Heat Input Affects NOx Emissions from Internal Flue Gas Re-Circulation Burners

Presenter: Doyle Bishop

Next Generation Ultra Low NO_x Burner Development

CALLIDUS TECHNOLOGIES, LLC

The Environmental & Combustion Experts.

ExxonMobil

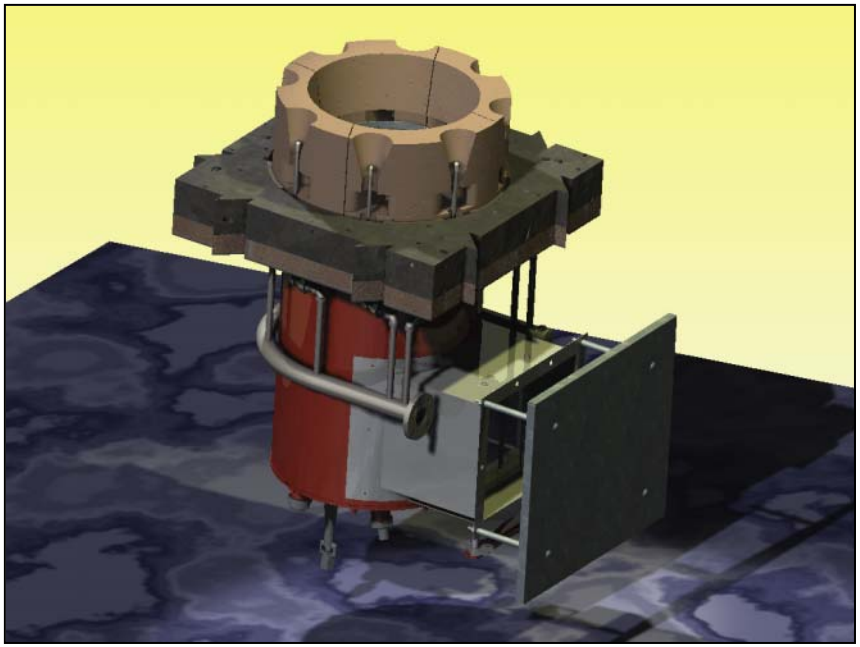
TIAX

Powered by Innovation

DEPARTMENT OF ENERGY · UNITED STATES OF AMERICA ·

Next Generation Ultra Low NO_x Burner Development

- Joint project between ExxonMobil, DOE, TIAX, and Callidus Technologies
- Commercially introduced in 2000
- In excess of 40 installations
- Field NO_x readings from 3 PPM to 25 PPM
- Natural Draft, Forced Draft, Preheated Air
- Wide range of fuels
- High Turndown Ratio
- No special operating requirements

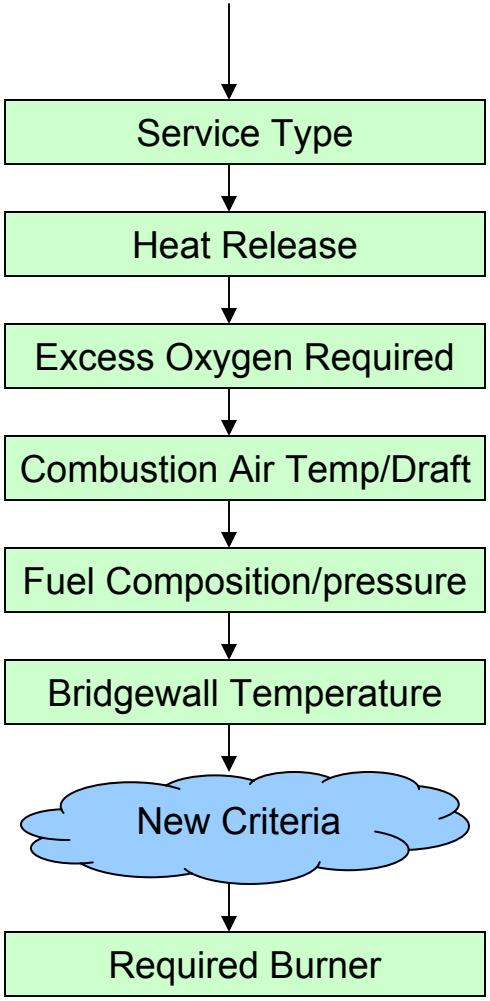


Callidus Ultra Blue Burner (**CUB**)

Beta Testing

Introduction

- There have been rapid advances in NO_x reducing technology for process heater burners in the last several years
- Previous methods for determining the suitability of a burner for a particular application may no longer be sufficient with next generation burners
- The suitability of a burner for a particular application may also depend on the placement of the burners within a heater
- Successful application of ultra-low NO_x technology requires consideration of the interactions of the furnace-burner system

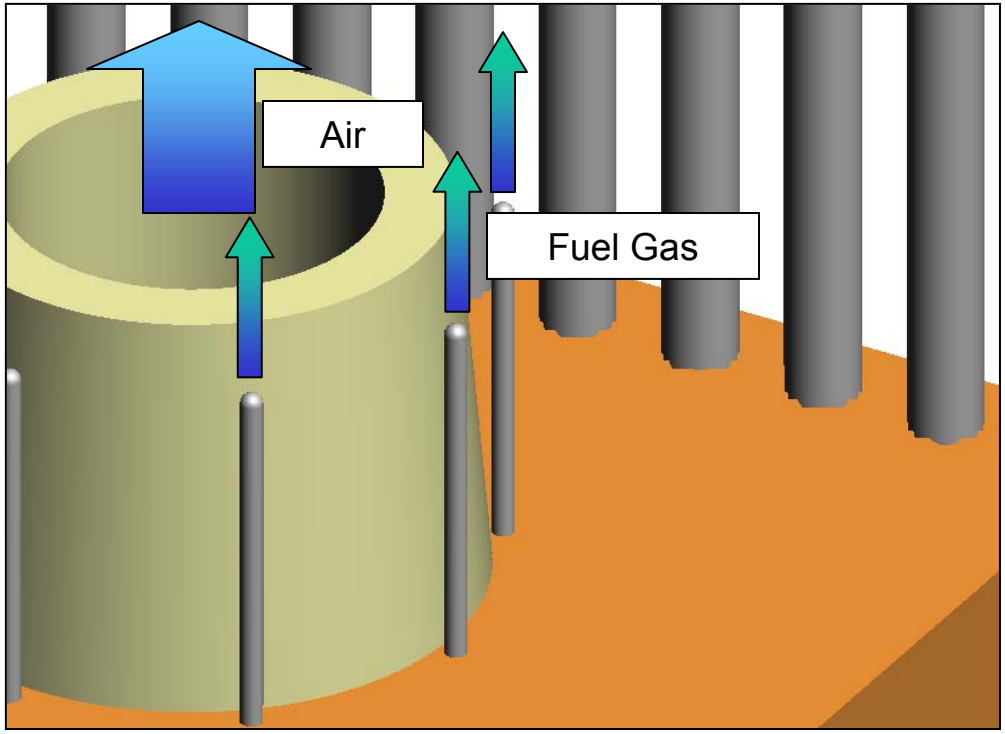


Background

- Three mechanisms for NO_x production:
  - Prompt NO_x
  - Thermal NO_x
  - Fuel NO_x
- Most successfully commercialized improvements have been made in the reduction of thermal NO_x
- Fuel/air staging and flue gas re-circulation have been the most successfully utilized NO_x reduction technologies

