ClearSign

Duplex™ Technology

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South Coast Air Quality Management District
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WHAT IS CLEARSIGN COMBUSTION (CLIR)?

ClearSign's Duplex™ technology

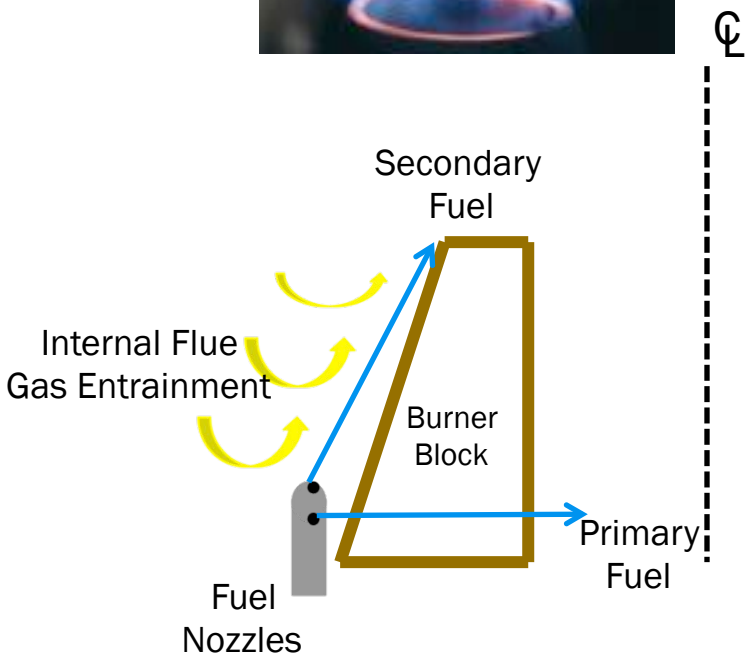
improves combustion system performance:

- *Reduced emissions*
- *Improved operational performance*

ABOUT CLEARSIGN – COMPANY OVERVIEW

- Seattle based
- NASDAQ: CLIR
- Focused on industrial combustion solutions and innovations
- Experienced management team

ULTRA LOW NO_x BURNERS



NOx Reduction Strategies:

- Fuel Staging
  - Fuel Lean Primary
  - Fuel Rich Secondary
- Control Peak Flame Temperatures
  - Fuel Dilution by IFGR
  - Delayed Mixing (Stretched Flames)
  - Increase Flame Volume
  - Radiation Cooling

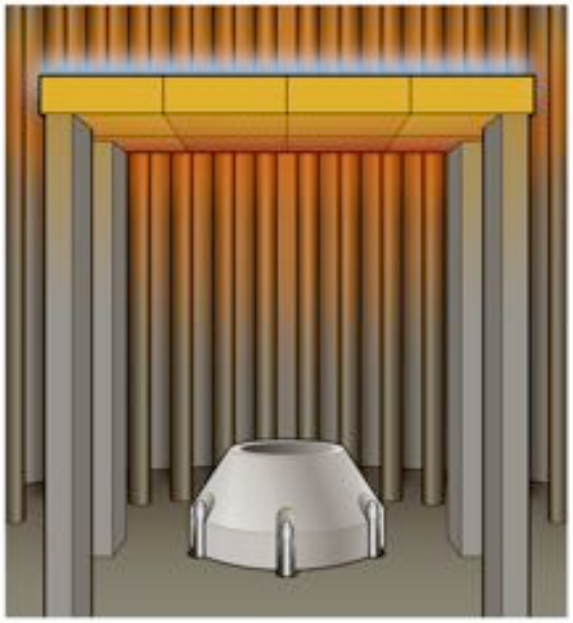
Typical NOx Guarantee: 15-25 ppm

Disadvantages:

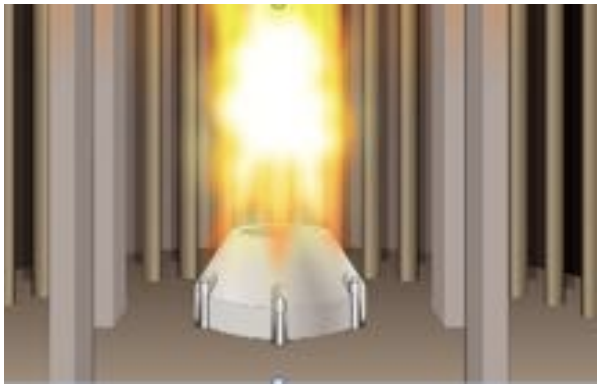
- Long Lazy Flames (Coalescing/ Impingement)
- Large Burner Throat
- Cannot Meet Most Stringent Regulations

DUPLEX™ FEATURES

- High Temperature Porous Ceramic Matrix
- Flame Confined Within Duplex
- NOx Levels Below 5 ppm
- Surface Radiation vs. Gas Radiation
- Enhanced Fuel/Air Mixing
- Improved IFGR (Entrainment Length)
- Bluff Body Stabilization
- Noise Reduction

