Canadian Boiler Society 2019 Education Days

Modern NOx Reduction Strategies

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Emission Limitations

What factors determine achievable emissions?

- NOx
  - $O_{2,}$ Excess Air
  - Combustion Temp.
  - Reaction with Nitrogen
  - Lowering CO
- CO
  - $O_{2,}$ Excess Air
  - Combustion Efficiency
  - Low NOx and FGR
  - Combustion Temp.

- VOC
  - Combustion Efficiency
  - Combustion Temperature
- SOx
  - Fuel Dependent, Sulfur
  - Particulate

Emissions – NOx

Fuel NOx

Fuel Bound Nitrogen (FBN)

- Highly dependent on the concentration of fuel bound nitrogen
- Virtually all becomes NOx

Emissions – NOx

Prompt NOx

- Formed in the very early portion of the flame zone where air and fuel first mix or react. The reaction occurs in a part of the flame where little, if any, Thermal NOx is formed.

Emissions – NOx

Thermal NOx

- For most gaseous fuels, the major concern is Thermal NOx.
- Thermal NOx formation rates are highly sensitive to peak flame temperatures.
- Thermal NOx begins to form at **2800°F (1538°C)**
- Above 3200°F (1760°C), the NOx formation rate doubles for every 190°F (88°C) increase in flame temperature.

Emission Conversion Chart

- ***Burners***
- ***Flares***
- ***Incinerators***
- ***Combustion Systems***

COMMON EMISSION CONVERSION CHART

TO CONVERT	From	To: Multiply by									
			NO_x	SO_x	CO	lb/MMBtu			g/GJ		
		mg/Nm^3	ppm	ppm	ppm	$COAL_a$	OIL_b	GAS_c	$COAL_a$	OIL_b	GAS_c
	mg/Nm^3	1	0.487	0.350	0.800	6.65E-04	6.25E-04	5.92E-04	0.286	0.269	0.255
NO_x	ppm	2.053	1			1.36E-03	1.28E-03	1.21E-03	0.587	0.552	0.523
SO_x	ppm	2.858		1		1.90E-03	1.78E-03	1.69E-03	0.818	0.768	0.728
CO	ppm	1.250			1	8.30E-04	7.80E-04	7.39E-04	0.358	0.336	0.318
lb/MMBtu	$COAL_a$	1503	734	527	1205	1			429.95		
	OIL_b	1600	781	561	1283		1			429.95	
	GAS_c	1689	824	592	1353			1			429.95
g/GJ	$COAL_a$	3.495	1.702	1.223	2.797	2.33E-03			1		
	OIL_b	3.721	1.813	1.302	2.978		2.33E-03			1	
	GAS_c	3.928	1.913	1.374	3.143			2.33E-03			1

Notes:

a: COAL: Flue Gas dry 3% excess O_2; Assumes 263 dsm^3/GJ - 9780 dscf/MMBtu - Reference EPA 40CFR pt. 60, App. A, Meth. 19

b: OIL: Flue Gas dry 3% excess O_2; Assumes 247 dsm^3/GJ - 9190 dscf/MMBtu - Reference EPA 40CFR pt. 60, App. A, Meth. 19

c: GAS: Flue Gas dry 3% excess O_2; Assumes 234 dsm^3/GJ - 8710 dscf/MMBtu - Reference EPA 40CFR pt. 60, App. A, Meth. 19

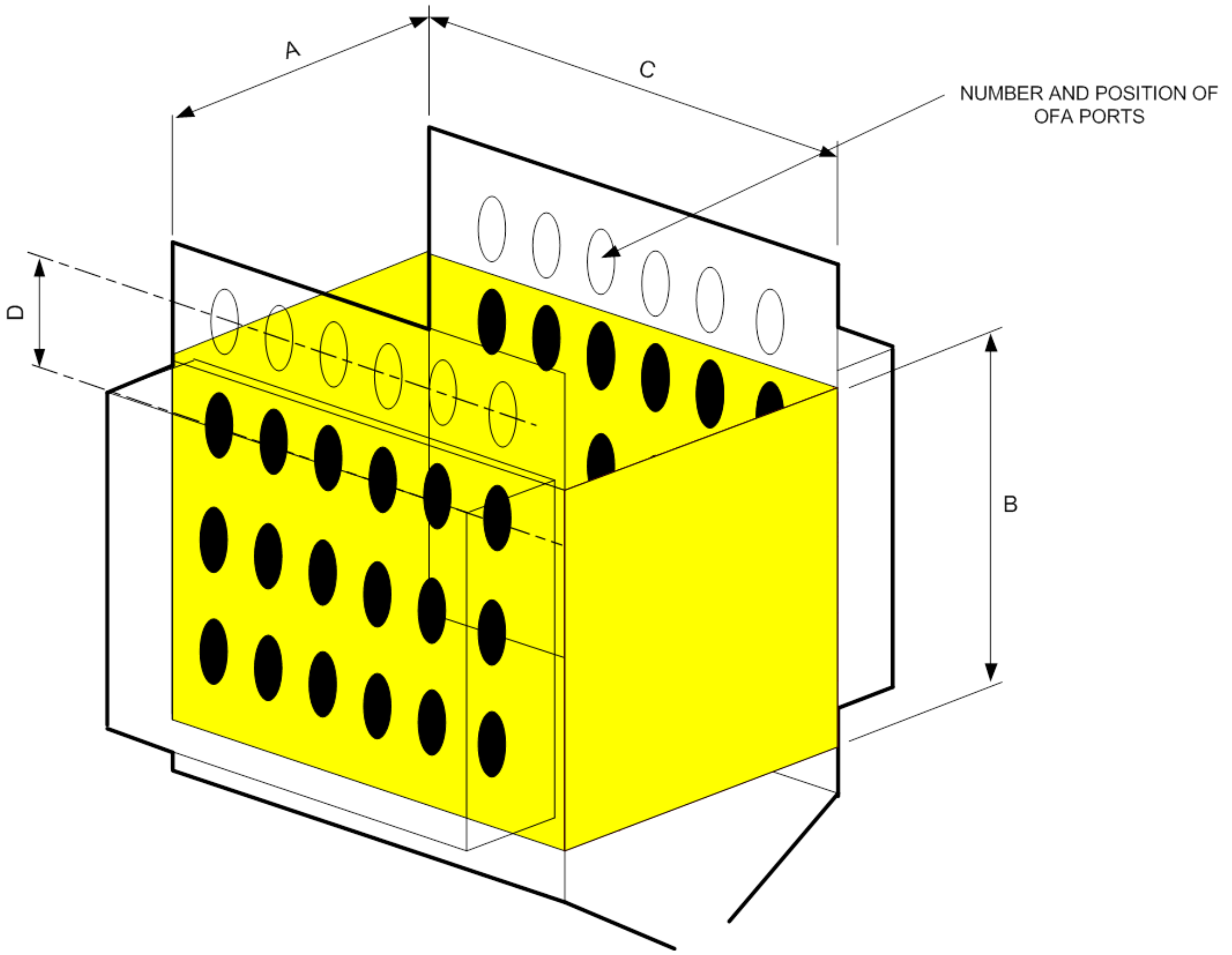
STANDARD CONDITIONS (IMPERIAL); 68°F, 1 atm.

NORMAL CONDITIONS (SI); 32°F, 1 atm.

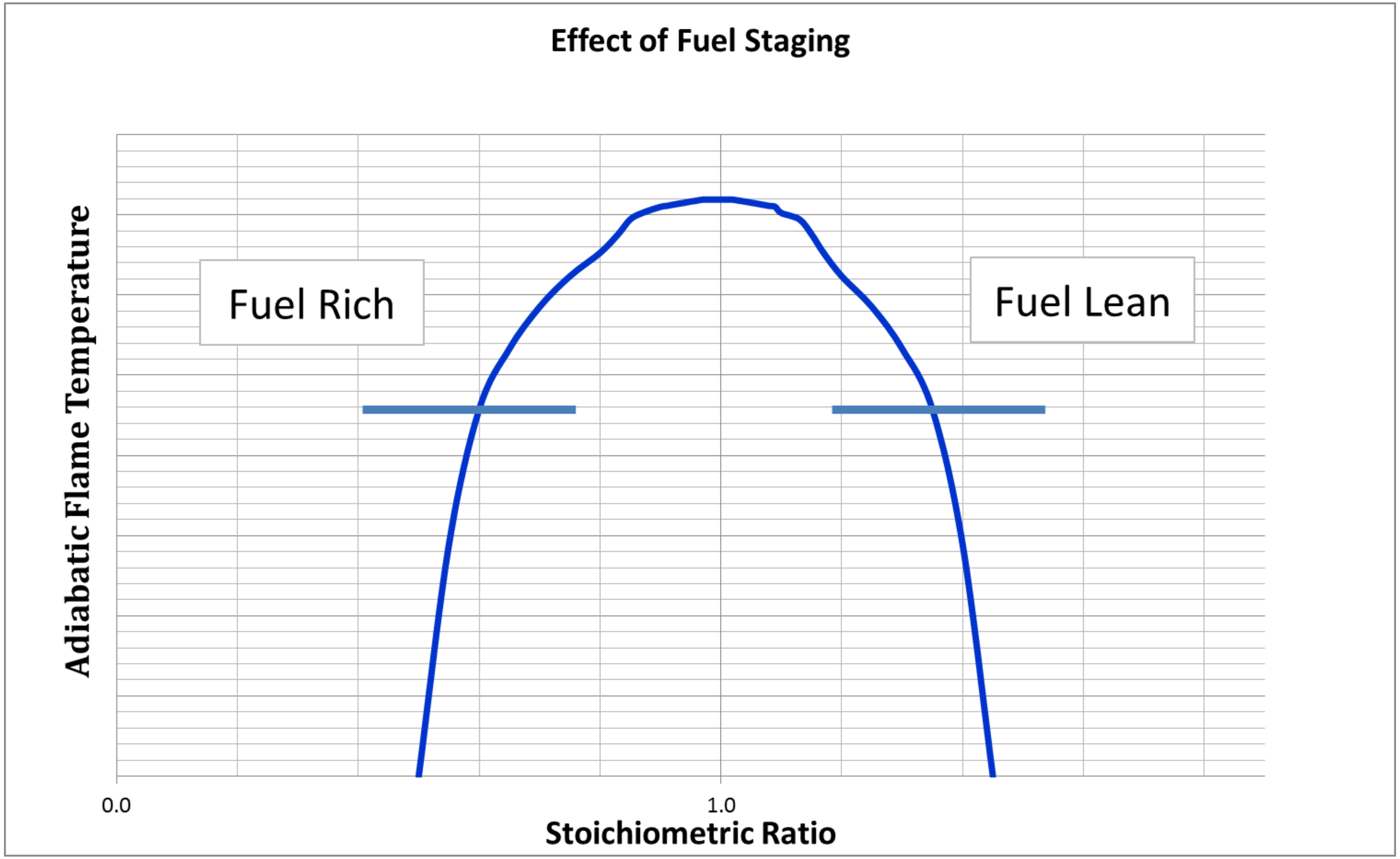
Burner Zone Heat Release - BZHR

What do we mean by Burner Zone Heat Release (BZHR)?

