Gateway to
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Fives Pillard - Rotary Kiln Burner

Eduardo Tater

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October 27-30, 2019
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Fives Pillard - A company of Fives Combustion business unit

<u>**Minerals and Energy Sectors**</u>

- Fives Pillard: **5 offices - France, Germany, Spain, China and India**
- Key markets: **5 continents**
- Income: **68 Mio €**
- Headcount: **385 persons**

In **110** | countries

More than **1300** | burners installed

Combustion efficiency

Burner operability

➔ **ROTAFLAM® Burner:**

- About **500 burners** installed excluding cement kilns.
- In more than **50 countries**
- For more than **20 different applications**:

– Lime
– Ferronickel
– Lithium
– Magnesia
– Alumina
– Zinc oxide
– Gypsum
– Iron
– Copper
– Pelletizing
– Uranium
– Phosphates
– Manganese
– Nickel / Cobalt
– Titanium dioxide
– Attapulgite
– Chromium
–Kaolin
– Chamotte
–….

Lime Calcination

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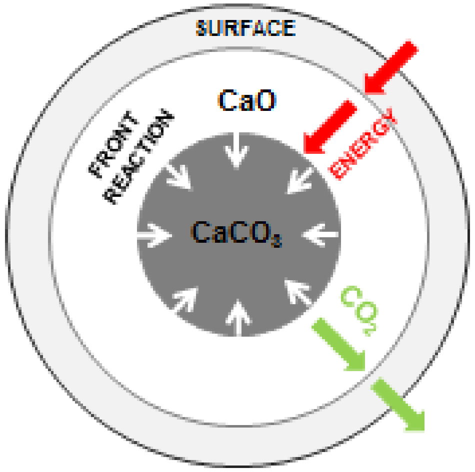
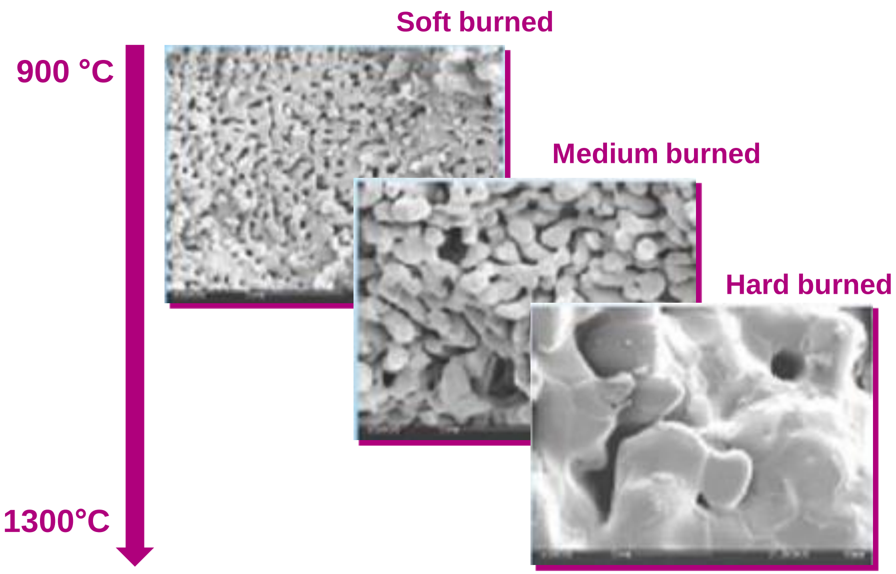
Lime calcination

$$CaCO_3 + \textbf{HEAT} \rightleftarrows CaO + CO_2 \uparrow$$

100g 3200 kJ/kg CaO 56g 44g

$CaCO_3$ dissociation T > 900°C

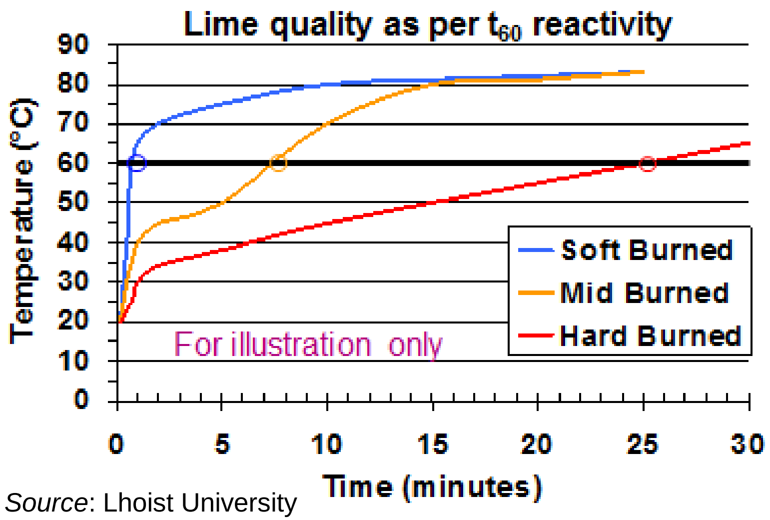




Source: [44, EuLA, 2006], [168, TWG CLM, 2007]

CALCINATION RATE & LIME REACTIVITY DEPENDS ON:

- Characteristics of the limestone / lime mud
- Particle size distribution
- Shape of the particles (for limestone calcination)
- Burning temperature & Temperature profile
- Residence time
- Crystalline structure of limestone / lime mud
- Presence of impurities creating interstitial liquid phase
- Kiln type (pebble lime) and fuel



Source: Lhoist University

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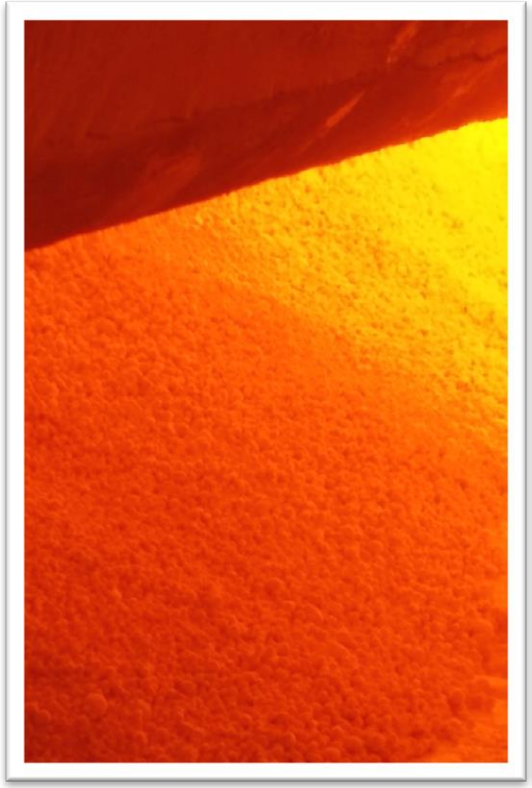
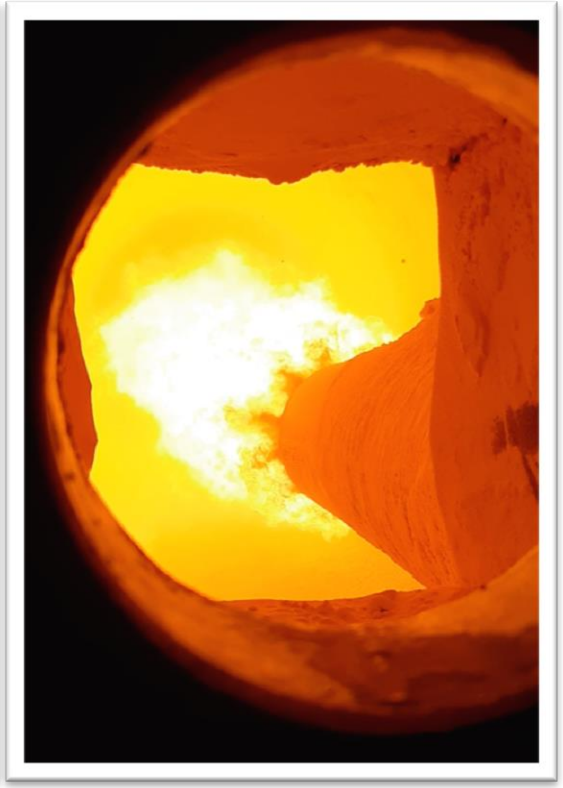
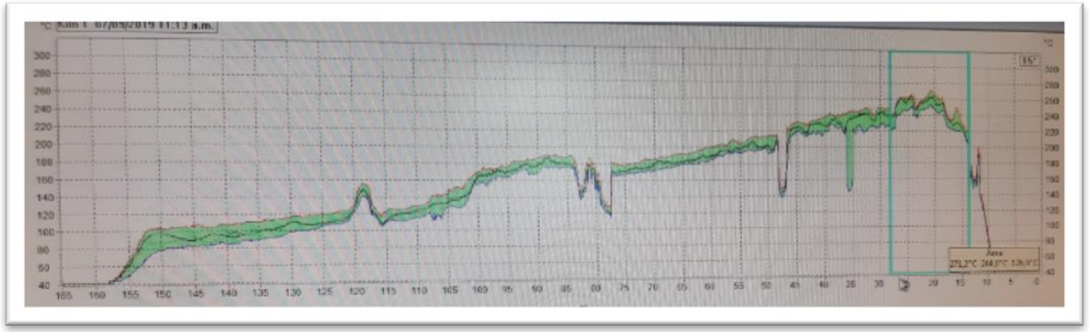
Lime calcination