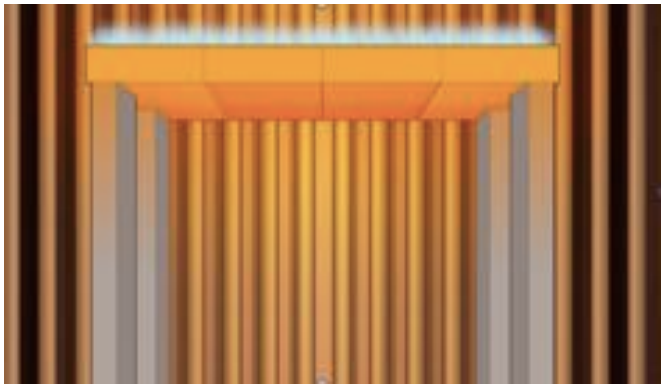


DUPLEX™ MODES OF OPERATION



Burner Mode
(Warm Up)

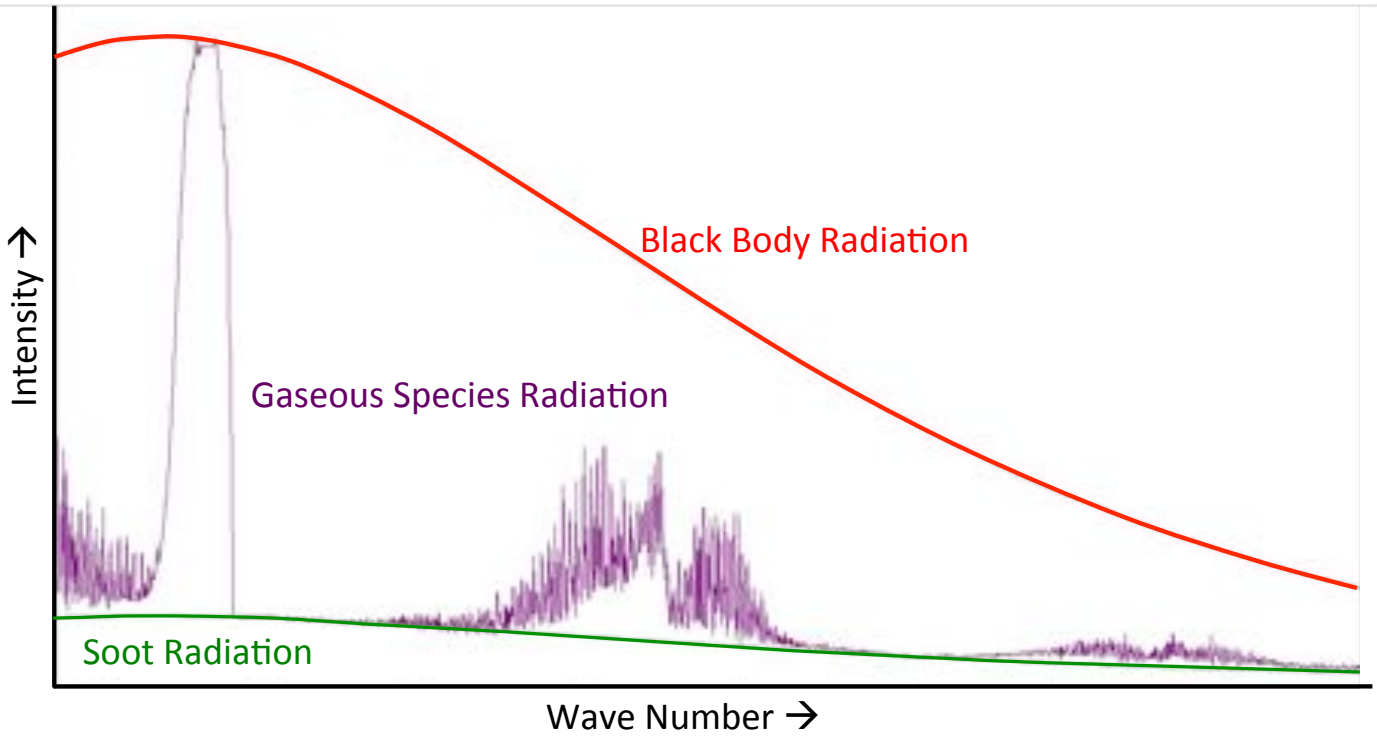
Transition



Duplex Mode

DUPLEX BURNER IN OPERATION

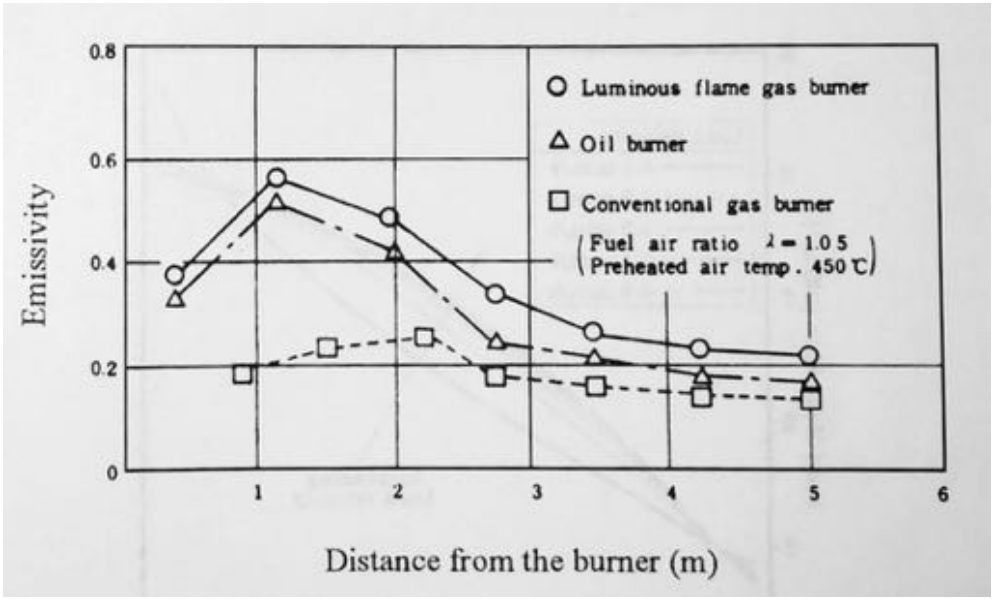
FLAME VS. SOLID SURFACE RADIATION



Website www.chec.kt.dtu.dk
Technical University of Denmark