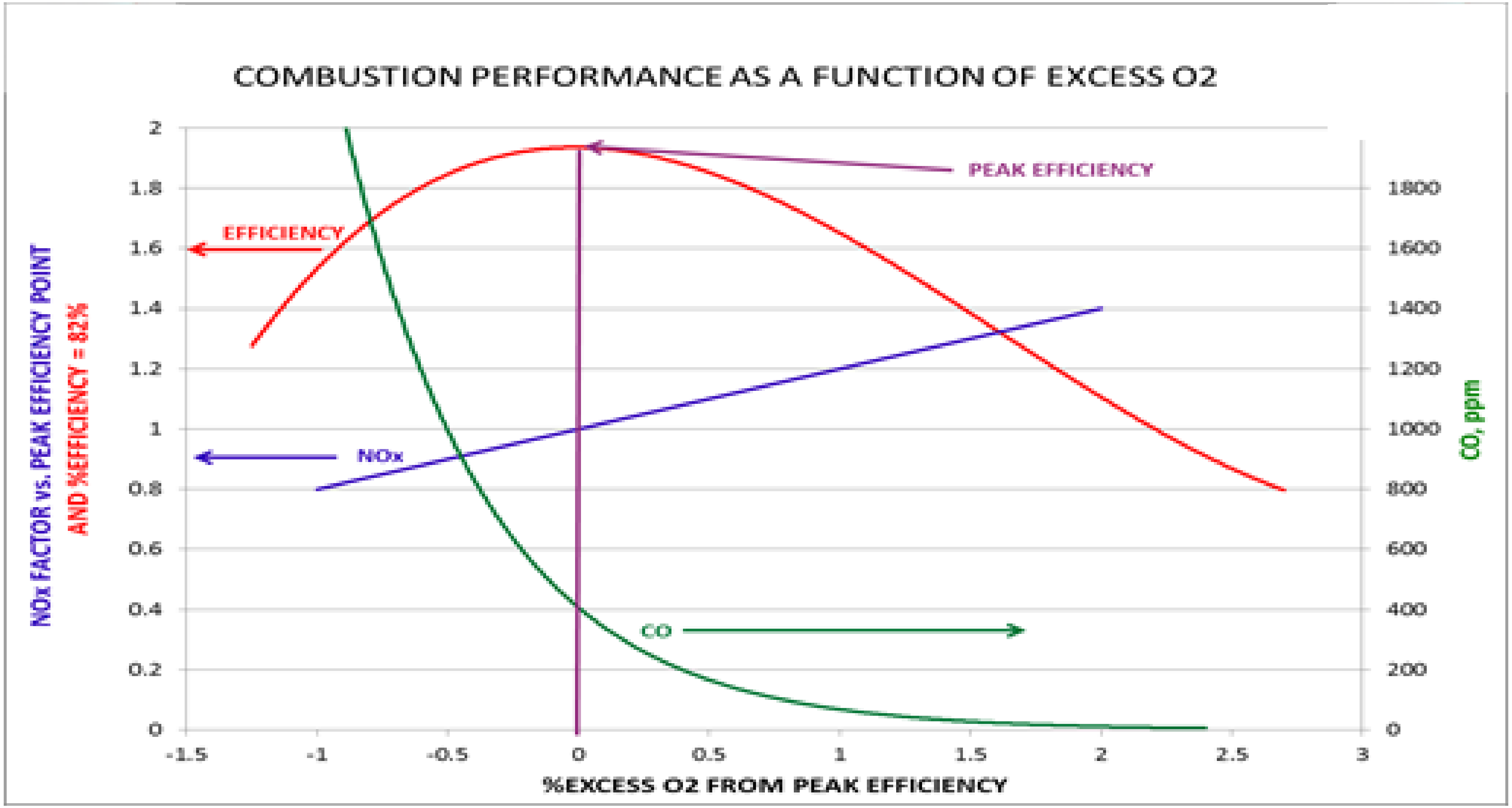
Available heating surface area compared to the heat input.