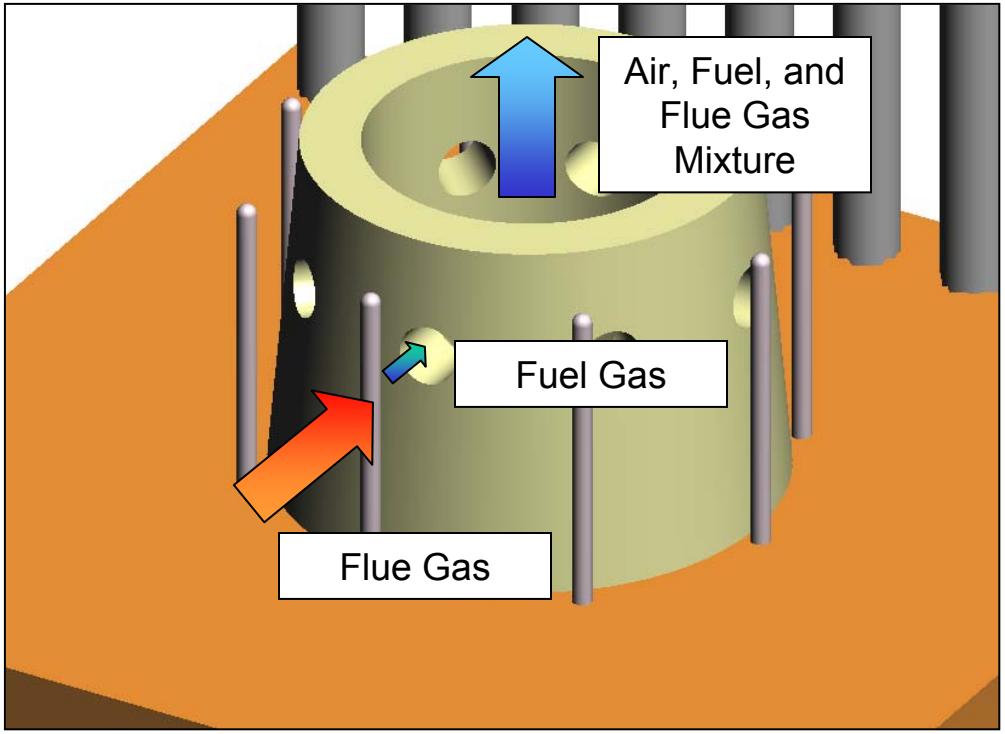
Background

- Fuel staging lowers NO_x in the following ways
  - Regions of varying stoichiometry are created
  - Flue gas is entrained by the fuel gas prior to combustion
  - The flame is lengthened, allowing the tubes to absorb duty as the combustion is completed
- All of these reduce NO_x by lowering peak flame temperature



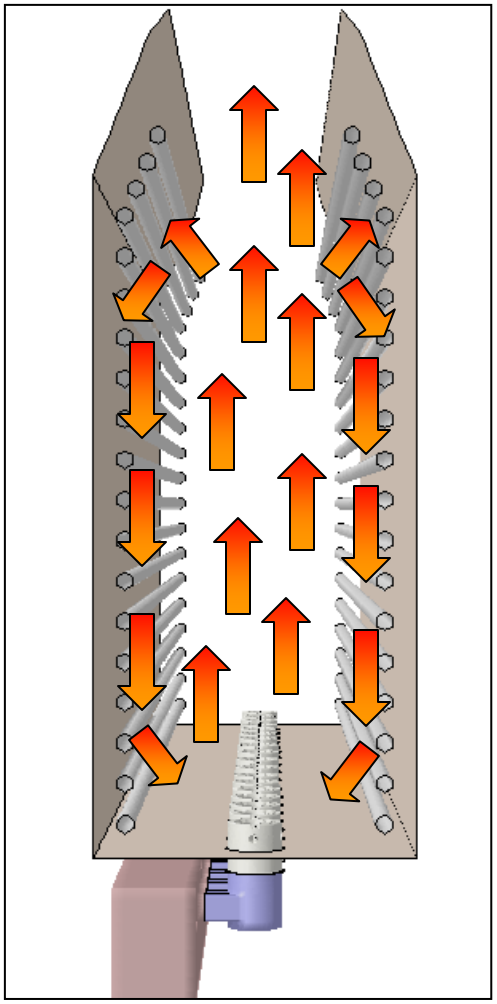
Background

- Flue gas re-circulation can be either internal to the fired equipment, or carried through external piping
- Internal flue gas re-circulation (IFGR) is currently more cost effective
- IFGR lowers NO_x in the following ways
  - The partial pressure of the oxygen is reduced in the flame zone
  - The combustion reaction 'loses' heat to the flue products
- The NO_x is lowered by lowering peak flame temperature



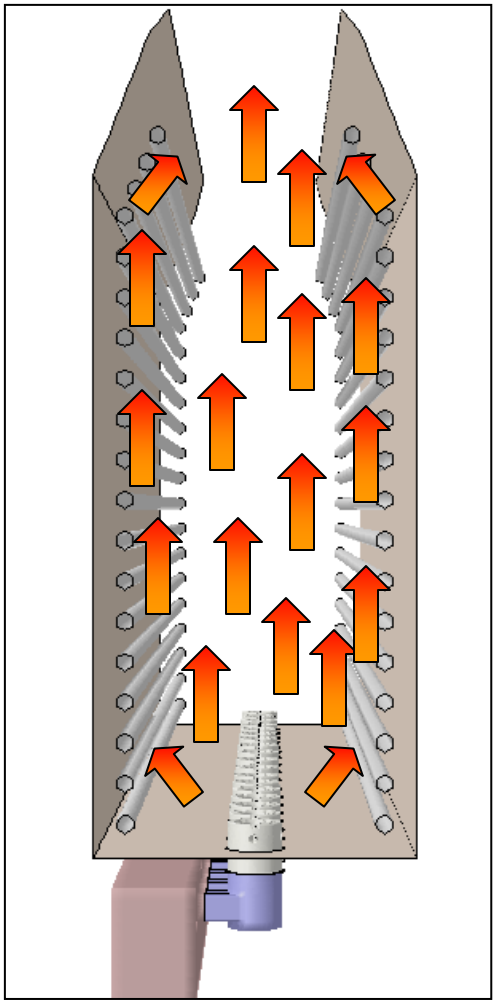
Gas Flow In Heaters – Normal Flow

- Buoyancy effects or forced flow causes an average upward velocity in the furnace
- As the flue gas looses heat to the process, the gas cools and travels down the walls of the heater
- A standing circulation pattern is established
- IFGR burners (and even purely staged burners) rely on the cooler gas flowing to the floor as a source of flue gas used to lower NO_x