Burner impact on the lime calcination:

- ✓ Controls flame shape and the kiln temperature profile:
  - One of the main parameters affecting the lime quality (residual carbonate & reactivity).
- ✓ The flame should have the correct length:
  - Too short ➔ Excessive temperatures in burning zone, lime surface overburning and reducing reactivity. Risk of refractory failure.
  - Too long ➔ Insufficient radiant heat transfer in calcining zone, higher back-end temperature and lower thermal efficiency. Risk of rings and build-ups formation due to lazy and unstable flame (temperature variations)







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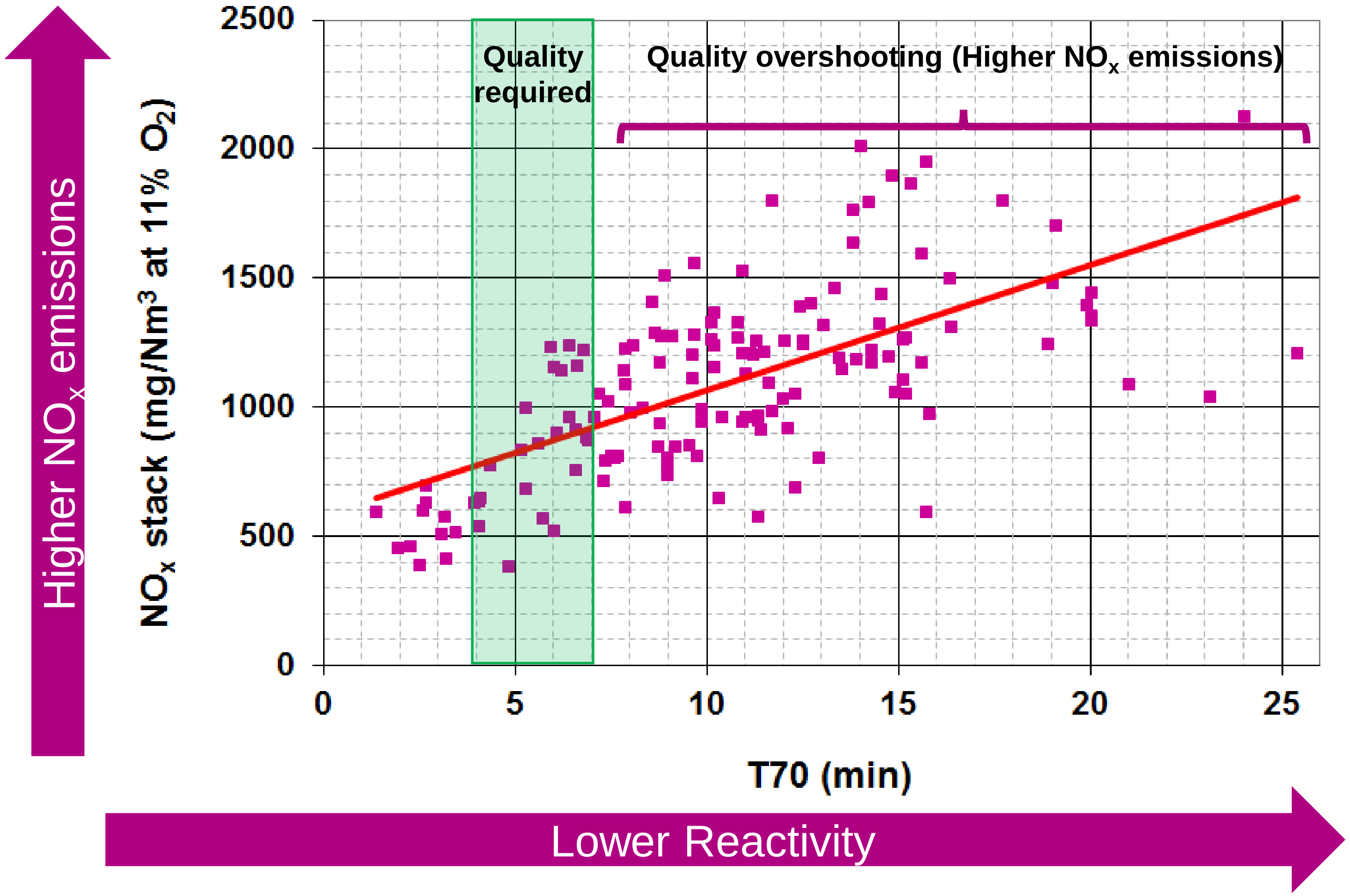
Lime calcination

NO$_x$ emissions: a good indicator of burning zone conditions

- NO$_x$ emissions in rotary kilns: mainly of thermal origin (vary exponentially with the temperature).
    - ✓ Good indication of process stability and burning zone conditions (burning zone cooling down, stable or getting hotter).
- **Example 1:** NO$_x$ emissions in function of pebble lime reactivity (t70).
    - ✓ Lower reactivity (higher t70) are accompanied by higher NO$_x$ emissions, indicating that the lime was overheated (higher burning zone temperatures).



ROTARY KILN BURNER

&

FLAME THEORY

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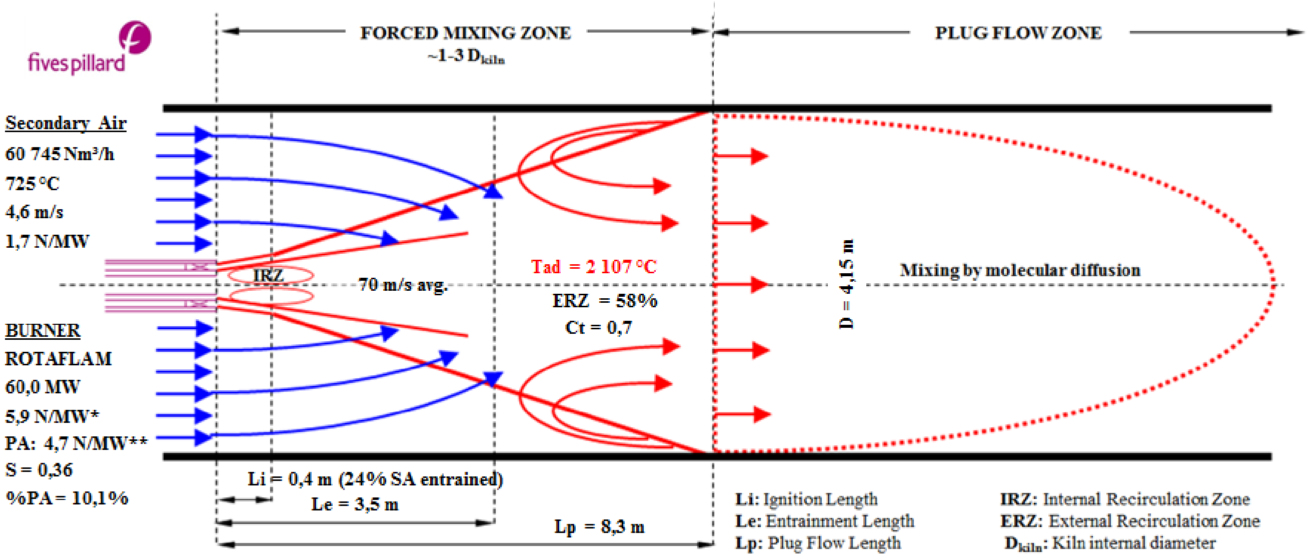
Rotary Kiln Burner & Flame Theory

➔ Function of a rotary kiln burner:

- Mix fuel and combustion air to produce a stable flame and to release heat in a way adapted to process requirements.

➔ Diffusion flames:

- Burner fed with 100% of the kiln fuels but only ~10% of required combustion air (Primary Air). The other 90% of combustion air comes from the cooler (Secondary Air), to recover the material energy. Thus, with only 10% of the combustion air, the burner must be able to produce:
    - ✓ An adjustable thermal profile
    - ✓ A stable flame:
    - ✓ Efficient combustion & Reduced air emissions



➔ Impulse (Momentum):

- Force generated by the primary air and fuels discharge velocity at the burner tip.
    - ✓ ***Impulse (N) = Mass flow (kg/s) x Velocity (m/s)***
- It generates the secondary air and the fuels mixing.
- Proportional to the heat release: **Specific Impulse (N/MW)**

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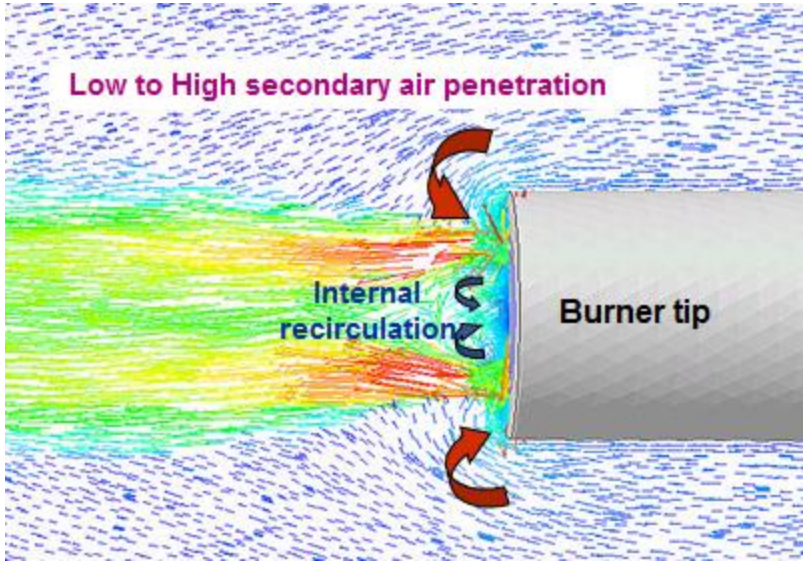
Rotary Kiln Burner & Flame Theory