CHEC Research Centre, Dept. of Chemical & Biochemical Engineering.

FLAME VS. SOLID SURFACE EMISSIVITY

$$Q_{rad} \propto \varepsilon \bullet (T_2^4 - T_1^4)$$



"Heat Transfer in Industrial Combustion," C.E. Baukal, Jr., Published by CRC Press, 2000

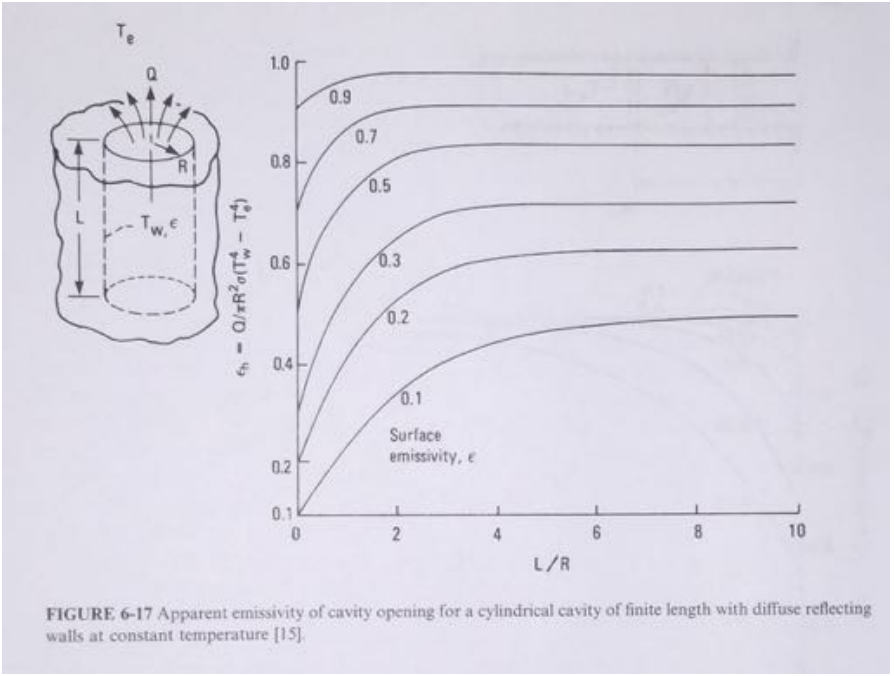
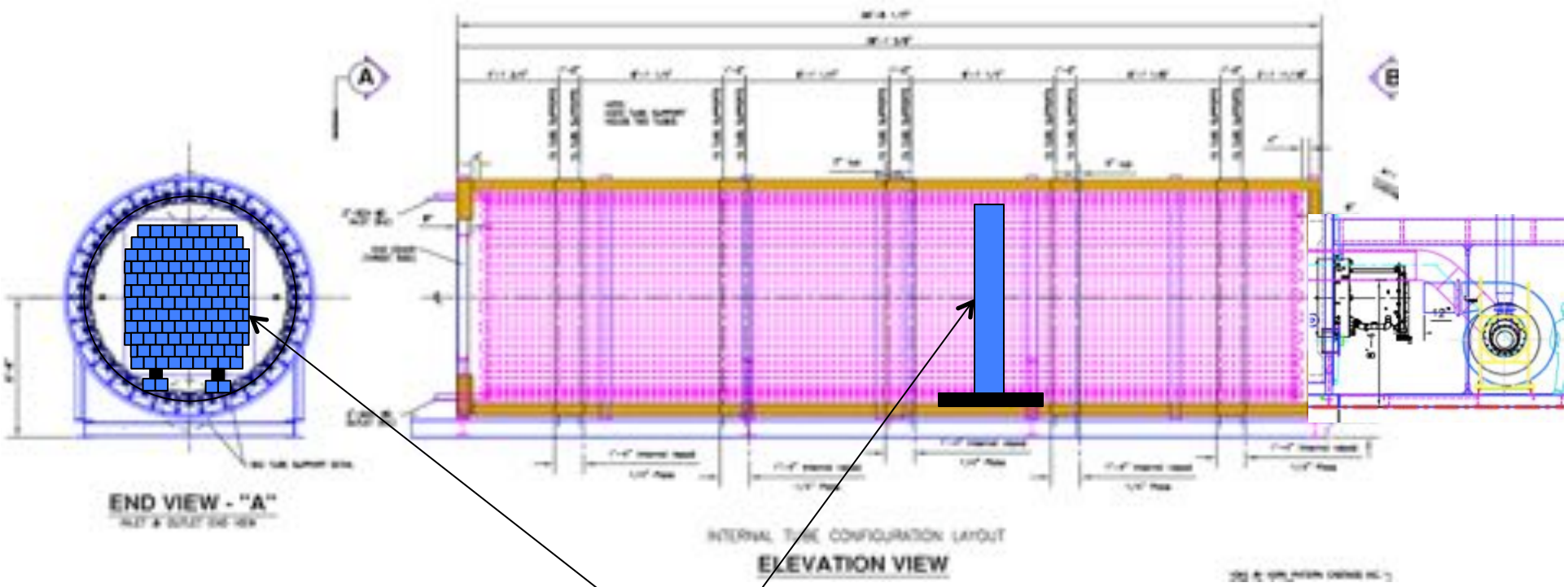