Gas Flow In Heaters – Plug Flow

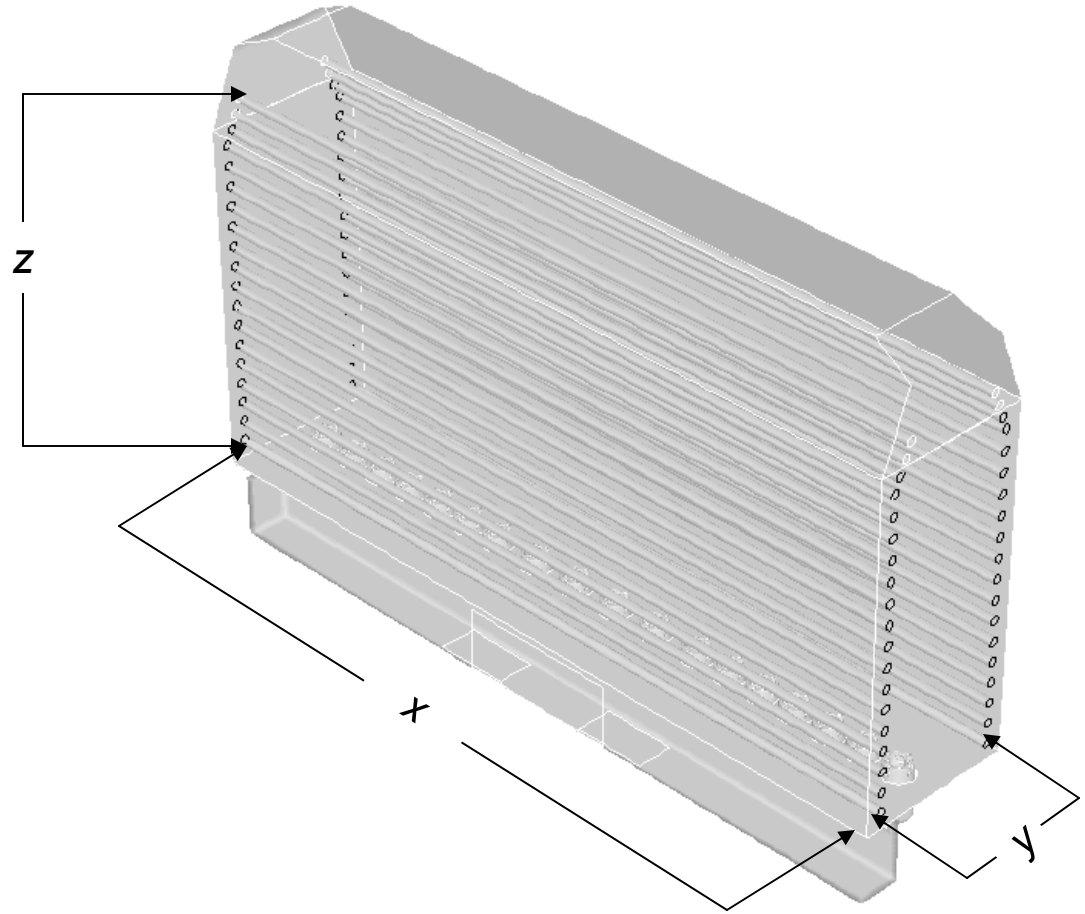
- When the total duty of the heater is increased, a plug flow may form
- Relatively little gas is re-circulated from high in the radiant section
- Burners have no source of cool flue gas to lower NO_x
- The re-circulation ports still function, but with no source of flue gas, the burners may "short-circuit" and feed on the gases directly exiting the burner tile
- Side effects include
  - Very poor flame pattern
  - Very high NO_x
  - Possible tube impingement
- ***<u>Plug flow is generally not seen if the original design firing rate of the heater is maintained</u>***



Volumetric Heat Density in Heaters

- The duty per unit volume contained within the radiant section tubes is termed the **heat density** of the heater

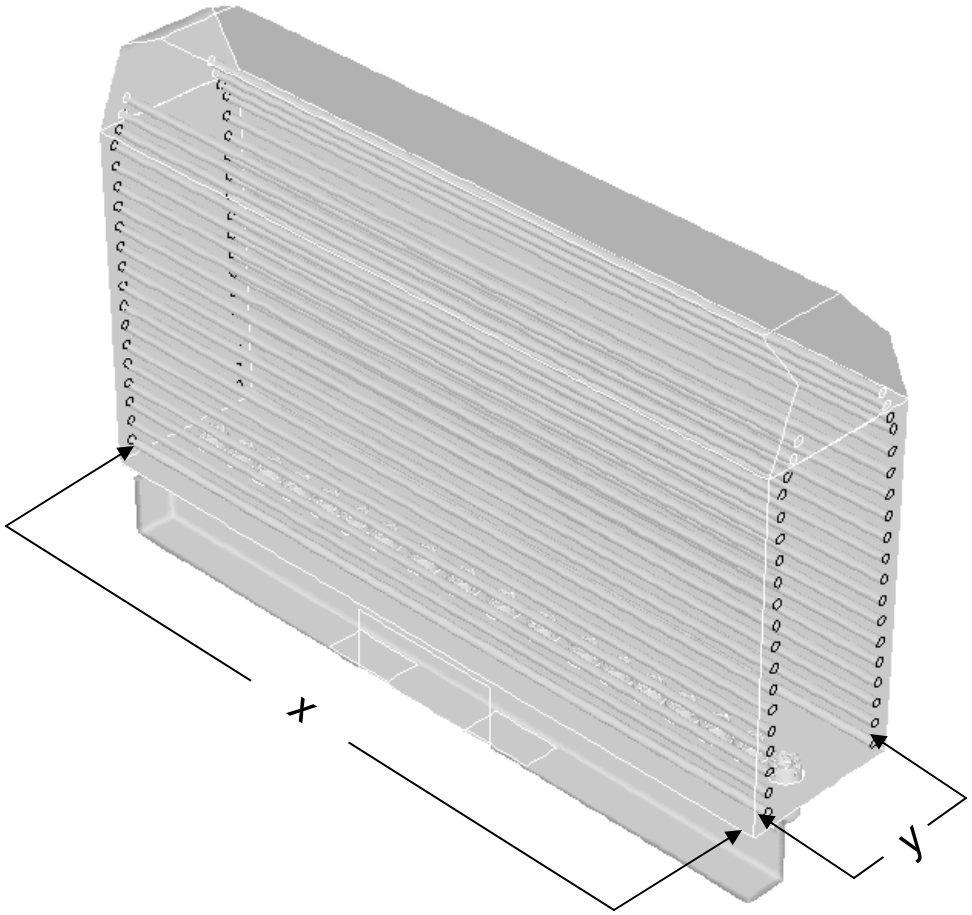
$$\overline{\rho}_{heat} = \frac{xyz}{Q_{in}}$$