➔ **Burner design takes into account:**

- ✓ Kiln characteristics and dimensions
- ✓ Cooler characteristics and secondary air temperature and flow pattern
- ✓ Product type (soft, hard/dead burned)
- ✓ Fuels type and substitution ratio
- ✓ Customer targets : Improve combustion efficiency, higher alternative fuel ratio, low NO_x emission…

➔ **Main design criteria:**

- ✓ Primary air momentum : the harder to burn a fuel, the higher the impulse necessary to optimize its combustion.
  - ➢ 3-5 N/MW : HFO / NG (around 6-8 % primary air)
  - ➢ 5-6 N/MW : HFO / NG + Low LHV gas at low pressure (around 9-10 % primary air)
  - ➢ 6-7 N/MW : Pulverized coal / Petcoke (around 10-12 % primary air)
  - ➢ 7-8 N/MW : Main fuel + High alternative solid fuel substitution (around 12-14 % primary air)
- ✓ Swirl number : Usually between $0.10 < swirl < 0.3$

Fives Pillard

Rotaflam® Burner

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Fives Pillard Rotaflam® Burner – Multichannel Burner

➔ Rotaflam® Multichannel Burner

1. Adjustable Axial air, Radial air & Natural Gas tips

- ✓ Flame shaping:
  - Adjustable tips cross section during operation
  - Independently adjustable primary air & natural gas pressure & flowrates

2. Central stabilizer

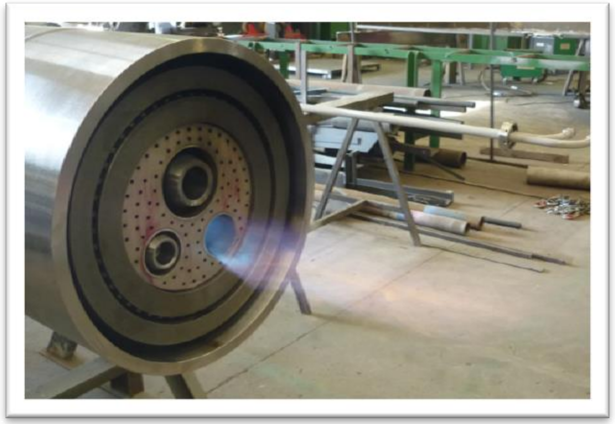
- ✓ Improved flame stability (bluff body = internal recirculation)
- ✓ Possibility for integrated warm-up burner for gaseous or liquid fuel
- ✓ Possibility for integrated igniter & flame detection
- ✓ Possibility for integrated lance for solid, liquid or gaseous fuels

3. Fuel concentration for NO_x reduction

- ✓ Fuel injection inside primary air
- ✓ Low O_2 content at flame core

HFO / NG / Biogas / NCG / Petcoke

HFO / Methanol – Ignitor trial



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Fives Pillard Rotaflam® Burner – Main Characteristics

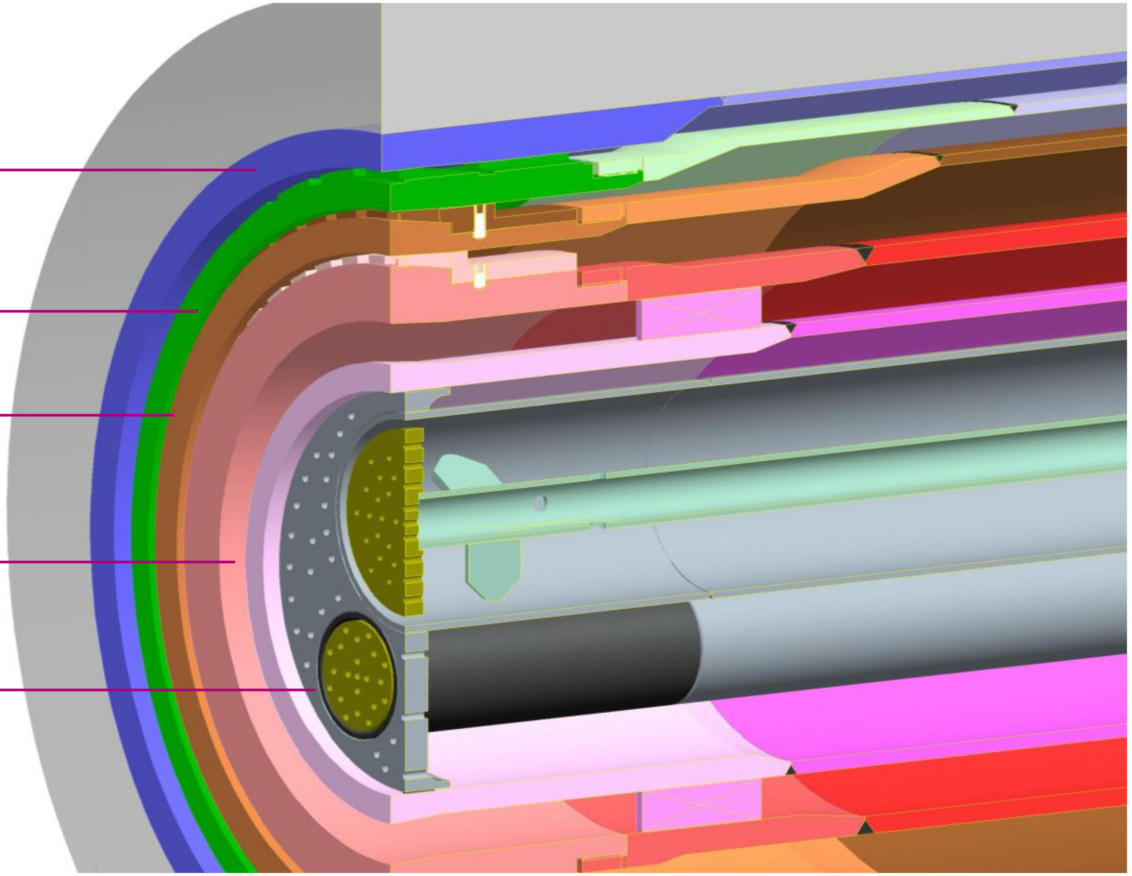
– **Axial primary air**
✓Adjustable cross section