FIGURE 6-17 Apparent emissivity of cavity opening for a cylindrical cavity of finite length with diffuse reflecting walls at constant temperature [15].

"Thermal Radiation Heat Transfer," R. Siegel & J. Howell, Published by Taylor & Francis, 4th Edition, 2002

OTSGS

PROPOSED APPROACH

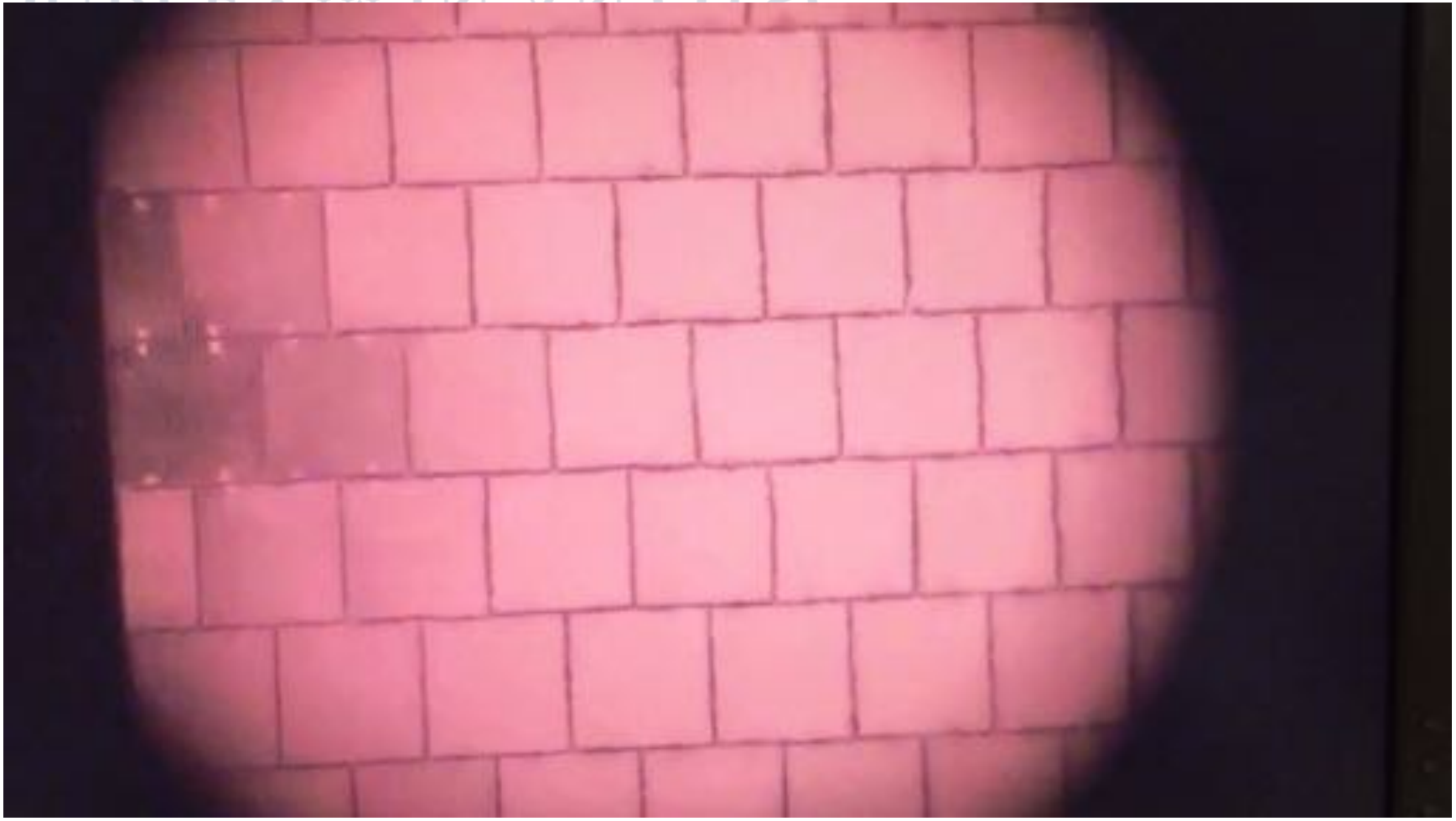


Duplex™ Tile

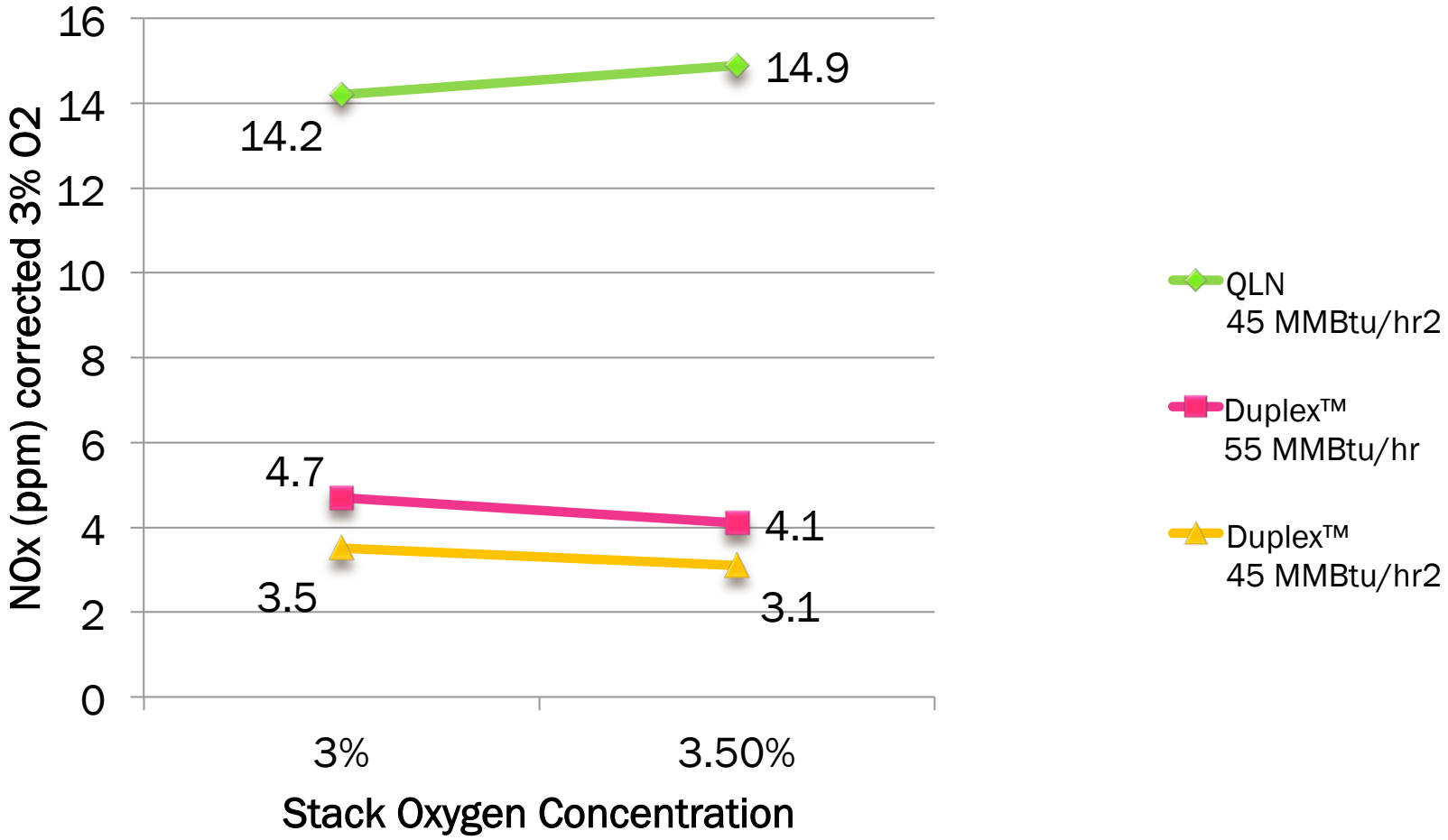
DUPLEX™ WALL IN OTSG

DUPLEX™ IN 62.5 MMBTU/H OTSG

DUPLEX™ IN AN OTSG



NOX PERFORMANCE



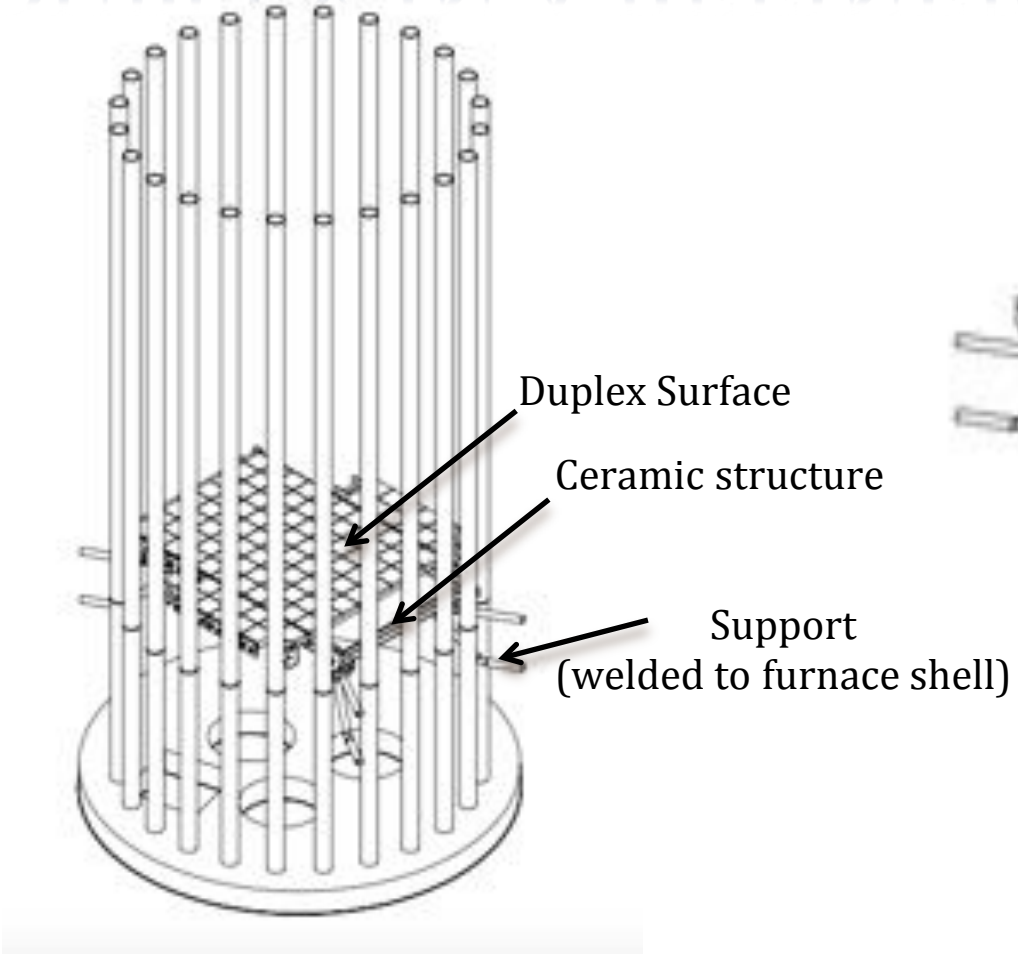
DUPLEX IN A REFINERY HEATER

REFORMER SPLITTER REBOILER HEATER

- Vertical Cylindrical Heater
- Maximum Capacity = 11.25 MMBtu/hr
- Dimensions:
  - Shell OD 9’ 6 ½“
  - Height 17’ 8 ½”
- Three ULN Burners
- Refinery Fuel

	H2 (vol. % @ STP)	CH4 (vol. % @ STP)	LHV (Btu/scf)
Maximum	68.7	55.6	1462
Minimum	22.8	12.3	636
Average	43.8	31.7	892