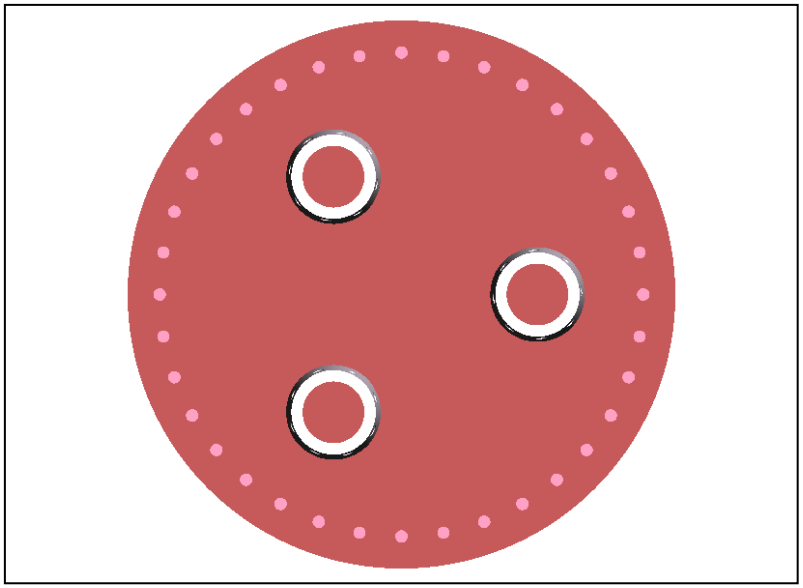
Area Heat Density in Heaters

- The duty per unit area contained within the tubes is termed the **area heat density** of the heater

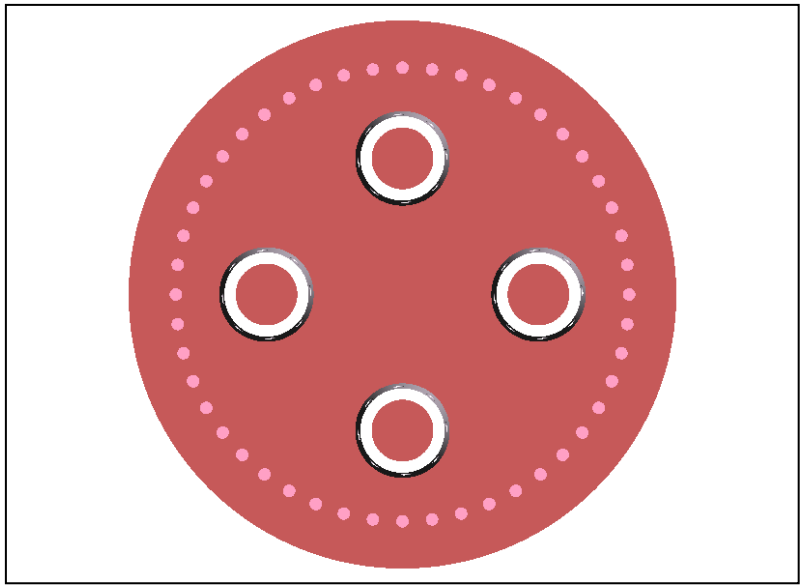
$$\overline{\rho}_{heat} = \frac{xy}{Q_{in}}$$



Area Heat Density - Example



Layout ‘A’

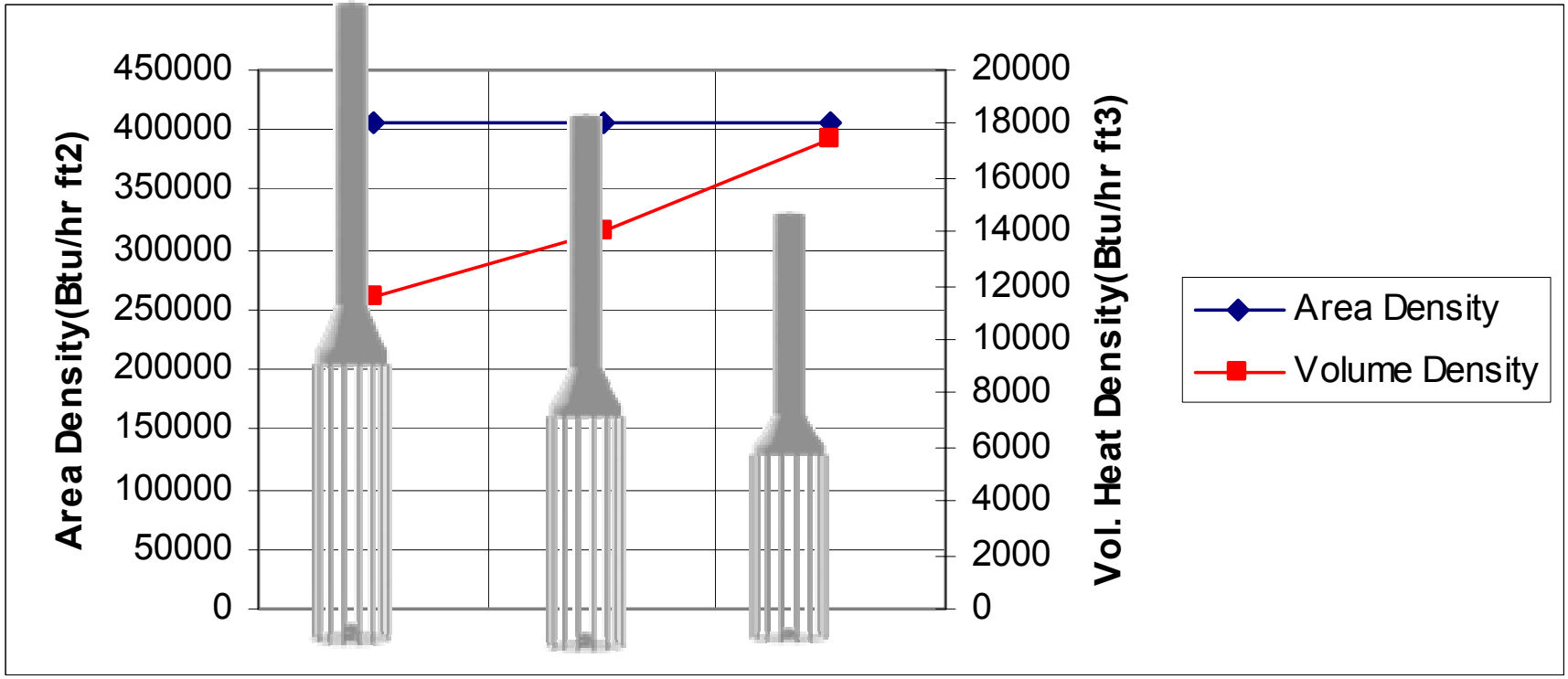


Layout ‘B’