– **Radial primary air**
✓Adjustable cross section

– **Natural gas**
✓Adjustable cross section

– **Coal / Petcoke / Anthracite / Lignite**

– **Central stabilizer**
- ASF / ALF / HFO / DO
- Ignitor / Flame detection



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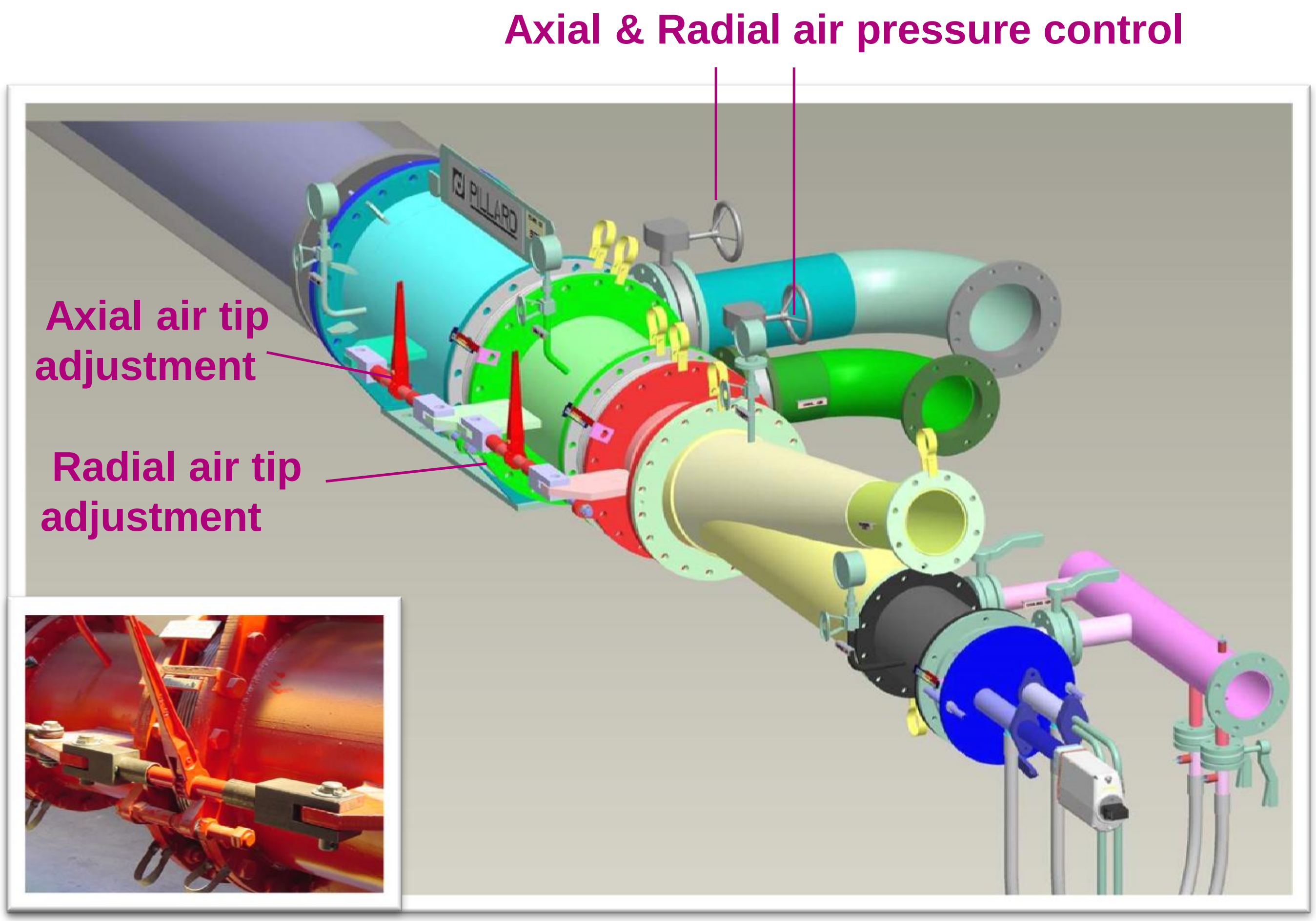
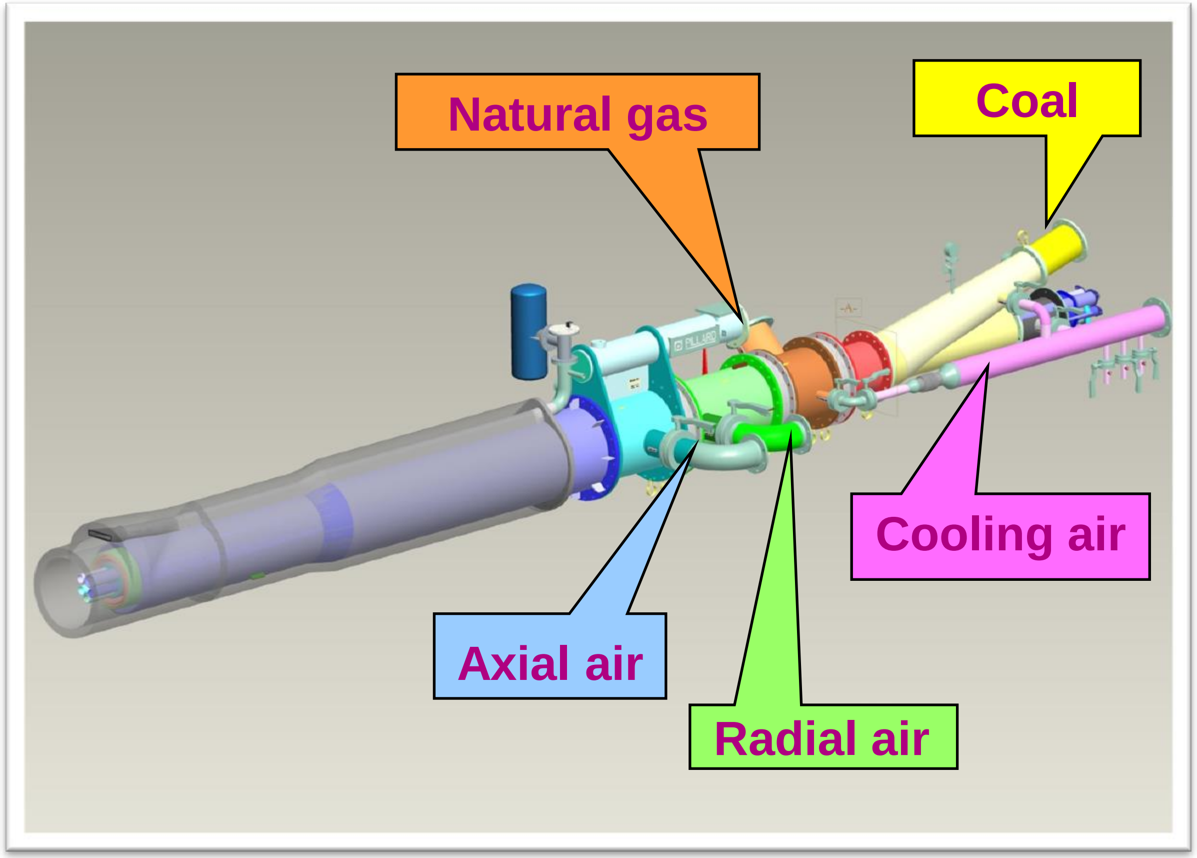
Fives Pillard Rotaflam® Burner – Main Characteristics





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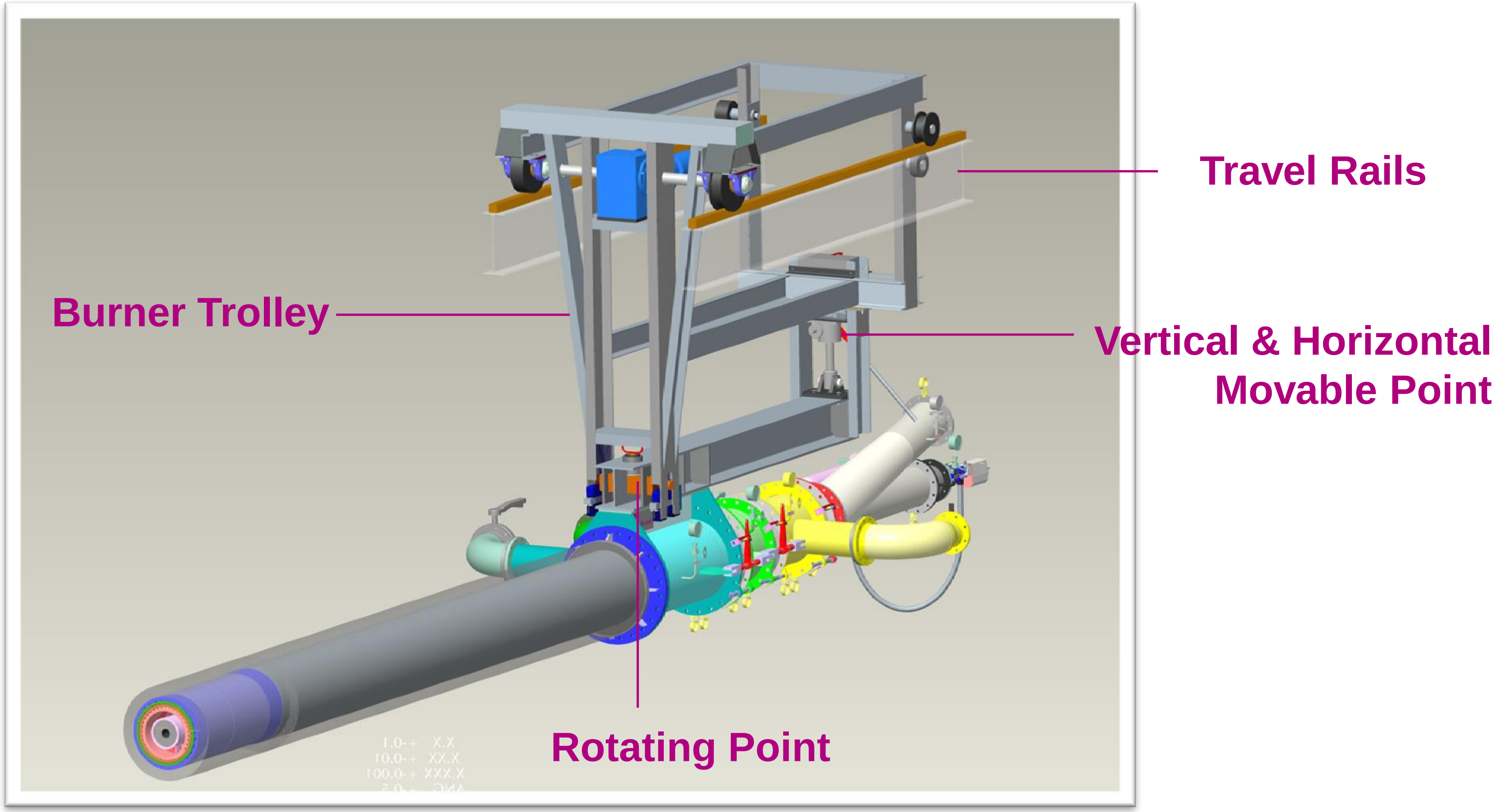
Fives Pillard Rotaflam® Burner – Main Characteristics



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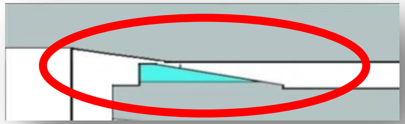
Fives Pillard Rotaflam® Burner – Adjustable momentum principle



