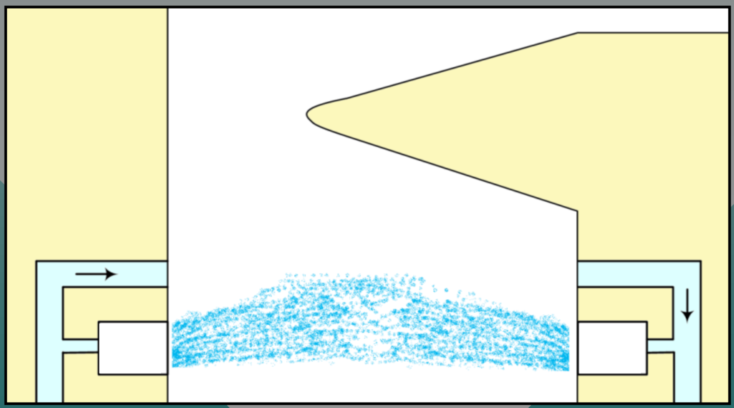
3 – Coal Stoker Boilers
Detroit Stoker
180 klb/hr @ 850 psi

Air Fuel Mixing on Stokers

Typically, Overfire Header Pressures less than 5” is insufficient to create adequate penetration and mixing for complete combustion. At lower header pressures, it becomes Tramp air, showing up as Excess O2, but not really available to complete the staged combustion.

Rather than reduce pressures below this, reduce air elsewhere if possible, or completely shut off ports or headers.





Test Load Ramps

Make Controlled Manual Ramps

Test Robustness Under Natural Ramps

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