- Layout A: 3 Burners @ 10 MMBtu/hr, 36 tubes, 1600 F BWT
- Layout B: 4 Burners @ 10 MMBtu/hr, 48 tubes, 1600 F BWT
- Bridgewall temperature does not adequately represent the situation:
  - ‘Layout A’ Area Heat Density: 305,578 Btu/hr/ft^2
  - ‘Layout B’ Area Heat Density: 407,437 Btu/hr/ft^2

Area Heat Density – Motivation for Use

- Area heat density is a preferred measure to volumetric heat density because the height of the radiant section affects the volumetric heat density calculation
  - Area heat density is a better indicator of possible plug flow



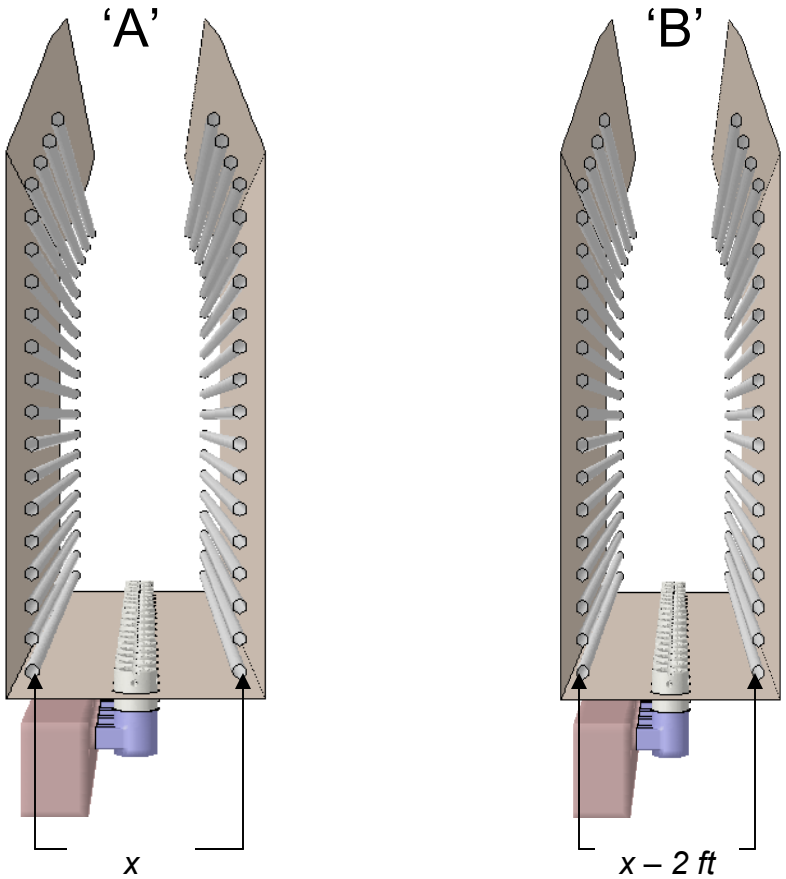
Field Data

- Averaged field data for different styles of IFGR burners
- Similar excess air

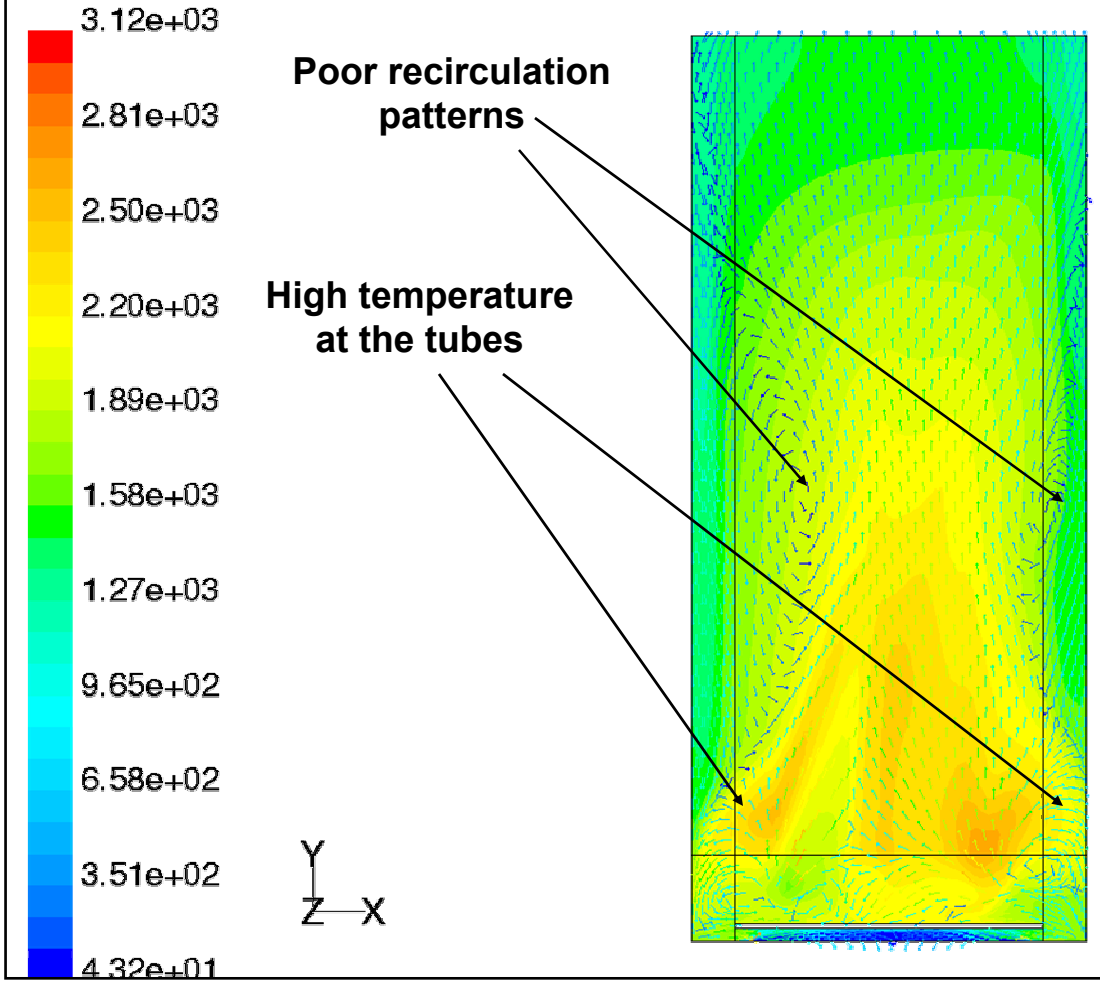
Relative IFGR Flow	Area Heat Density (Btu/hr/ft2)	NOx (PPM)
High	270,000	15.0
High	270,000	20.0
Low-Medium	305,000	28.5
Low-Medium	315,000	35.0
Low-Medium	320,000	32.0
Low-Medium	355,000	30.0
High	545,000	32.0