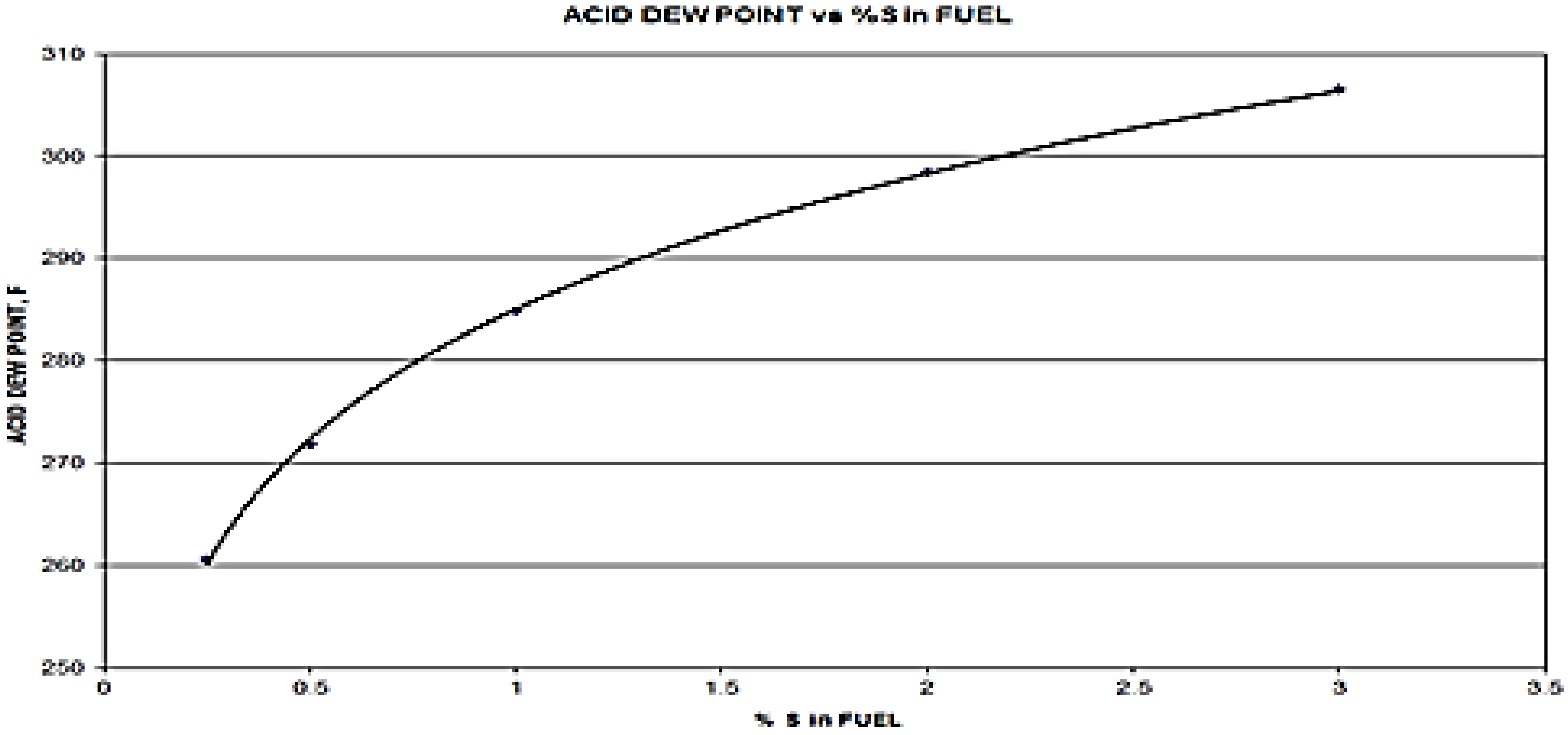
➤ Effect of Fuel Staging



NOx Correlation

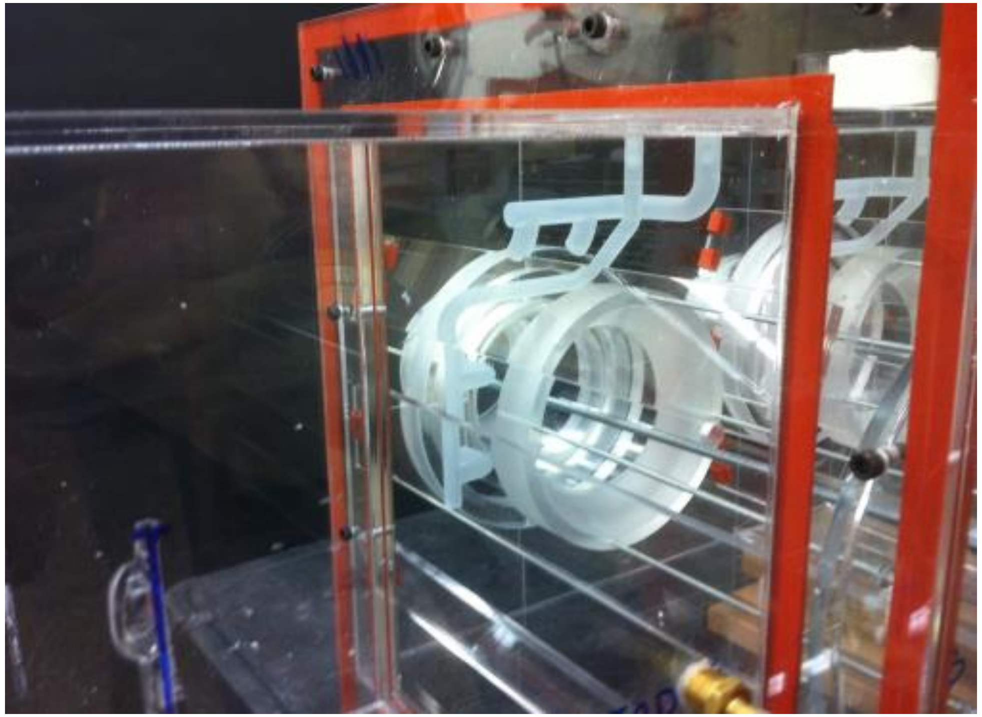


Acid Dew Point



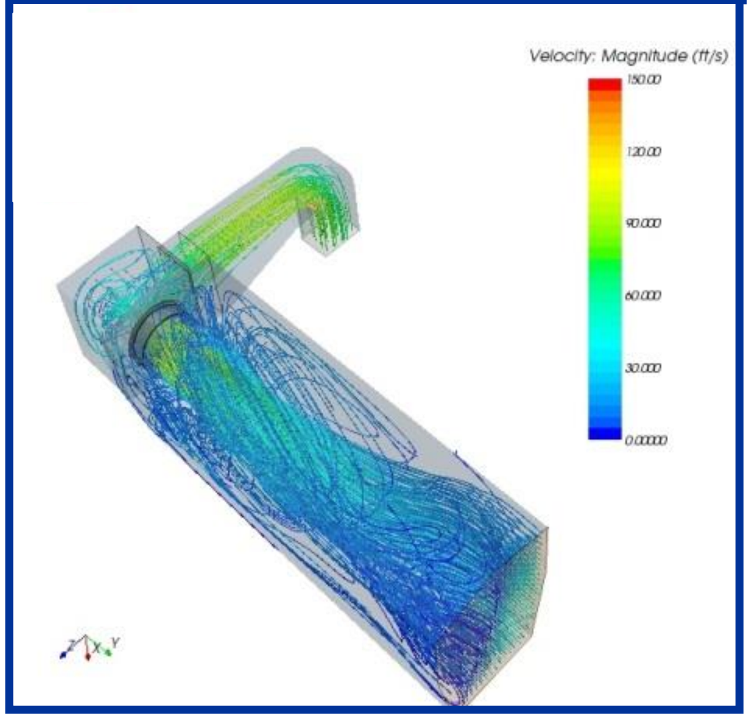
Proper Combustion Air Flow

- **95% OF MASS FLOW IN THE COMBUSTION PROCESS IS AIR**
- **THREE FUNDEMENTAL ASSUMPTIONS OF BURNER DESIGN**
  1. Balanced airflow to all burners +/-2%
  2. Even peripheral distribution around each burner entrance +/-15%
  3. No swirl entering the burner, other than what's imparted by the burner itself

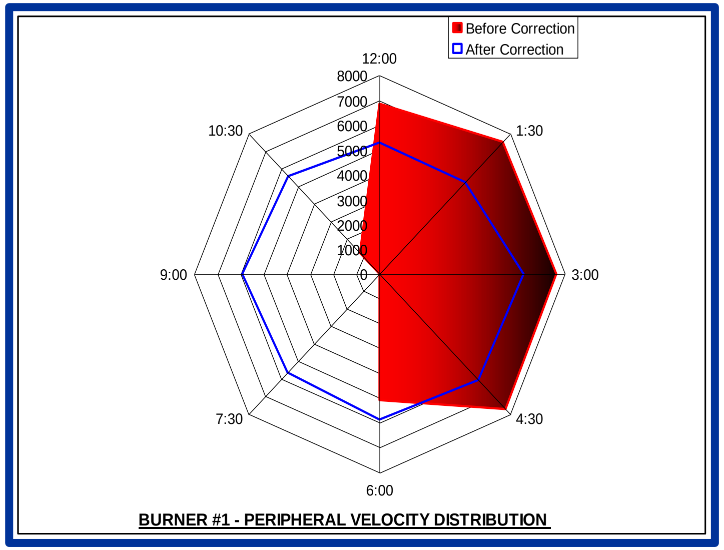


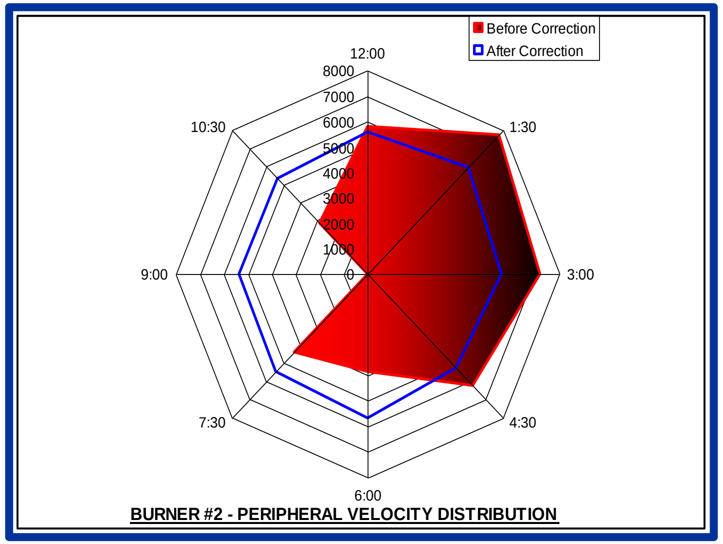
Physical Flow and CFD Modeling

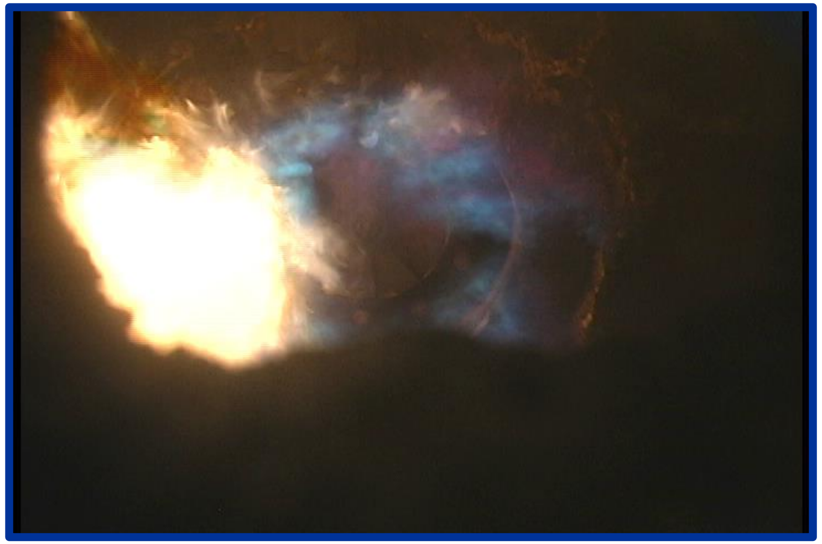
- Burner-to-burner balance for multi-burner installations
- Lowers excess air requirements
- Used on all burners / OFA / FGR systems
- Required for all fuels and unit types
- Lowers CO_2 footprint
- Minimizes startup and commissioning times
- Can Eliminate Combustion Vibration



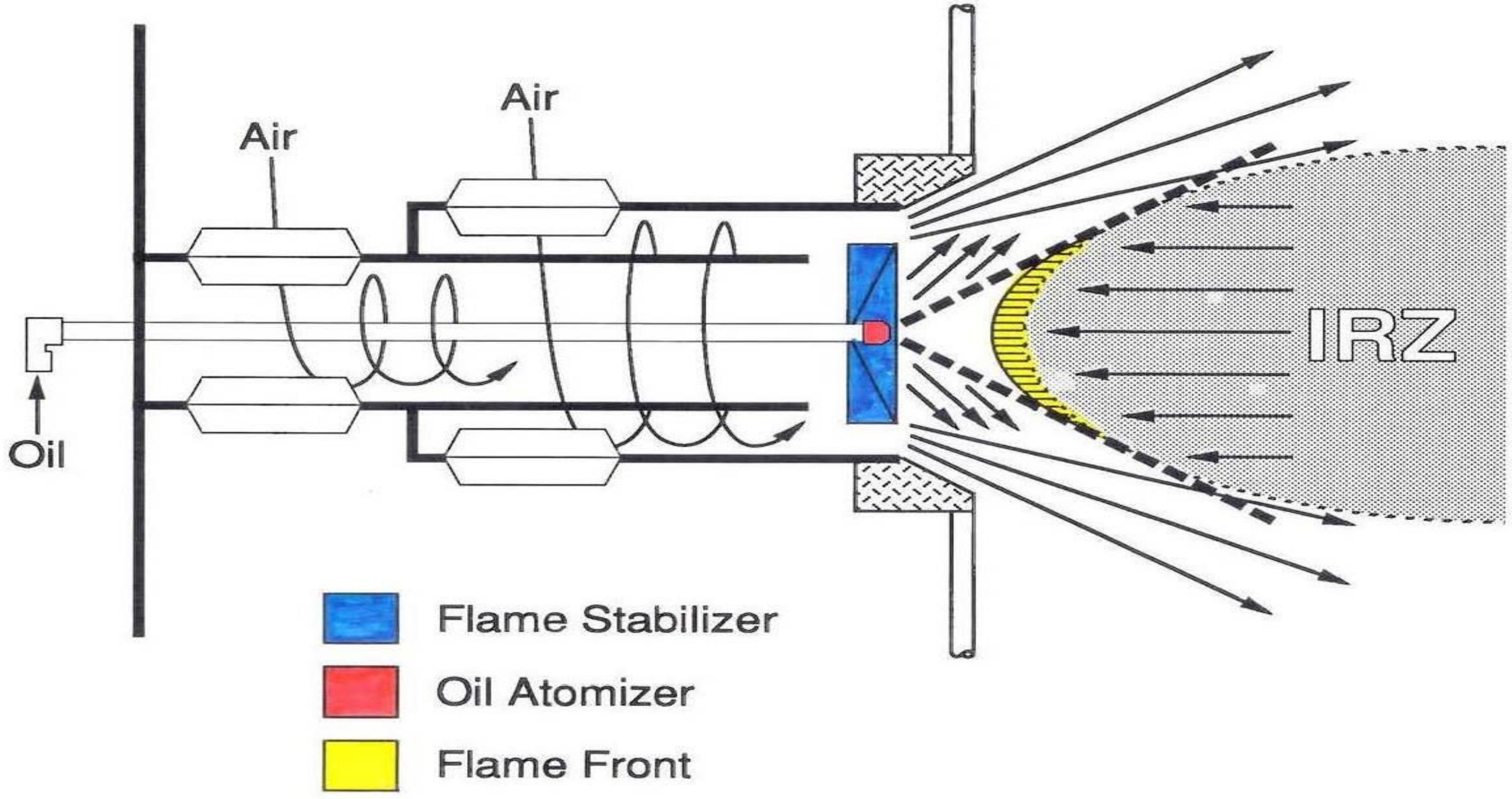
Airflow Imbalance = Flame Imbalance = Emissions