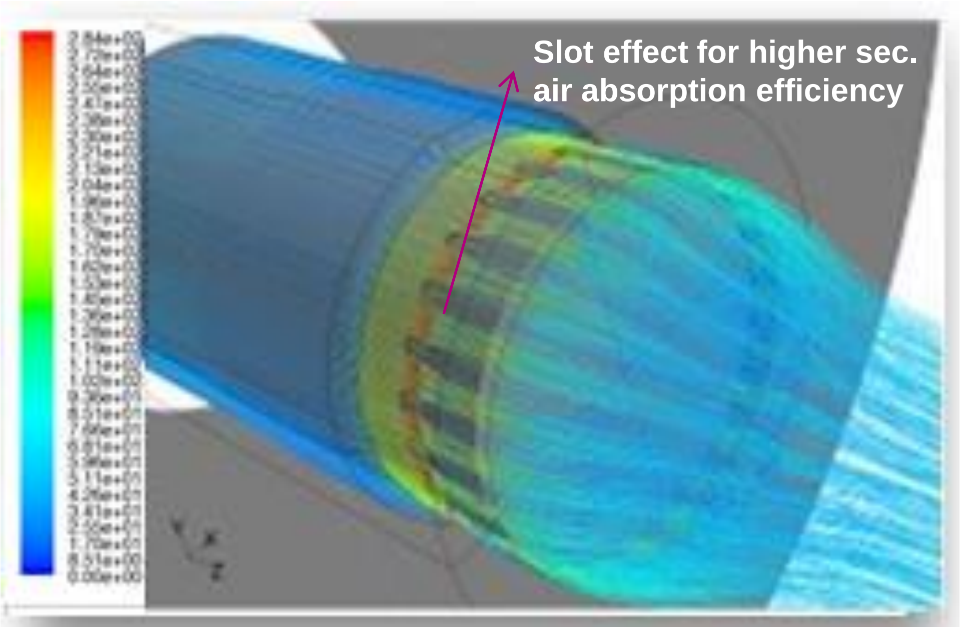
Axial tip: **CLOSED (minimum section)**

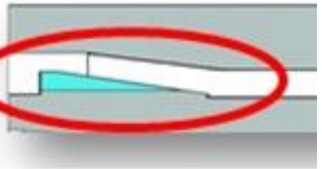
Air flowrate: REDUCED

Momentum: REDUCED (for similar pressure)

AXIAL MOMENTUM	Tip	Section mm²	Nm³/h	m/s*	N	N/MW
Axial air……………:	Closed	4 752	1 550	171	95	1,1

*230°C & 110 mbar (flat fan curve)





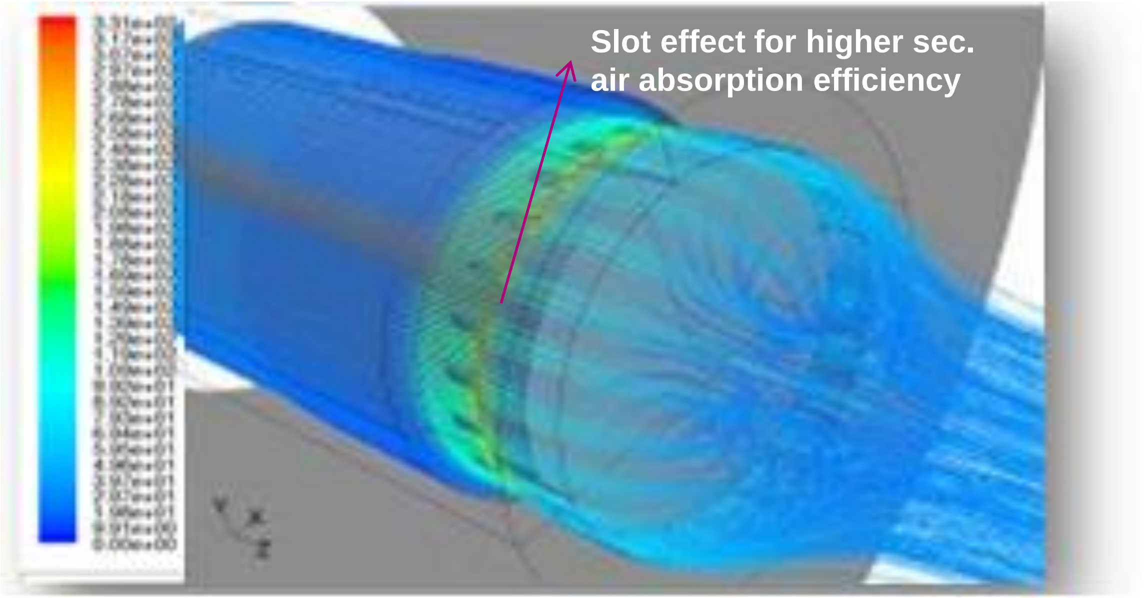
Axial tip: **OPEN (minimum section)**

Air flowrate: INCREASED

Momentum: INCREASED (for similar pressure)

AXIAL MOMENTUM	Tip	Section mm²	Nm³/h	m/s*	N	N/MW
Axial air……………:	Open	14 256	4 540	167	273	3,1

*230°C & 110 mbar (flat fan curve)



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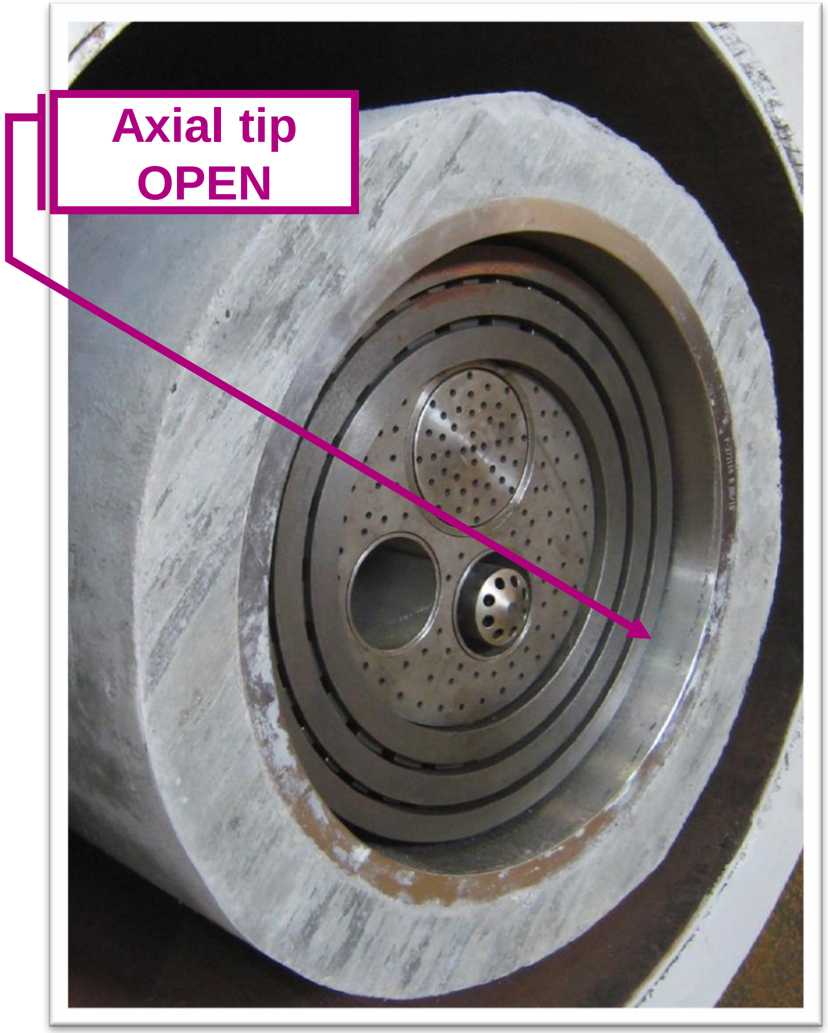
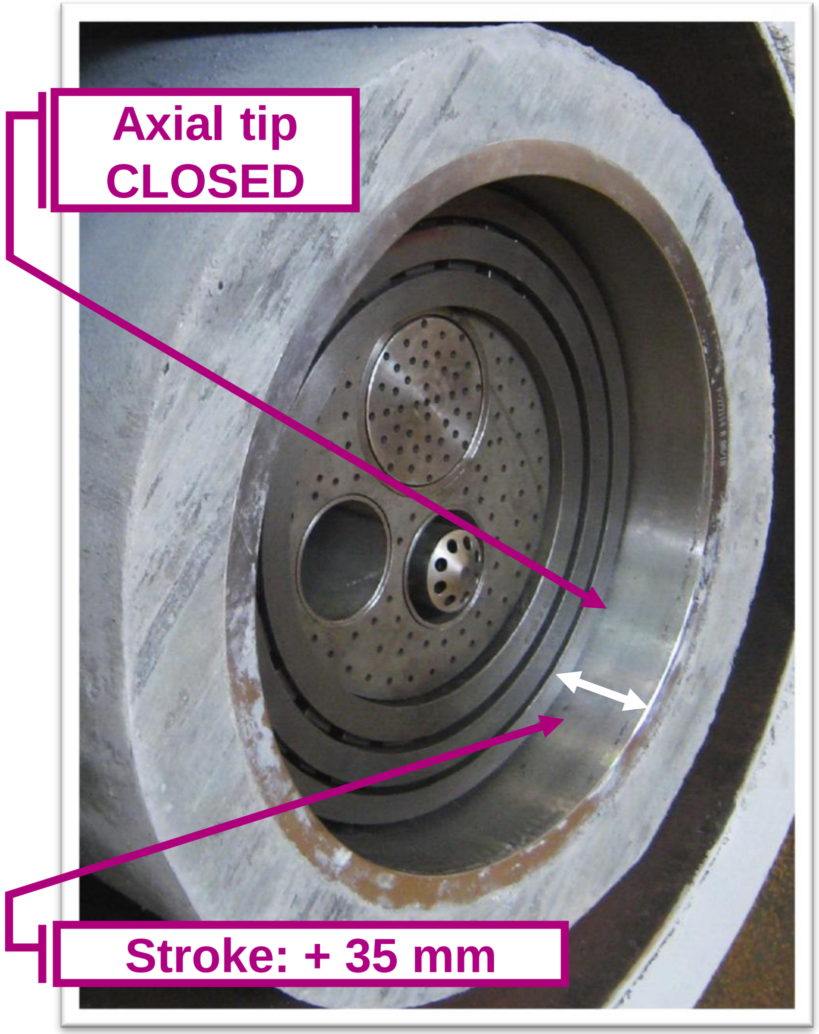
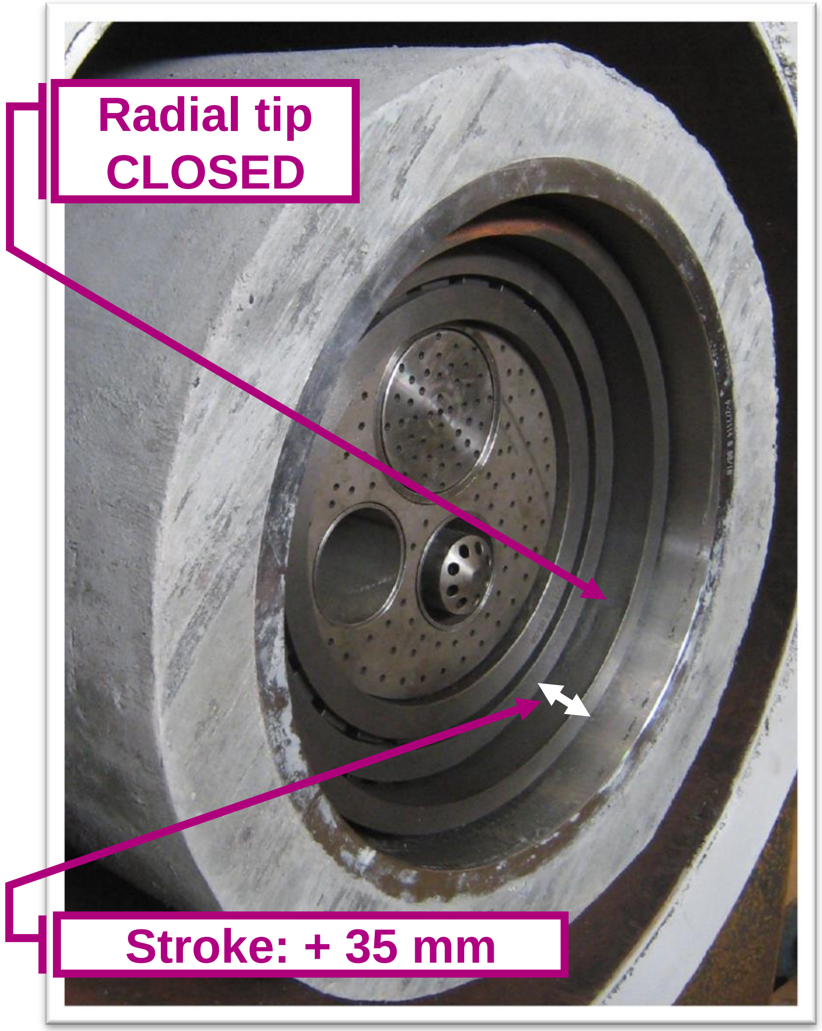
Fives Pillard Rotaflam® Burner – Adjustable momentum principle