Field Data

- Two heaters configured in the same way, with only the width varying
- Heater ‘A’ NO_x: 10 PPM
- Heater ‘B’ NO_x: 25 PPM



CFD Extrapolation from Field Data

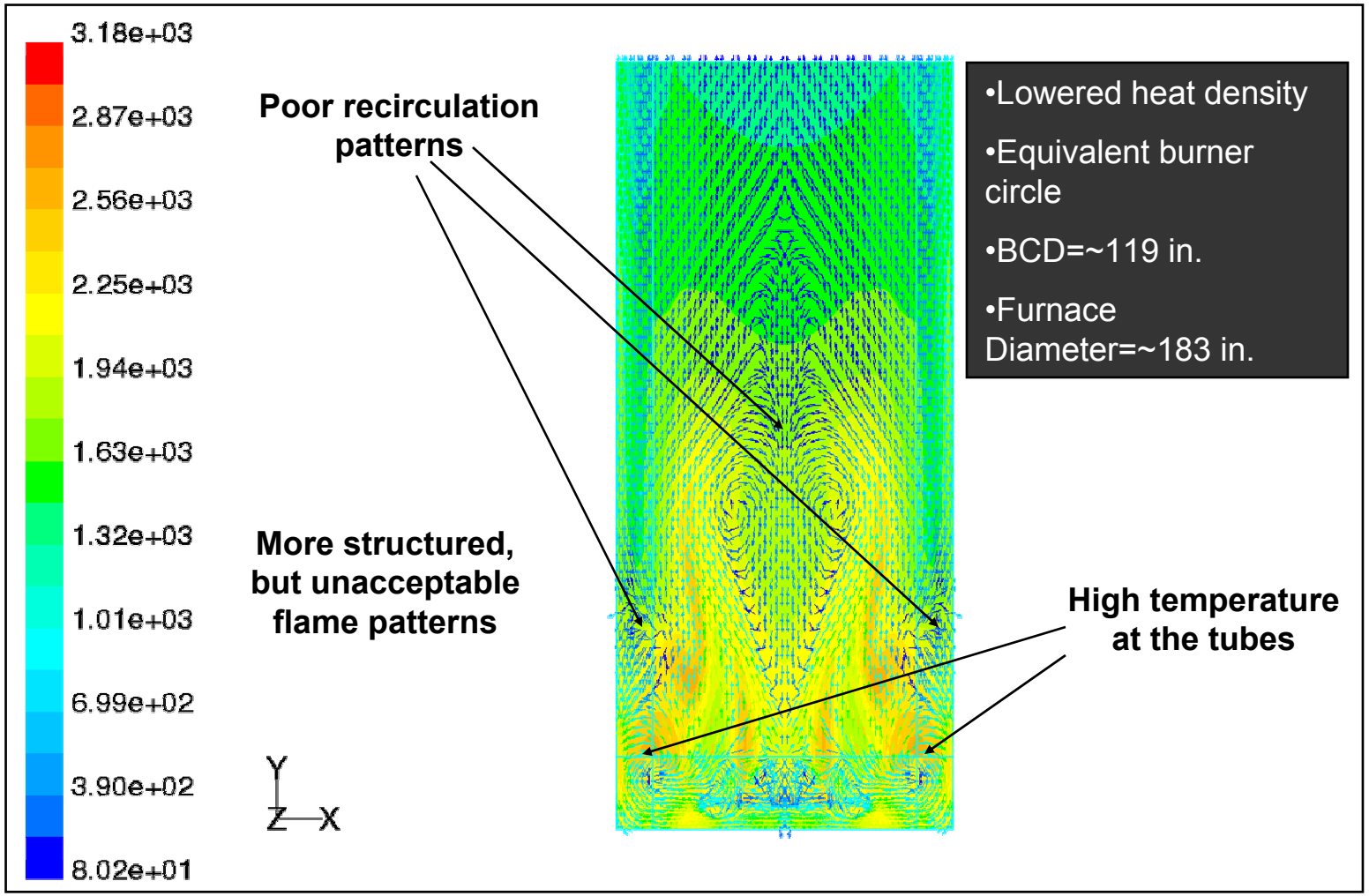


- High Heat Density
- Large Burner Circle <-> Close to tubes
- BCD=~119 in.
- Furnace Diameter=~183 in.

Visually Confirmed in the field

Heat Density: 680,629 Btu/hr/ft2

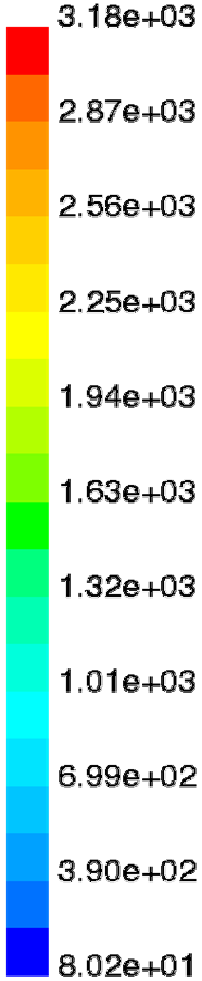
CFD Extrapolation from Field Data



- Lowered heat density
- Equivalent burner circle
- BCD=~119 in.
- Furnace Diameter=~183 in.

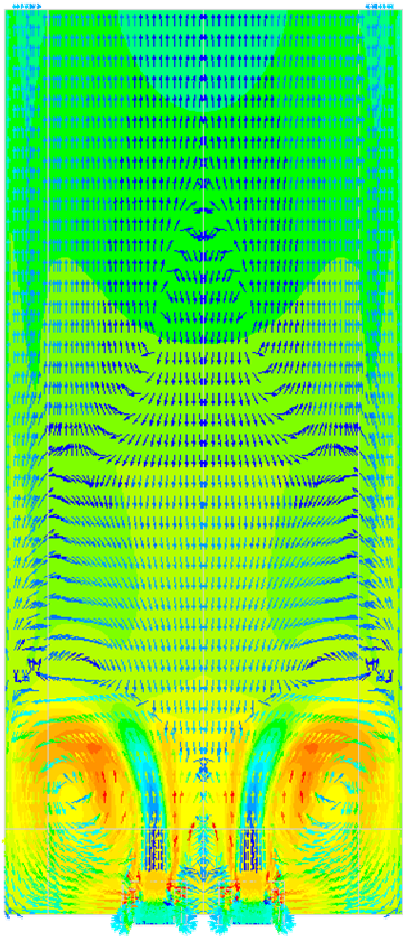
Heat Density: 544,503 Btu/hr/ft2

CFD Extrapolation from Field Data



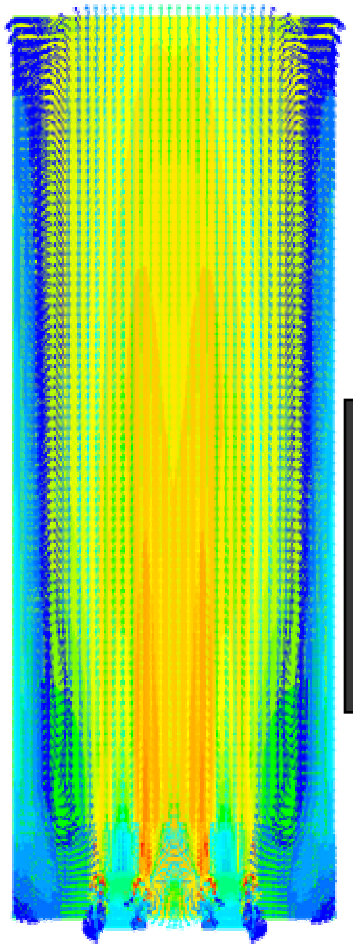
- Lowered heat density
- Equivalent burner circle
- BCD=~119 in.
- Furnace Diameter=~183 in.