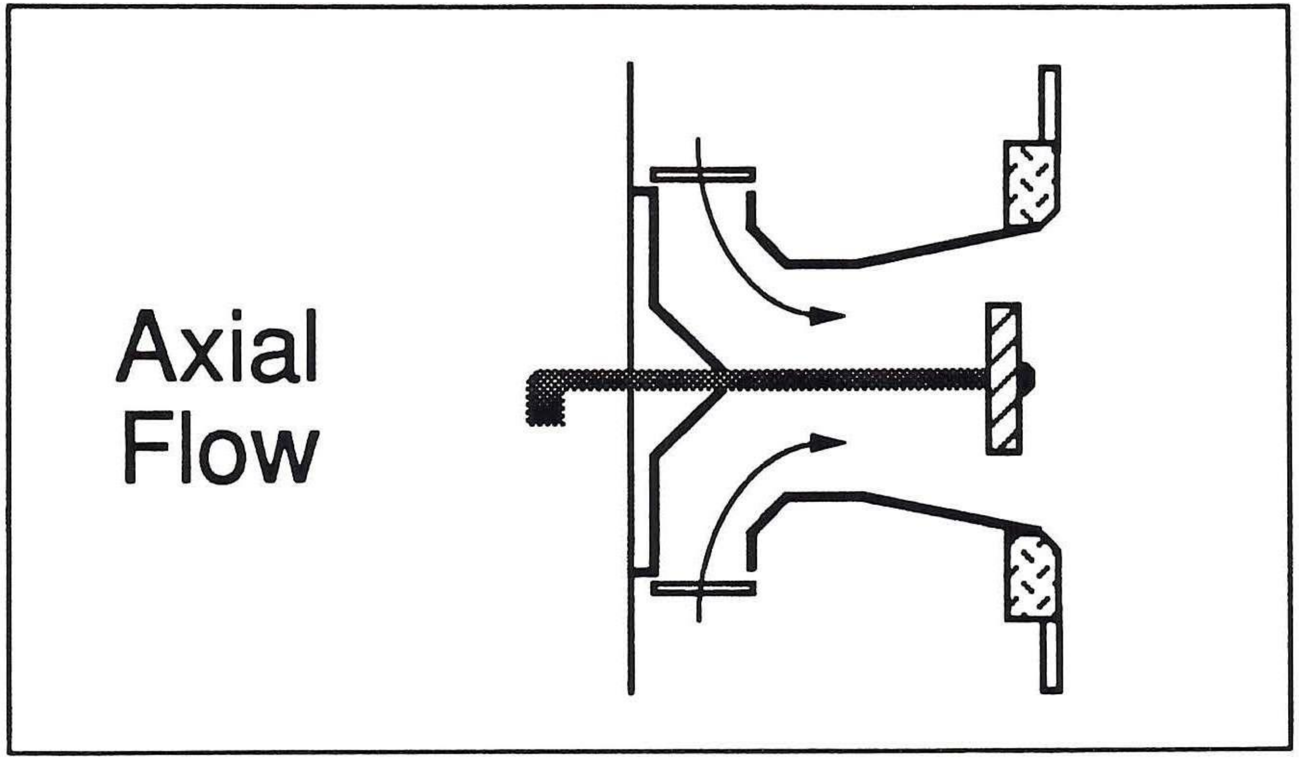




Dual Register Burner

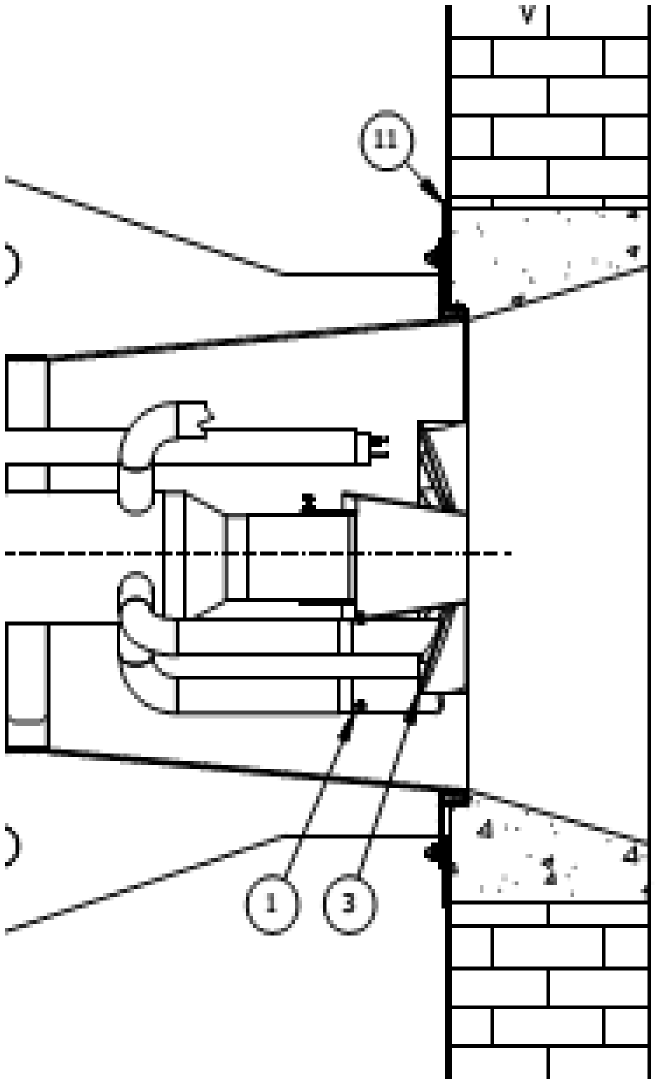


Axial Flow Register



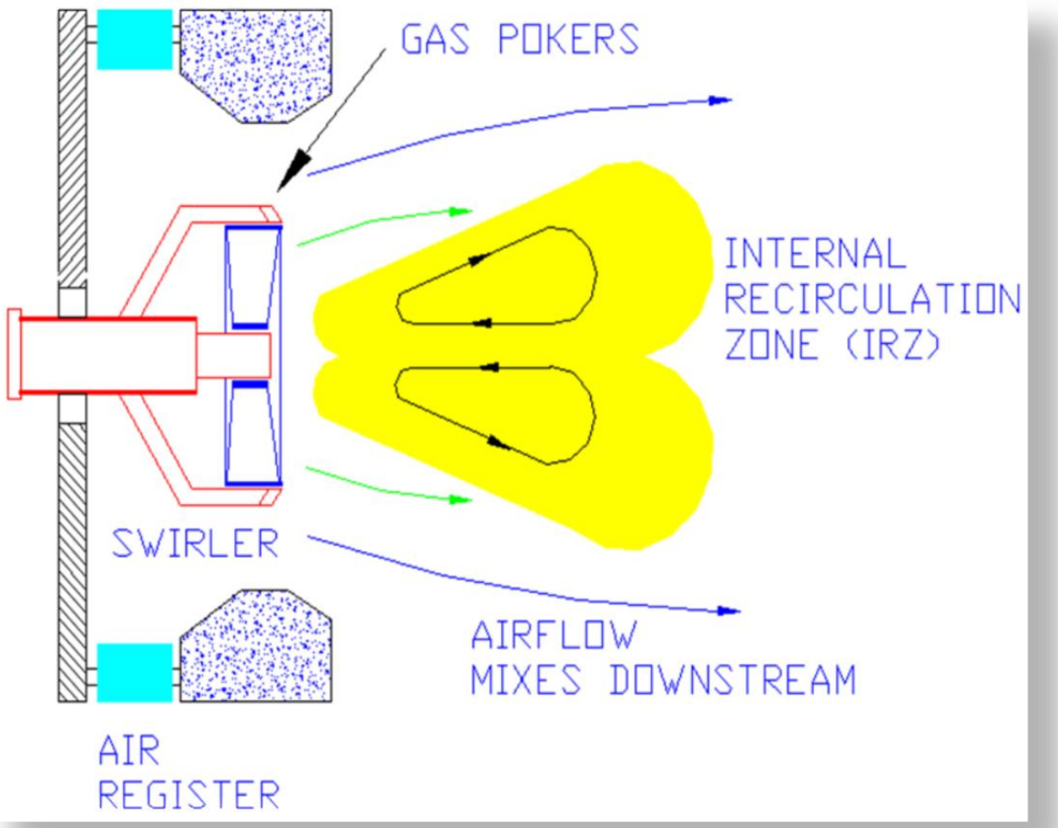
Low NOx Burner

- Players: Variflame, DLN, DeltaNOx, MSC, DFL, GB……
- Low NOx Design:
  - 50-80ppm w/no FGR
  - 30ppm with 15% FGR
  - 100ppm CO
- Staged Gas within throat for NOx Reduction