DUPLEX IN A REFINERY HEATER



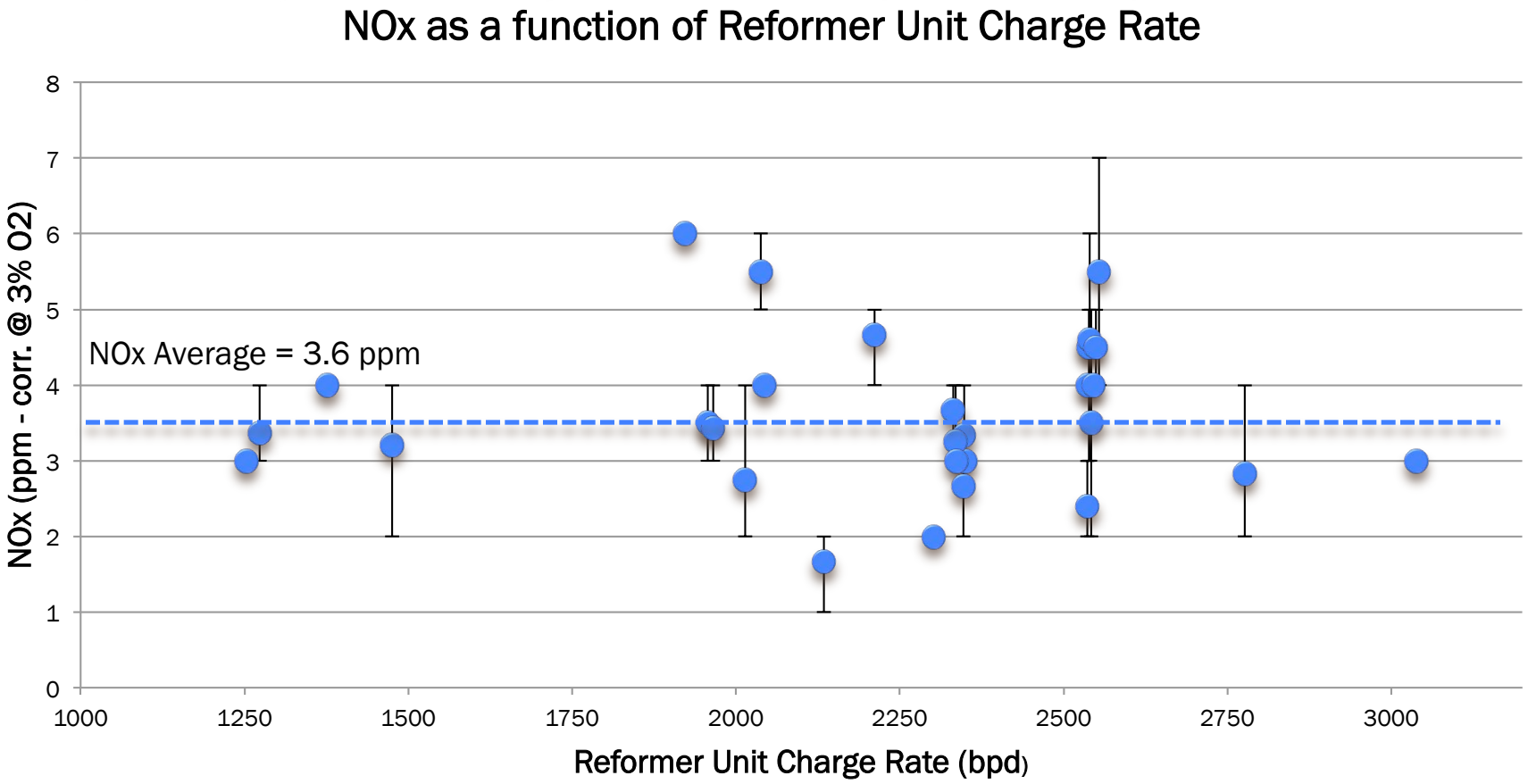
DUPLEX IN A REFINERY HEATER

Furnace side port

Furnace floor

Burner bottom plate

NOX VS. REFORMER CHARGE RATE



PLUG-AND-PLAY DUPLEX™

PLUG-AND-PLAY DUPLEX™

FLARING – SOME FACTORS TO CONSIDER

- Process vs. Emergency
- Enclosed vs. Open Flaring
- Fuel Characteristics
  - ✓ Composition
  - ✓ Heating Value
  - ✓ Contaminants
  - ✓ Liquids
- DRE
- NOx/CO/VOCs

DESTRUCTION EFFICIENCY (DRE)

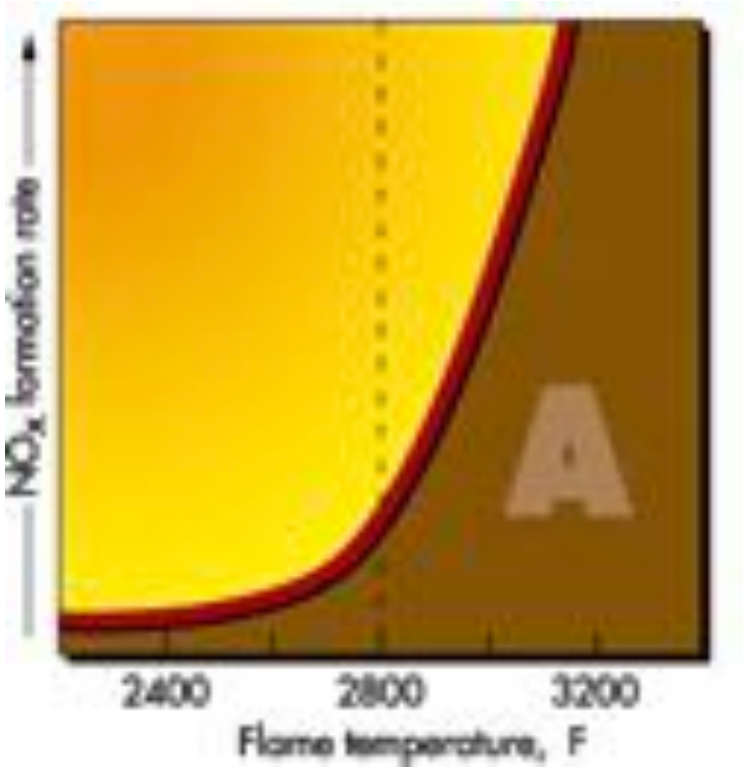
- 3 Ts
  - ✓ Temperature
  - ✓ Time
  - ✓ Turbulence