180 Degrees from Previous slide



Heat Density: 544,503 Btu/hr/ft2

CFD Extrapolation from Field Data



Normal recirculation patterns and “tight” temperature distribution

- Lowered heat density
- Smaller burner circle
- BCD=~80 in.
- Furnace Diameter=~183 in.

Heat Density: 408,377 Btu/hr/ft2

Recommendations

- Maximum area heat density appears to be in the range of 300,000 Btu/hr/ft^2 to 400,000 Btu/hr/ft^2
- Optimal area heat density ranges from 150,000 to 200,000 Btu/hr/ft^2
- Densities higher than the recommended maximum appear to rapidly increase the NO_x production rate as well as the potential for poor flame patterns

Burner Layout Strategies

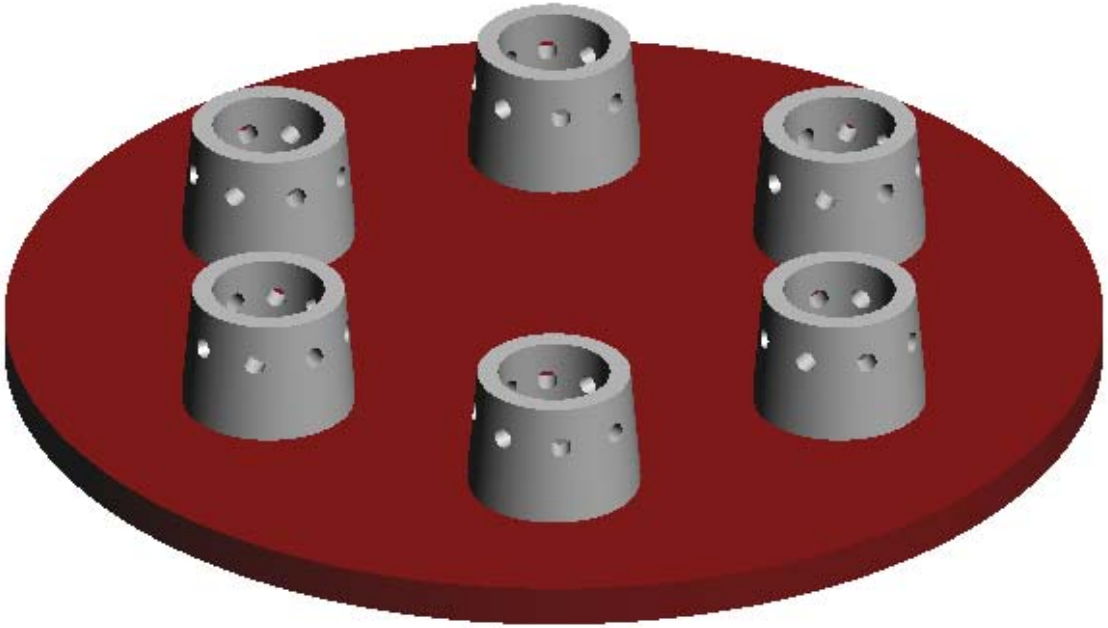
- Adequate pathways for flue gas re-circulation must be provided
- The relatively 'loose' flames of ultra-lox NO_x burners should be considered
- Attempting to avoid the following problems
  - 'Flame collapse': Multiple burner flames coalesce into a single mass of flame, increasing flame length and NO_x
  - 'Short-circuiting': IFGR burner feeds its re-circulation ports directly from its own flame
  - 'Flame lean': Flames have a prevalent velocity that is not along the axis of the heater
  - 'Flame-to-Flame Interaction': Multiple burner flames contact each other, but do not coalesce
- All of these patterns increase NO_x, erode flame quality, and raise the potential for tube impingement

Burner Layout Strategies

- Vertical cylindrical heaters tend to be more problematic than box or cabin style heaters because they usually have higher area heat densities
- Higher available airside pressure drop to the burner almost invariably improves flame pattern and the ability to effectively use IFGR burners
- Currently, a minimum of 8” tangential tile-to-tile spacing is recommended
- Another useful measure is 1” of tangential tile-to-tile spacing per MMBtu fired per burner
- Forced draft burners or low volumetric heat density heaters may allow for a relaxation of the above criteria

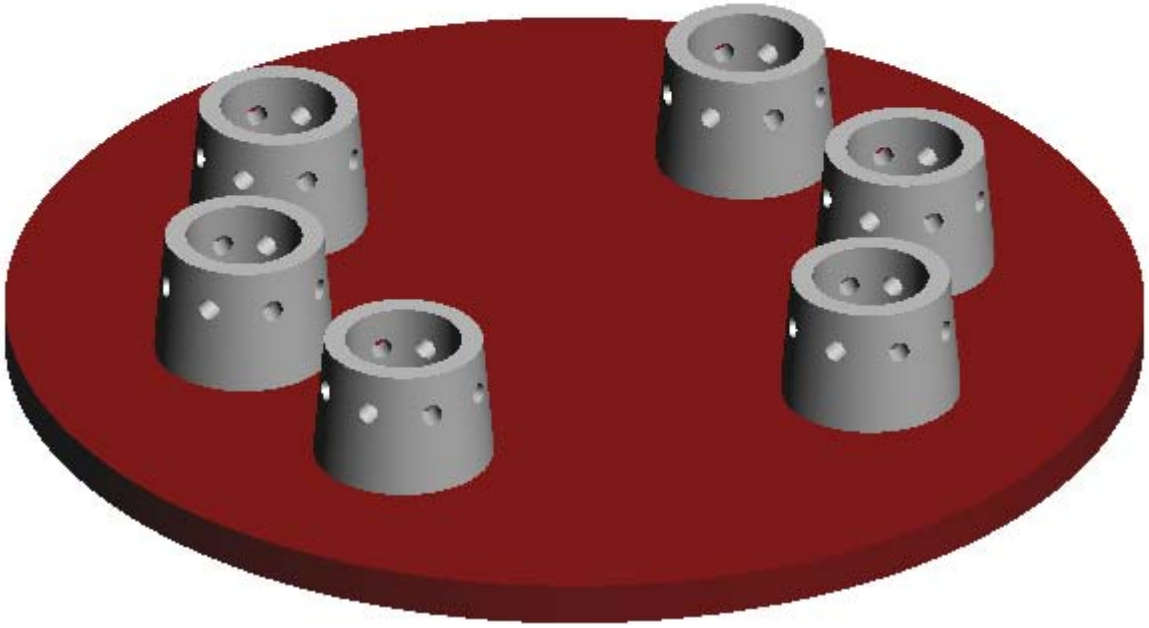
Burner Layout Strategies

- 'Classic Burner Circle'
  - Applicable Area Heat Density: 150,000 – 400,000 Btu/hr/ft^2
  - Motivation: Replication of existing pattern, even heat flux on tubes
  - Notes:
    - 8" tile-to-tile spacing should be maintained
    - API-560 Burner-to-Tube spacing