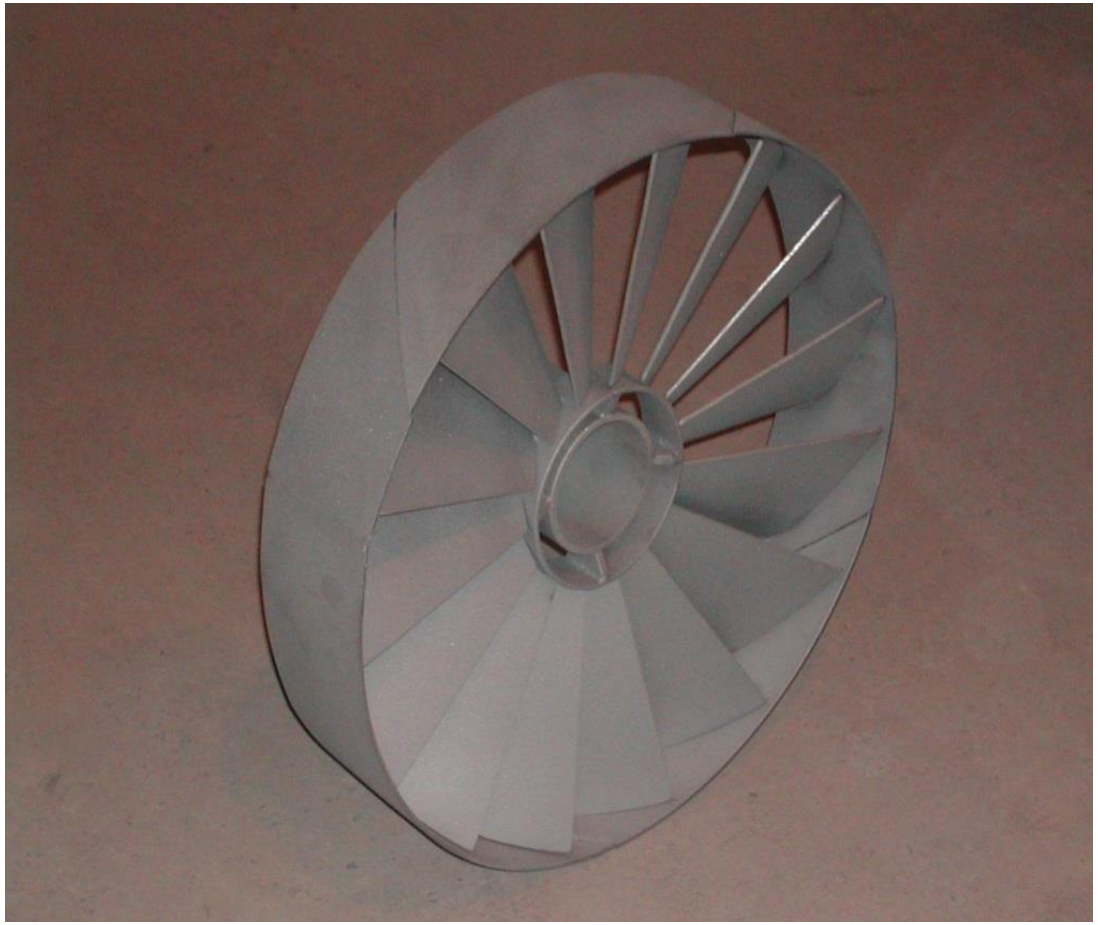
Burner Stabilization

- Swirling air produces a vortex at the burner outlet which induces hot furnace gases to flow back towards the burner
- This is referred to as the Internal Recirculation Zone (IRZ)
- The IRZ creates burner stability



Airflow Dynamics

- Burner Swirl Number (Sn) represents the ratio of tangential momentum to axial momentum
  - Sn = Tangential Momentum
  - Axial Momentum
- A ratio of 0.6 is required to form an IRZ



Airflow Dynamics

- Avoid airflow disruptions

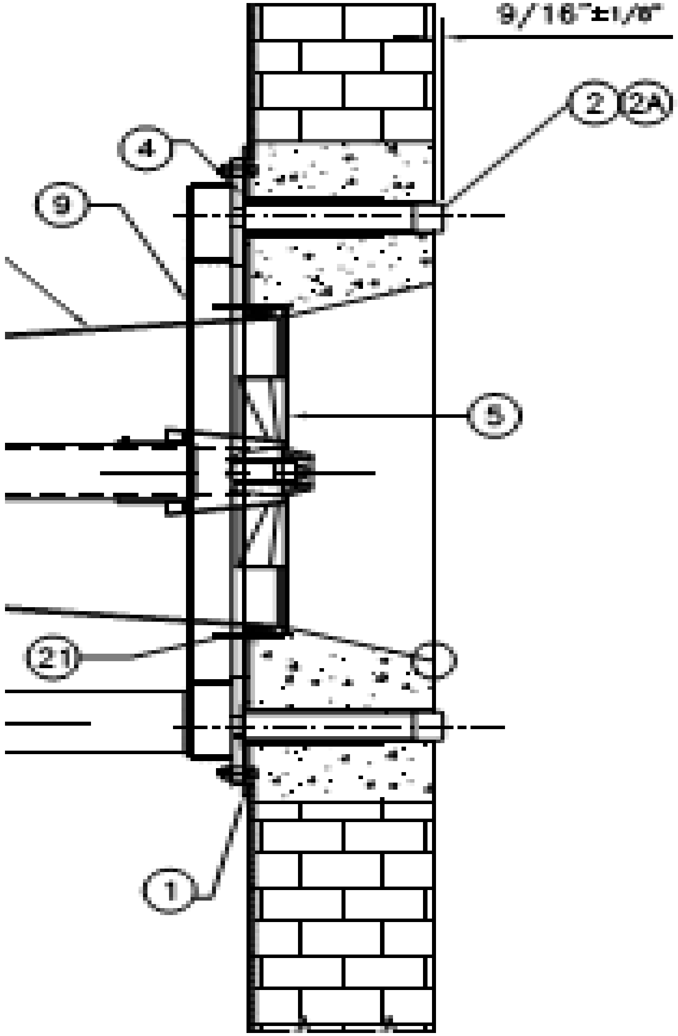
Defining Ultra Low NOx

- From a combustion point of view

  ULTRA LOW NOx = CONTROLLED INSTABILITY
- A very important point to be aware of and take into consideration. The significance of significant digits
  - EPA MACT Requirement is 0.01 lb./MMBtu
  - 0.01 does not necessary equal 0.010
  - 9 ppm equals 0.011 (9 ppm NOx = 23.22 mg/Nm^3)
  - 0.010 equals 8 ppm
  - 0.01 technically equals anything up to 0.0149 (12 ppm) (12 ppm or 24mg/Nm3)
  - **DON'T PAINT YOURSELF INTO A BOX WHEN APPLYING FOR PERMITS!**

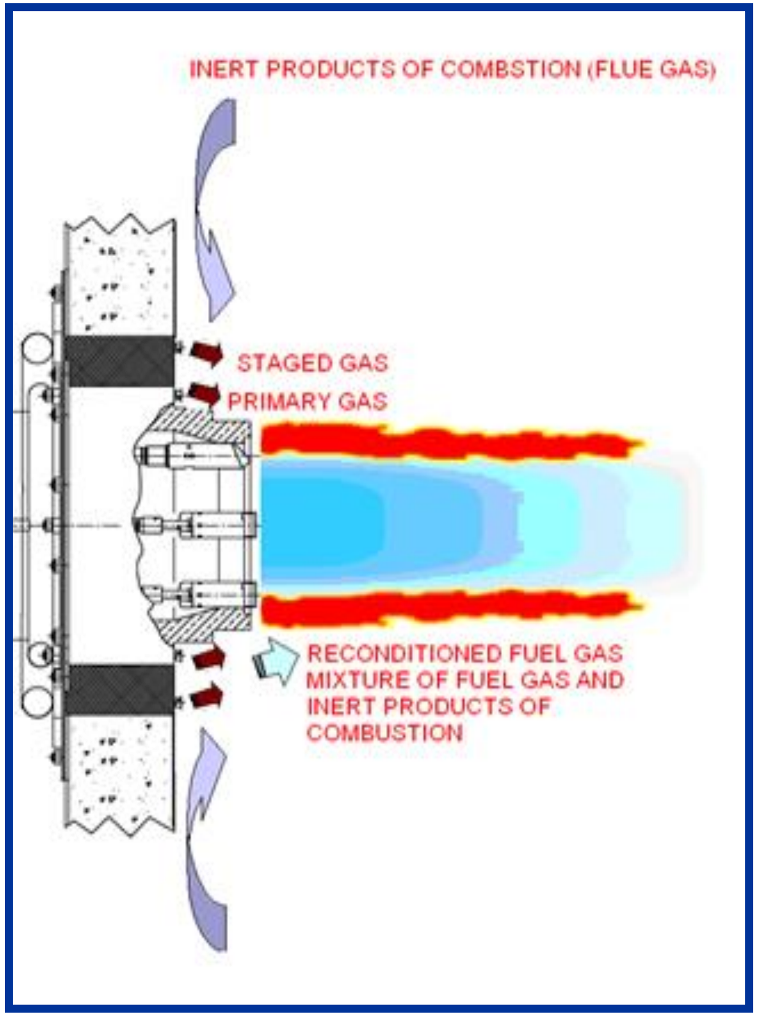
➤ Ultra Low NOx Burner

- Players: QLN, Variflame-II, Ecojet, Freejet-V
- Center Fired Gas for Stability
- Staged Outer Gas for NOx Reduction
- Stages fuel and air, and uses furnace gases to Dilute fuel
- Fuel gas is mixed with inert products of combustion before combustion occurs, thus "reconditioning the fuel gas"