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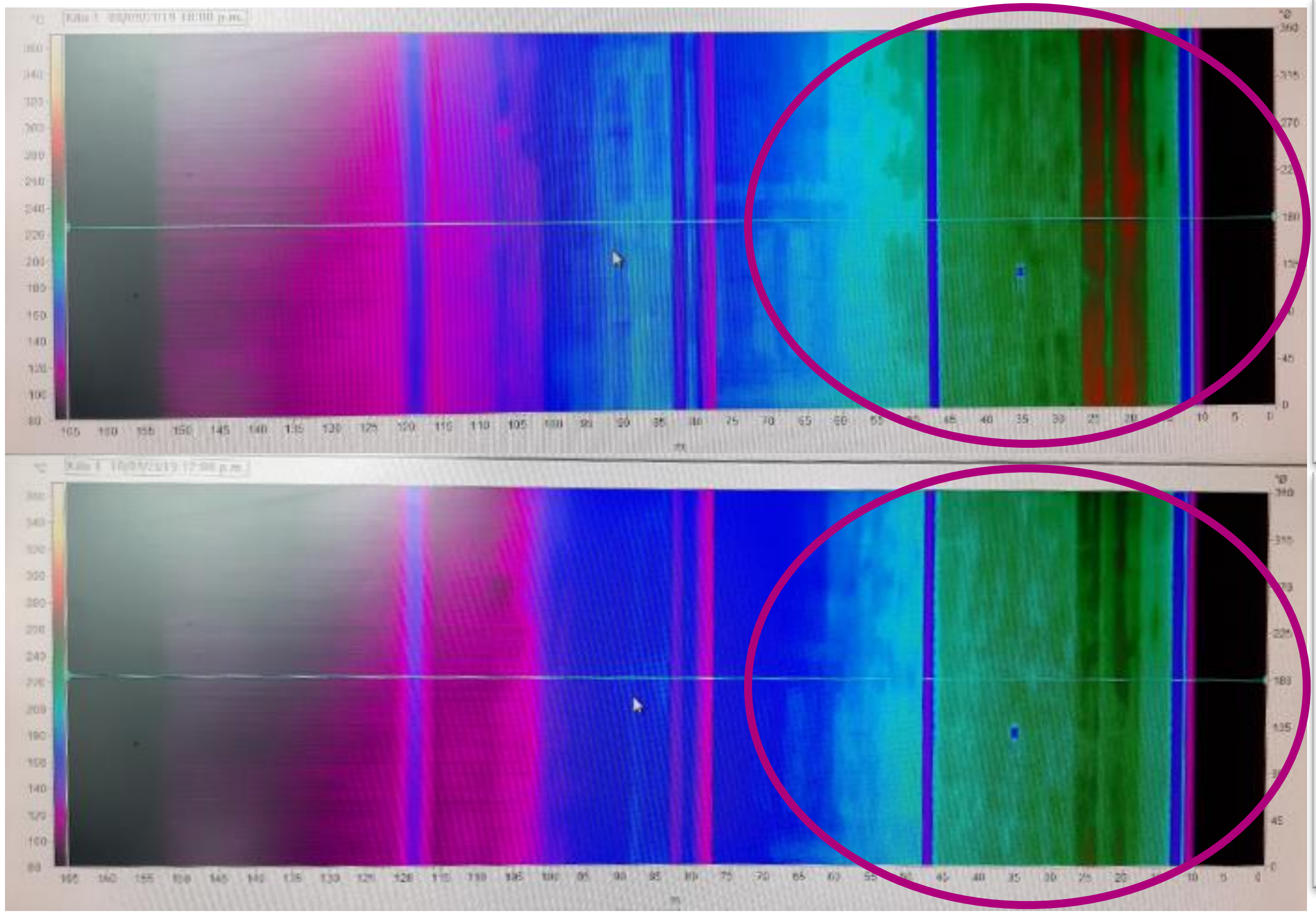
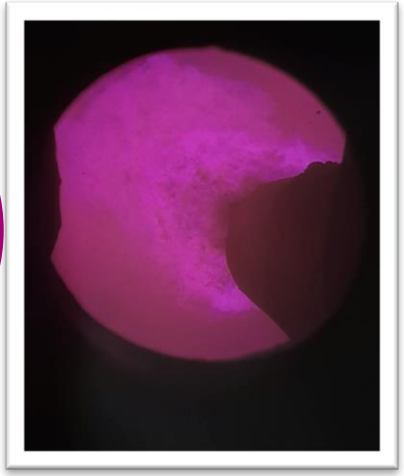
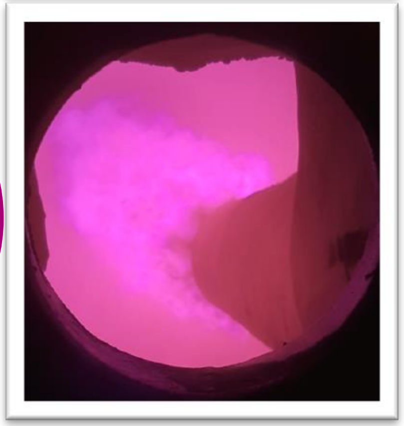
Fives Pillard Rotaflam® Burner – Shell Scanner vs. Flame Shape

Lime reburning kiln shell scanner







➔ **Example:** Flame shape impact on kiln shell temperature profile.