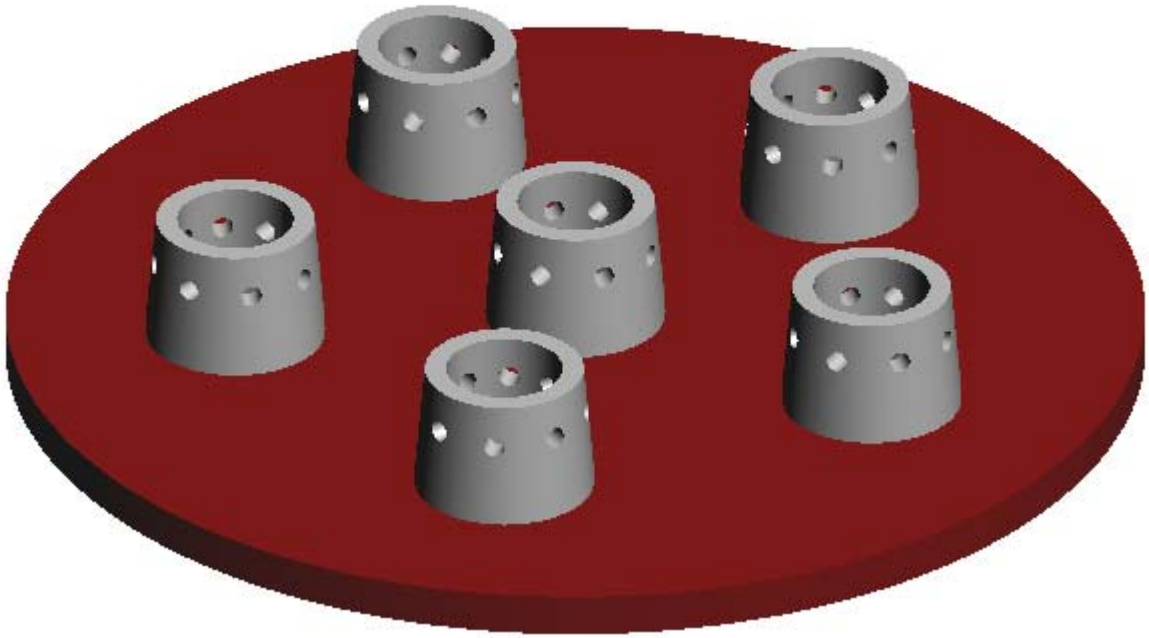
Burner Layout Strategies

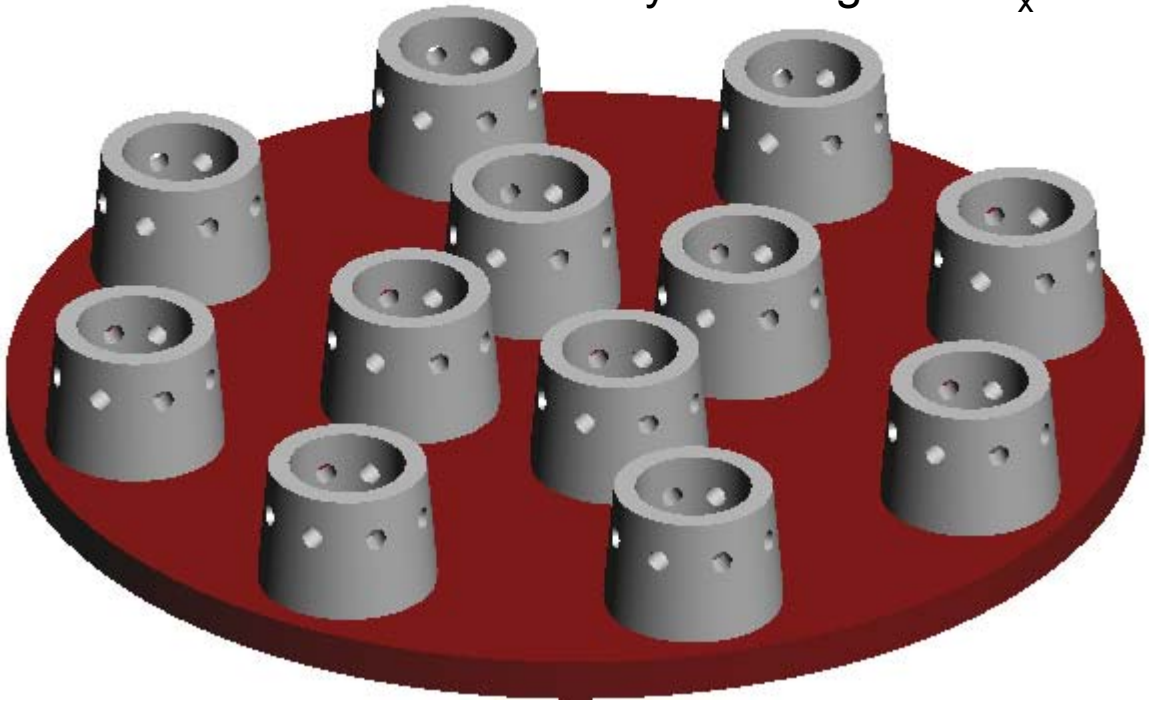
- 'Split Burner Circle'
  - Applicable Area Heat Density: 300,000 – 500,000 Btu/hr/ft^2
  - Motivation: Split circle allows cooler flue gas to the center of the heater, "de-pressurizes" center of burner circle
  - Notes:
    - Not useful where absolutely even tube flux is required



Burner Layout Strategies

- 'Star Pattern Burner Circle'
  - Applicable Area Heat Density: 300,000 – 500,000 Btu/hr/ft^2
  - Motivation: Center burner is used to provide upward momentum, possibly preventing flame collapse
  - Notes:
    - Center burner will most likely have higher NO_x



Burner Layout Strategies

- 'Dual Burner Circle'
  - Applicable Area Heat Density: 300,000 – 500,000 Btu/hr/ft^2
  - Motivation: Center burners are used to provide upward momentum, possibly preventing flame collapse
  - Notes:
    - Center burners will most likely have higher NO_x