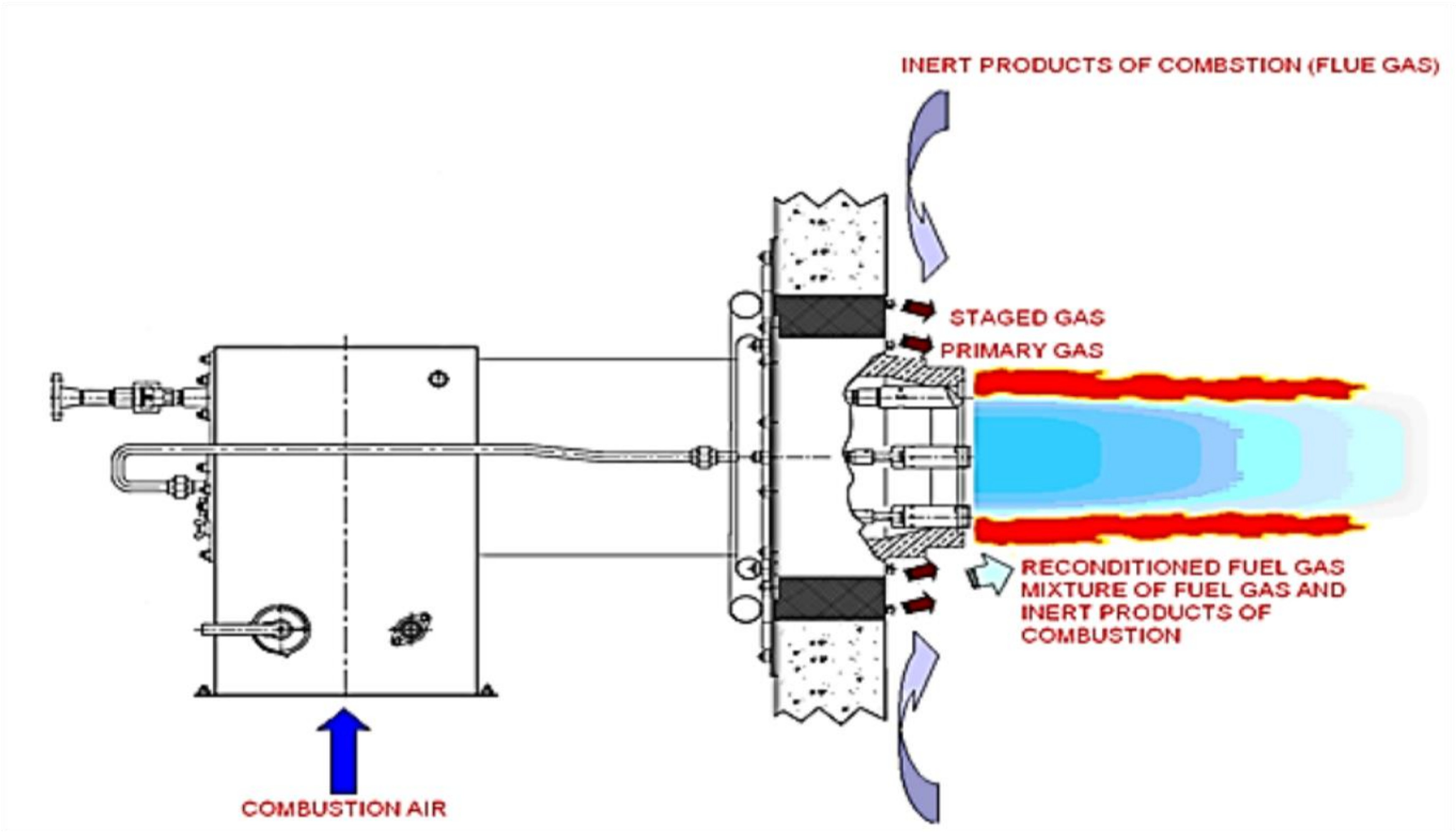


Ultra-Low NOx Burner Technology

- Applicable to virtually any boiler type, industrial and power applications
- **Lowest NOx / 10-15% Excess Air**
  - 9 ppm NOx with **12-18% external FGR**
  - 30 ppm NOx with **no external FGR**
  - 50 to 100 ppm CO
  - Up to 360 MMBtu/hr in a single burner
- Can use **Internal** and **External** FGR
- Multi-fuel Capability
- Turndown: 4 to1 on emissions, 10 to 1 on operation



Ultra-Low NOx Burner Technology



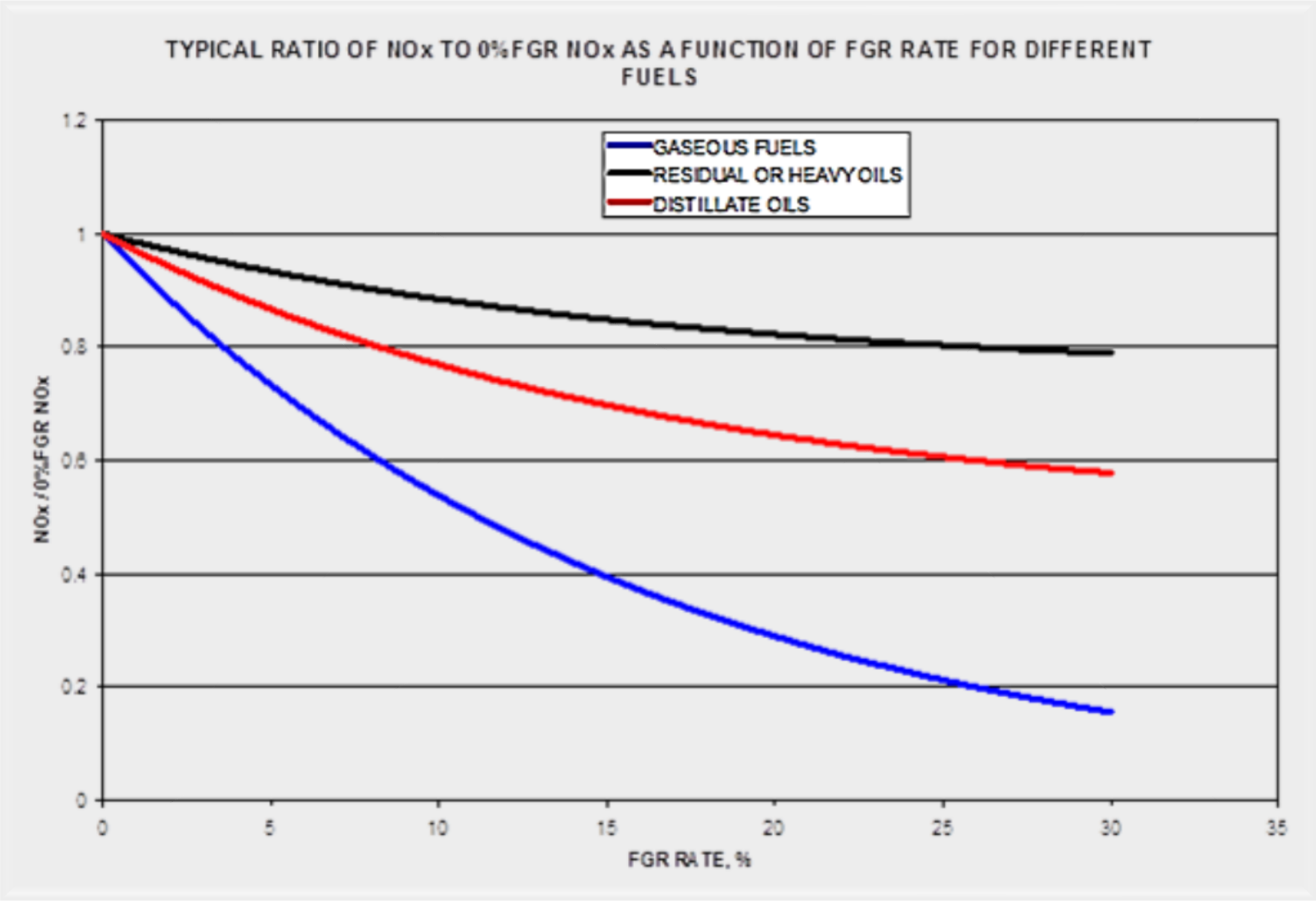
Flue Gas Recirculation

- A portion of the exhaust gas is directed back to dilute the air/fuel stream of the burner in order to:
  - Absorb some of the heat of combustion
  - Reduce adiabatic flame temperature, and thereby reducing Thermal NOx
- FGR is most often expressed as a percent and refers to the mass percent of the flue gas exiting the stack that is being directed back to the burner

Flue Gas Recirculation (FGR) - Lower Thermal NO_x

- Applied to Field-erected and Package boilers alike
- Forced FGR Fan and Duct requirements
  - Higher capital and maintenance
  - Added controls
  - Less efficient system
- External FGR will impact balance of heat transfer
  - Lower radiant furnace heat transfer and higher convective heat transfer
  - Lower FEGT out of furnace
  - More mass flow through convective bank
  - When adding more than 10% FGR, a boiler impact study should be performed