- The initial flame was wider and lazier, with erratic combustion at the flame end. The temperature in the calcining zone was higher.
- After changing the burner settings and the liquid fuel nozzle, the flame shape changed. The flame was thinner and more centered, thus lowering the shell temperature.

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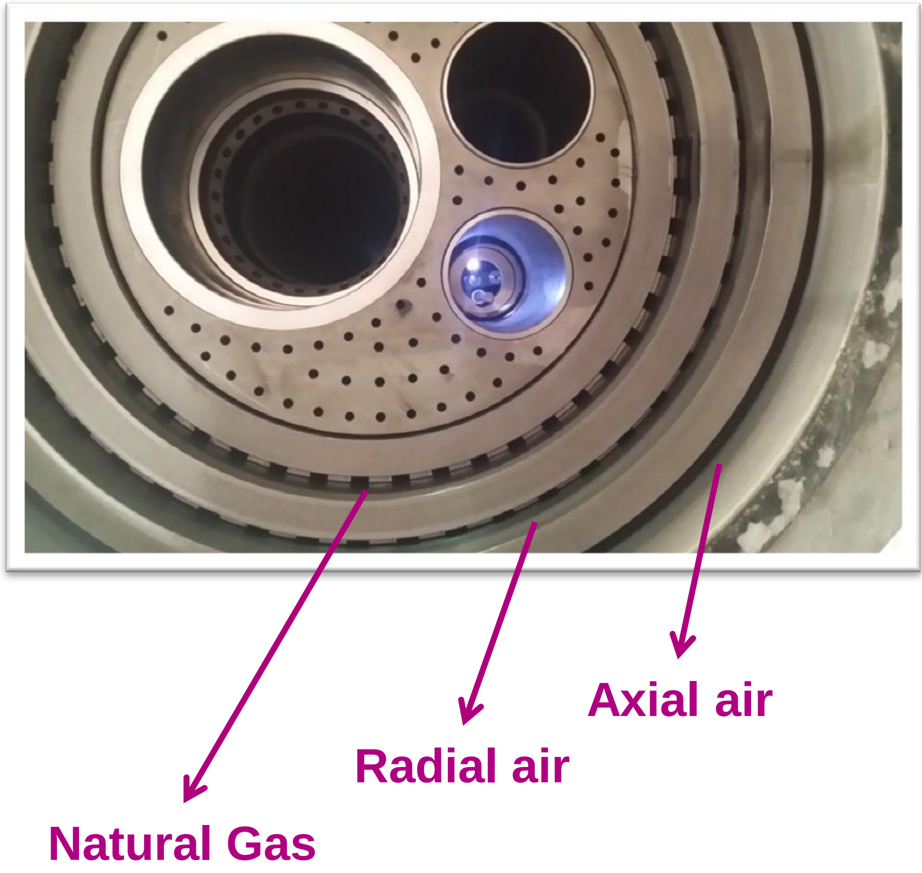
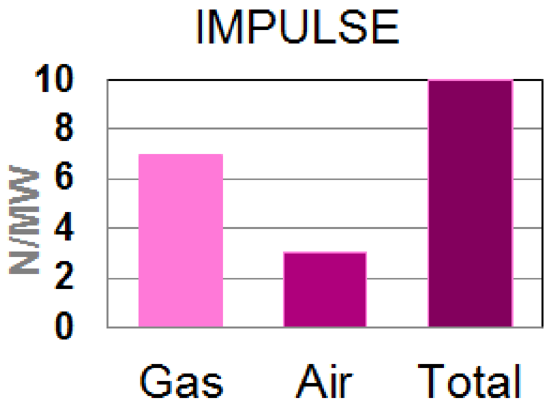
Fives Pillard Rotaflam® Burner – Natural Gas



- ➔ Natural gas injected via annular section, inside axial & radial air channels
- ➔ Stabilizer creates a « bluff body » effect to improve flame internal recirculation, favoring early ignition
- ➔ Adjustable cross-section allowing to vary the gas pressure from 200 to 800 mbar for a fixed gas flowrate (momentum control independent of flowrate)
- ➔ Possibility to split the gas injection between annular injection & gas gun in the burner center
- ➔ Lower primary air required as the gas generates enough momentum for mixing with hot secondary air
- ➔ Radial air not mandatory / Gas can generate swirl to improve mixing

As the natural gas is injected at high pressure (200-800 mbar), it generates a high momentum. Thus, a lower amount of air is required when firing 100% gas.



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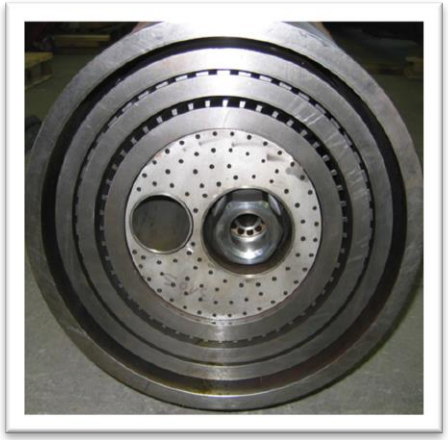
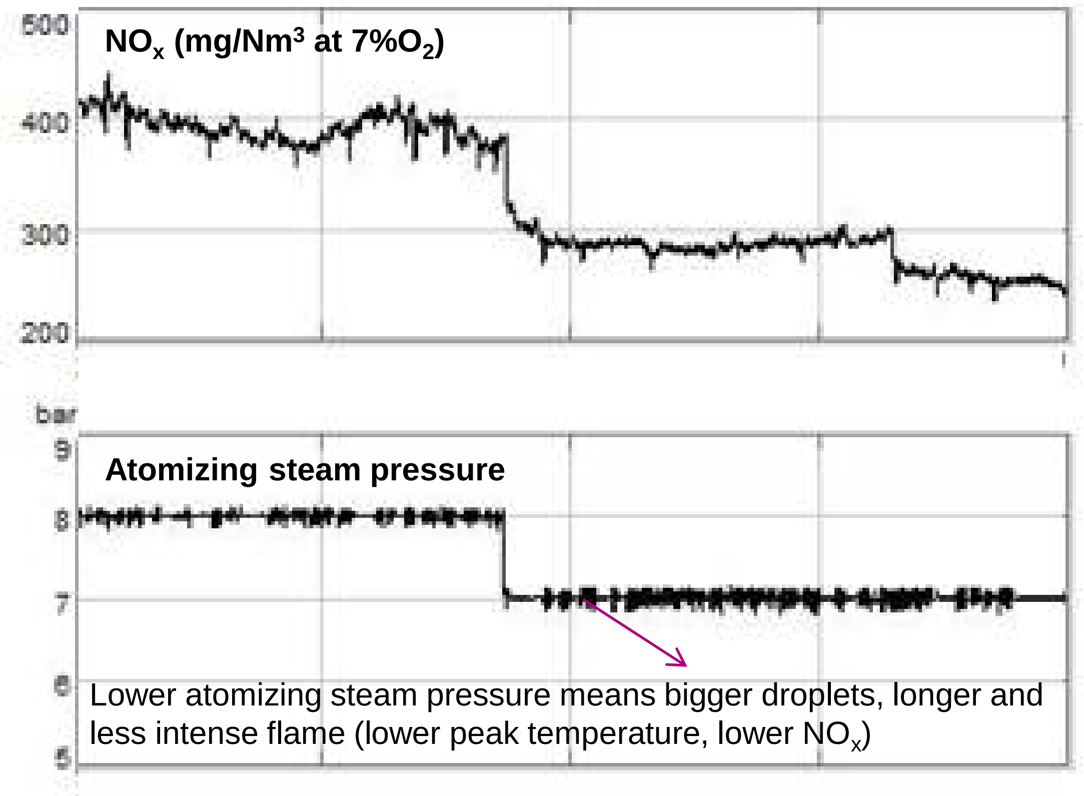
Fives Pillard Rotaflam® Burner – Liquid Fuel Injectors

- ➔ The key parameter for a proper liquid fuel combustion is the atomization quality.
- ➔ The size of the fuel droplets will determine how fast it will burn and how far it will go. Thus, it is possible to change the flame length and shape by changing the atomization quality.