NOX FORMATION

- Three Mechanisms
  - ✓ Thermal NOx (Zeldovich)
  - ✓ Prompt NOx (Fenimore)
  - ✓ Fuel Bound NOx

$$C_{NO} = AC_{N2}\int e^{-\frac{b}{T}} C_{O2}^{\frac{1}{2}}\, dt$$

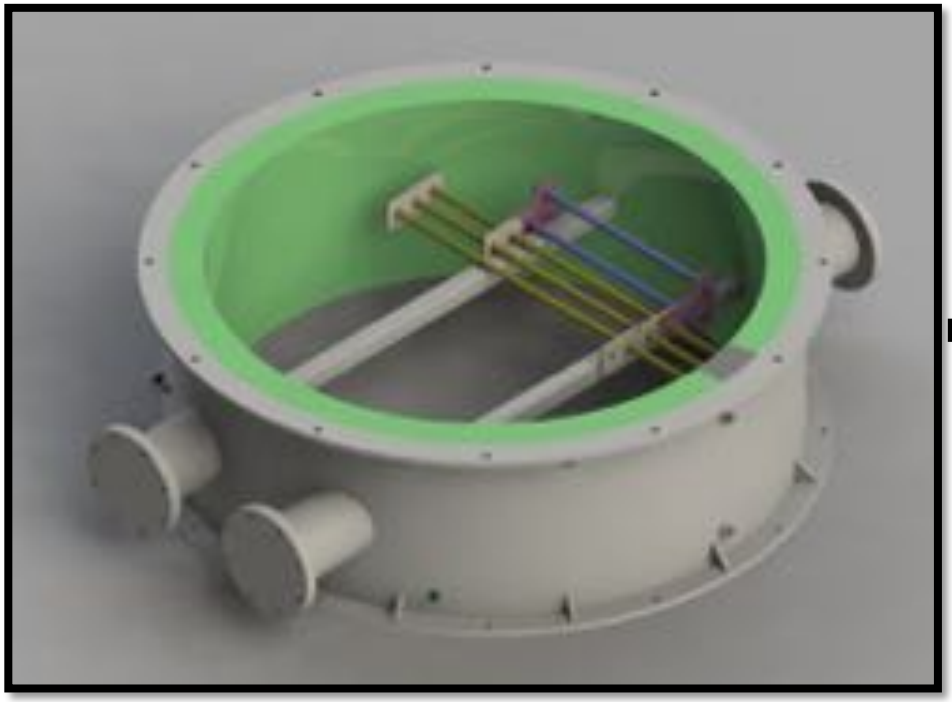
C_{NO}	= Concentration of nitric oxide
C_{N2}	= Concentration of nitrogen
C_{O2}	= Concentration of oxygen
T	= Temperature
t	= Time
A	= Constant



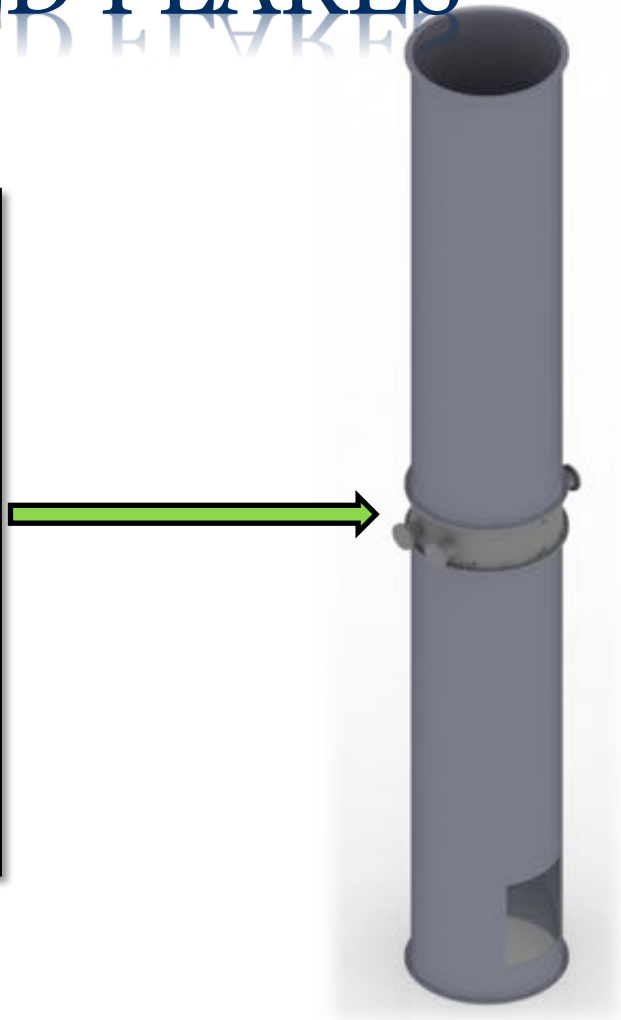
ENCLOSED FLARES

ENCLOSED FLARES

DUPLEX IN ENCLOSED FLARES



DUPLEX ™ WAFER



TYPICAL INCINERATOR STACK

DUPLEX IN ENCLOSED FLARES

DUPLEX IN ENCLOSED FLARES

- Incineration of stranded gas in oil production
- 1500-1700 Btu/scf gas

	Permit	Performance After Duplex™
NOx	6.5 ppm	< 4 ppm
CO	3.5 ppm	0-3 ppm
VOCs	5.0 ppm	< 4 ppm
DRE	99.9 %	> 99.999 %

OTHER RELEVANT PROJECTS

- 100 MMBtu/hr Single-burner Water tube boiler (China district heating application)
- 60 MMBtu/hr Single-burner Water tube boiler (California refinery)
- 150 MMBtu/hr Multiple-burner Water tube boiler – sponsored by SCAQMD (California refinery)

C'est fini!