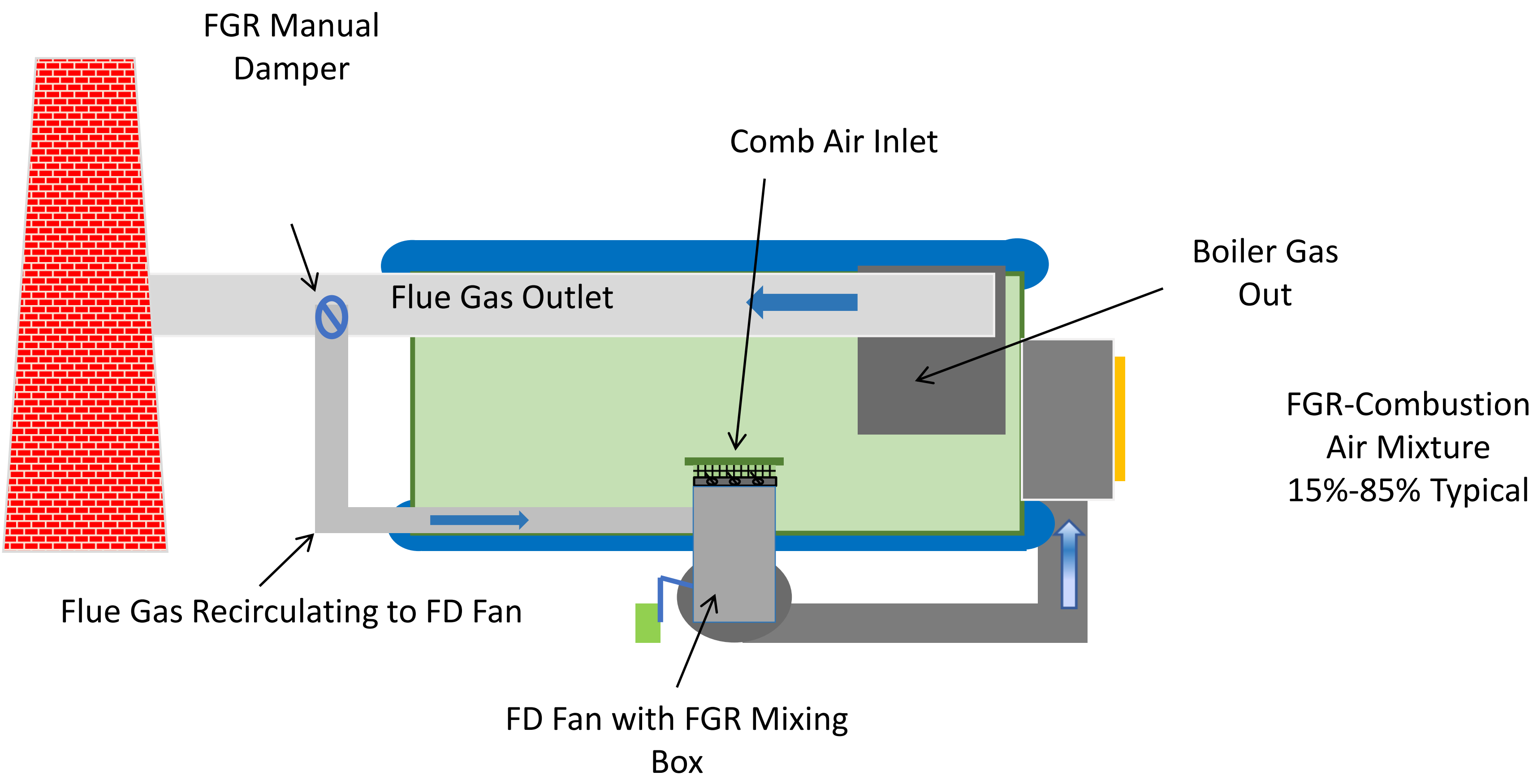
Flue Gas Recirculation Rates



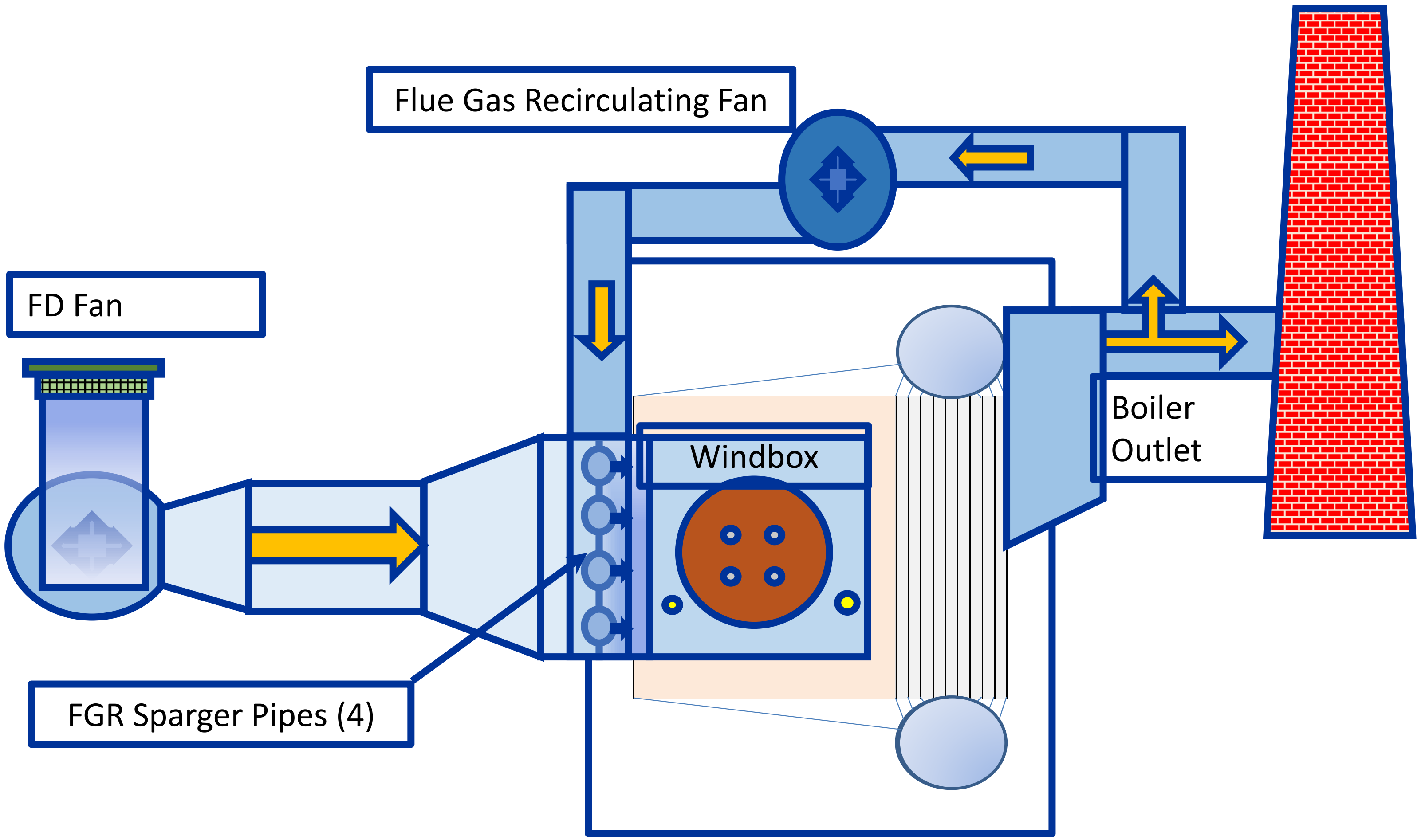
Flue Gas Recirculation Systems

- Induced Flue Gas Recirculation – IFGR
  - Uses eduction of FD fan to draft flue gas from boiler outlet
  - Fan sizing could be an issue
  - System design and control of flow can be difficult
  - Great mixing of inert gas with combustion air

Induced FGR System



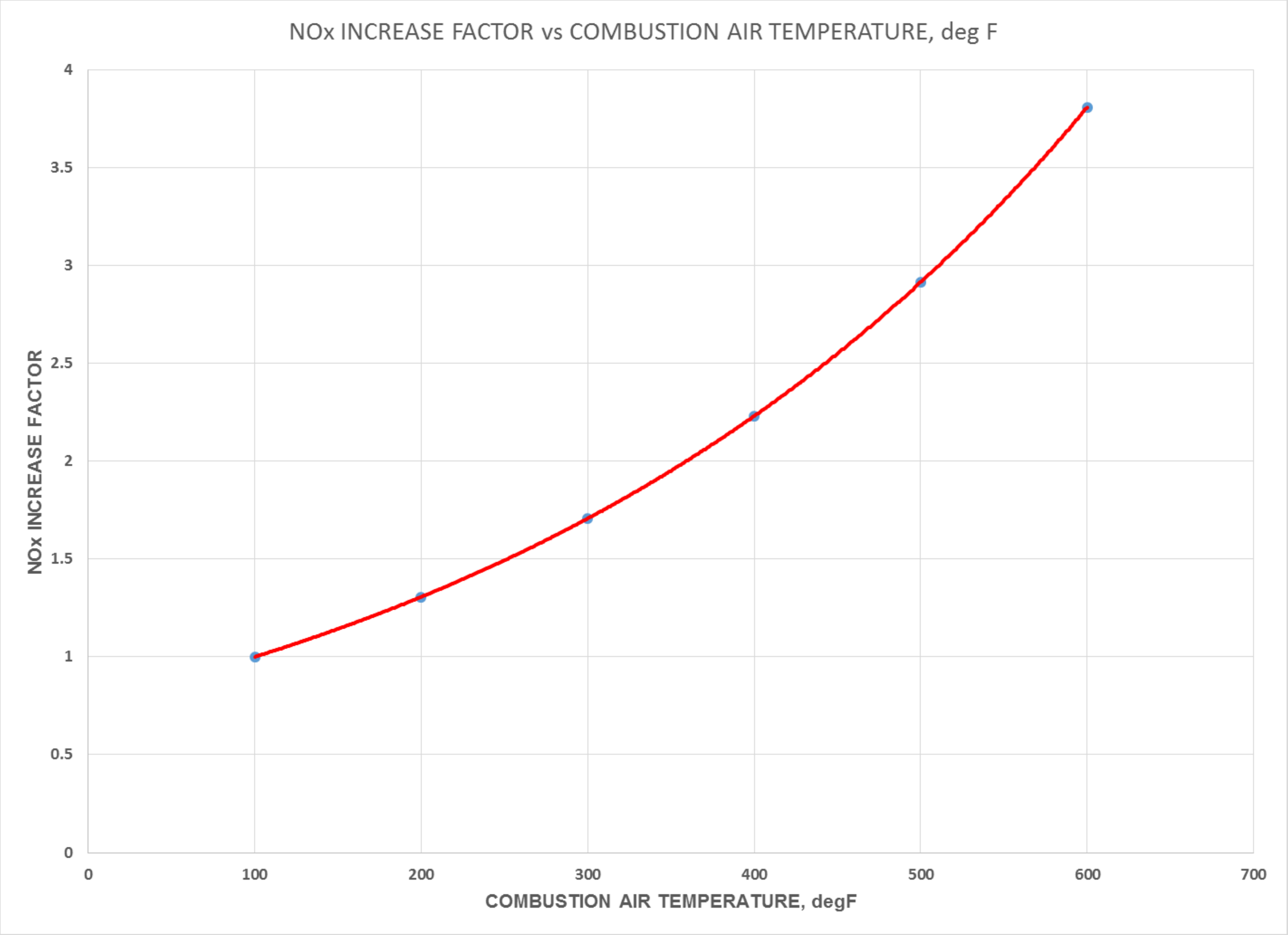
Forced FGR System



Different NOx Reduction Methods – OFA (and Fuel /Air Biasing)

- Applied to Field Erected Boilers with vertical gas path
- Has been unsuccessfully applied to package style / horizontal gas path boilers
- Typically designed for 15-30%
- Generally want 1-2 burner pitch (~6-16’) from top row of burners to OFA ports
- Minimum of 2 burner pitch (12-16’) from OFA port to nose
- BOOS (Burners Out Of Service)