Assisted Atomization (steam or compressd air)



Atomization quality vs. Flame intensity (Lime Reburning Kiln)



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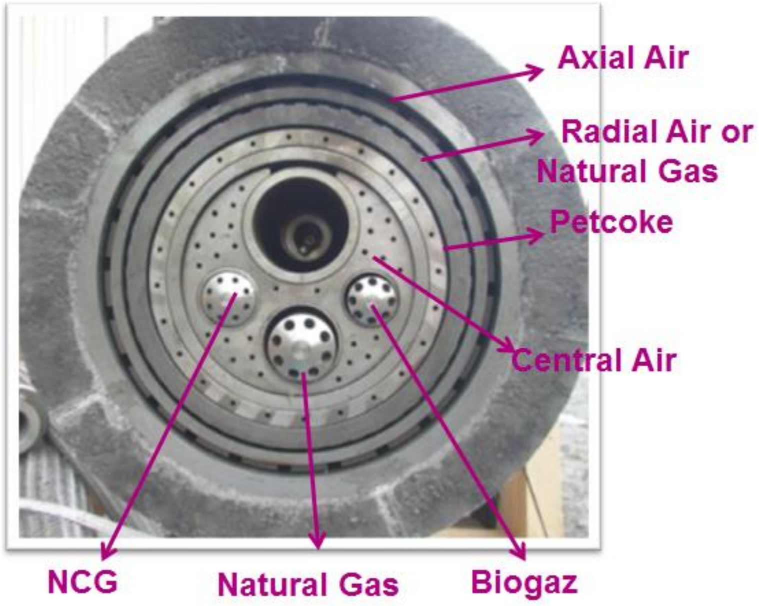
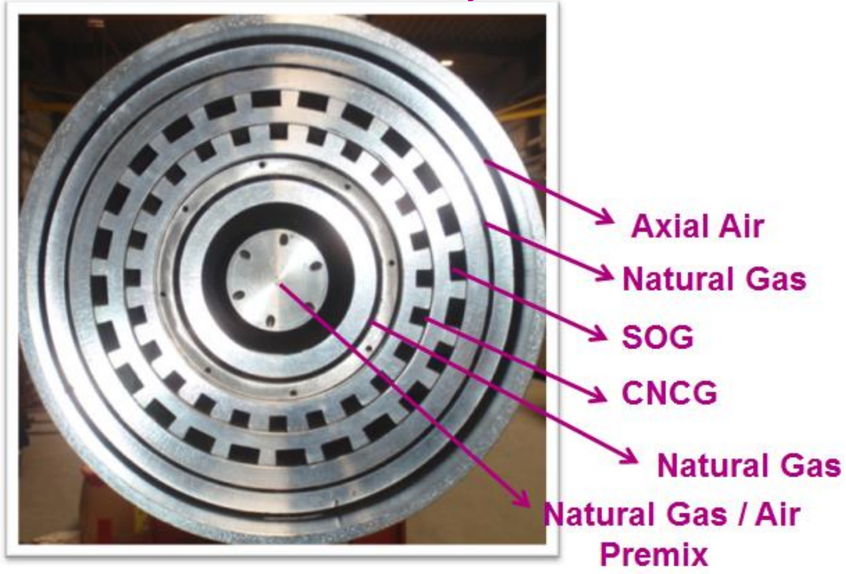
Fives Pillard Rotaflam® Burner – NCG & SOG

- ➔ It is possible to inject waste gases via the main burner or through a separate burner, according to waste gas characteristics (pressure, LHV, flowrate…). However, the kiln operation is always a compromise when trying to operate as an incinerator.
  - ➢ Waste gases may have variable LHV, pressure and flowrate, disturbing the flame and the process
  - ➢ In most cases, burning malodorous gases in a lime kiln results in a significant increase in the NO_x levels as the malodorous gases carry additional nitrogen to the kiln.
  - ➢ It may also increase the ring formation due to high sulphur content (corrosive).

NCG via nozzle injection



CNCG and SOG via annular injection



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Fives Pillard Rotaflam® Burner – Recent Developments

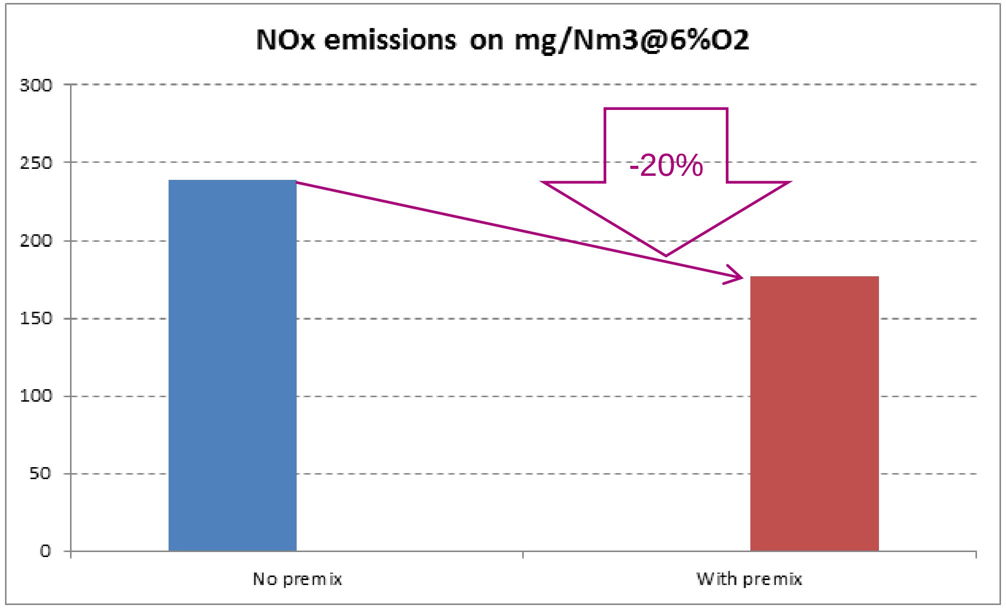
➔ **PGZ – Premix Gas Nozzle (Pillard Patented Technology)**

- NO_x reduction principle based on a 5-20% of the NG is premixed with air at sub-stoichiometric conditions and injected in the burner center. Stabilization of main gas flame, reducing the ignition distance (less secondary air mixed to the gas prior to ignition) and generating HCN and NH_3 radicals.

Example of a gas premix flame on a Pillard Novaflam® burner installed on a clinker kiln

Different Injection nozzles

Rotaflam® with premix gas installed on a lime reburning kiln in Europe



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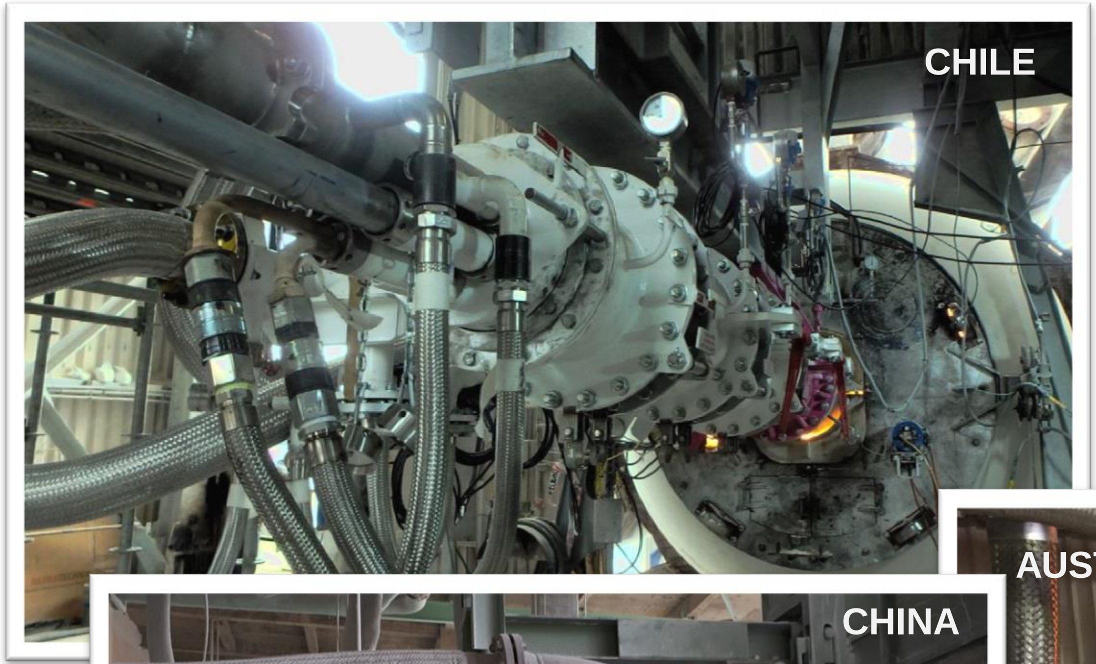
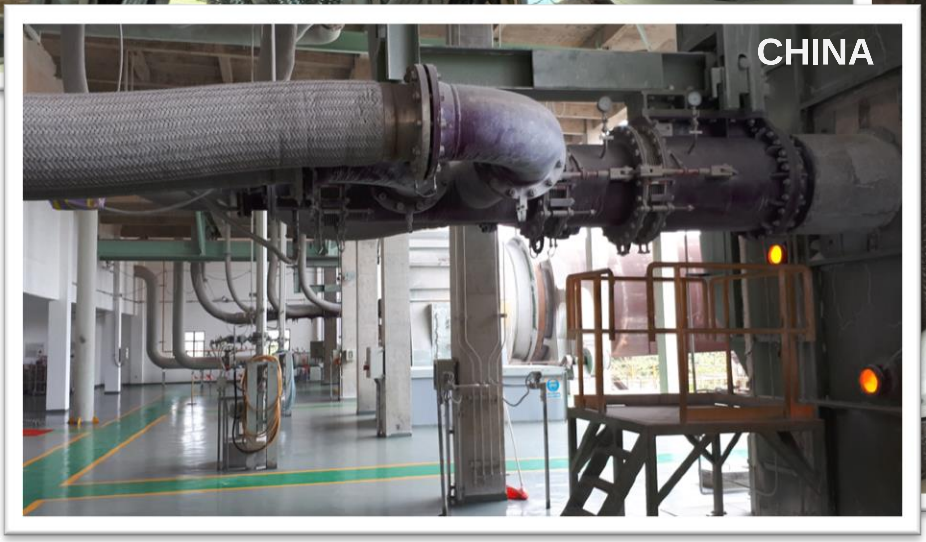
Fives Pillard Rotaflam® Burner – P&P & Pebble Lime References





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