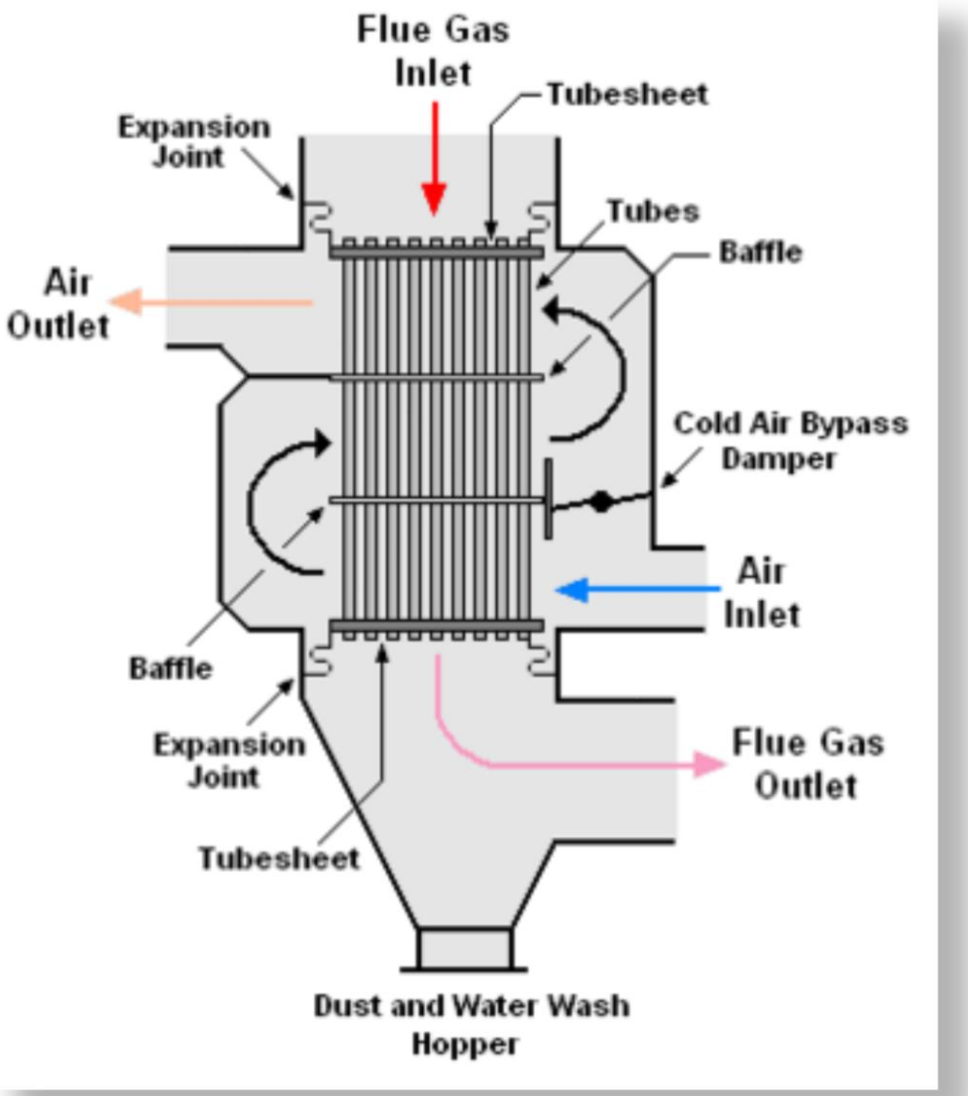
➤ Effect of Combustion Air Temperature on NOx



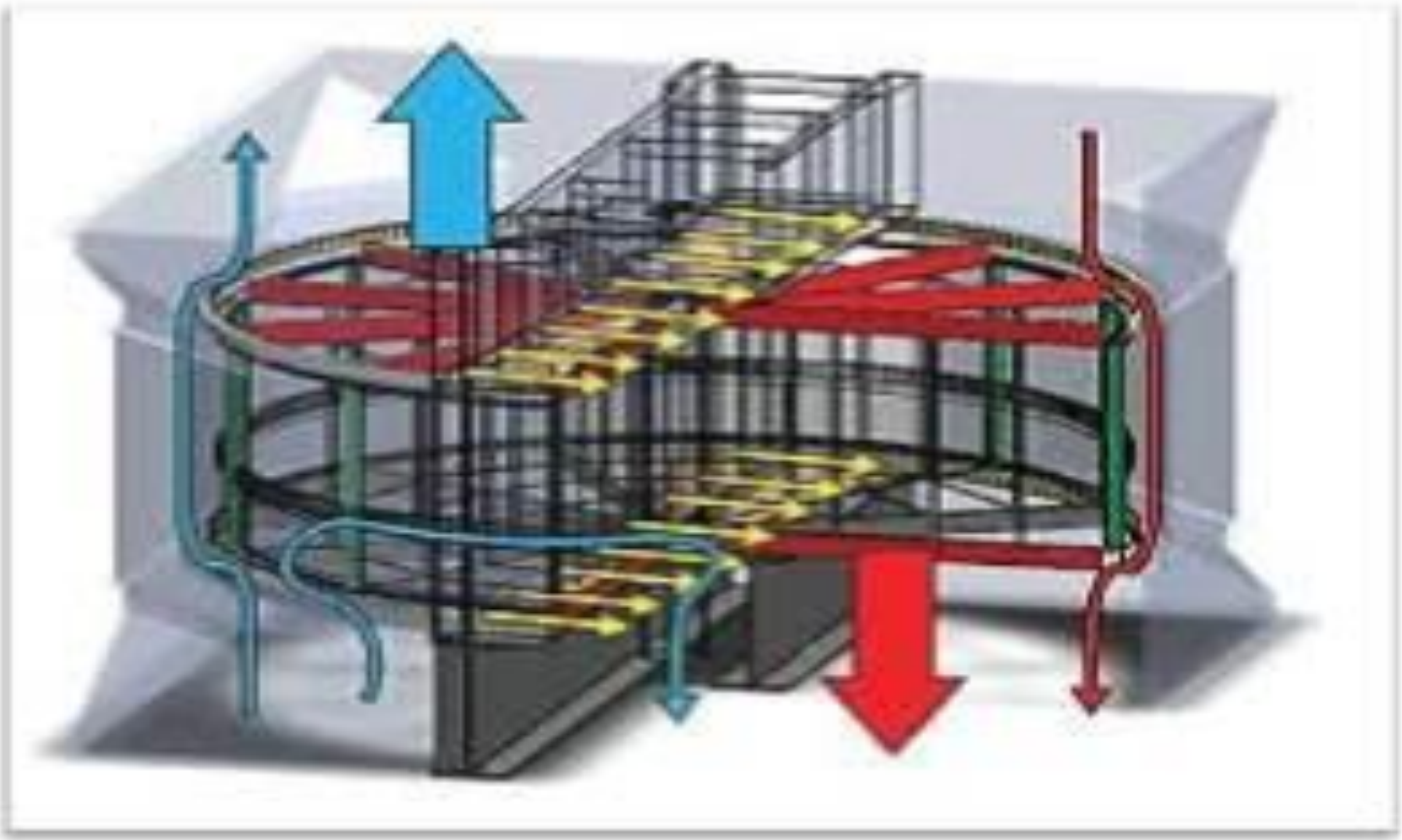
Other Reduction Methods

- Replace Air Preheater with Economizer / Upgraded Economizer
  - Recommended when converting from coal to all gas
  - Improves efficiency and pay for project with fuel savings
  - Allows use of existing fans, even when adding FGR
  - Typically requires a burner change due to lower Register Draft Loss (RDL)
- Tempering water/steam injection
- Post Combustion – SNCR / SCR

Tubular Type Air Preheater

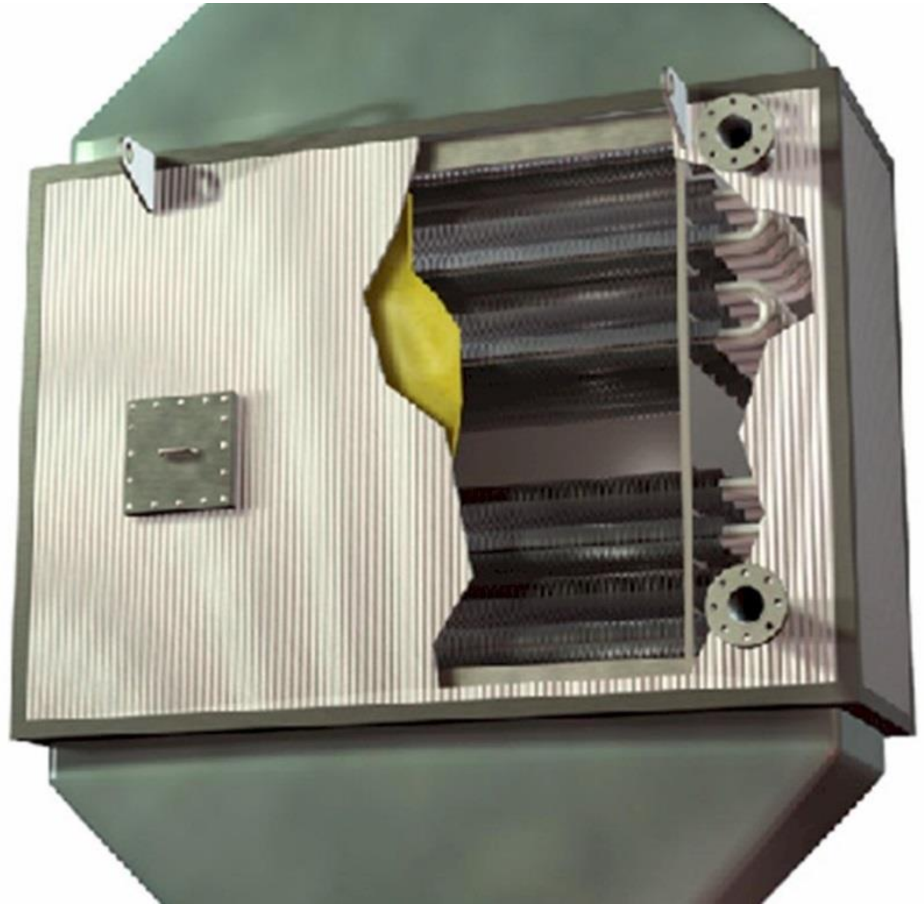


Regenerative Type Air Heater



Economizer

- Heat Exchanger
- Increases boiler efficiency
  - 1% for every 10^{o} increase in feedwater temperature



Different NOx Reduction Methods

FUEL/ TECHNOLOGY	GASEOUS	LIQUID/ SOLID
OFA	MODERATE	EXCELLENT
FGR	EXCELLENT	MODERATE (LFO)/ POOR (OTHERS)
STEAM INJECTION	EXCELLENT	MODERATE (LFO)/ POOR (OTHERS)
COMBUSTION AIR TEMP REDUCTION	EXCELLENT	POOR-NONE

Burner / System Solutions

Evaluation can consist of the following:

- Complete new burner systems
  - Conversions can potentially be the least expensive from a full project cost analysis
  - Lowest risk from an emission guarantee standpoint
- Retrofitting existing burner
  - Details on the burner needed
  - May be costly on a full evaluated basis
  - “Condition assessment” of existing firing system

Thank you!

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