Modeling Furnaces in the Chemical Process Industry

REACTION ENGINEERING INTERNATIONAL

Committed Individuals Solving Challenging Problems

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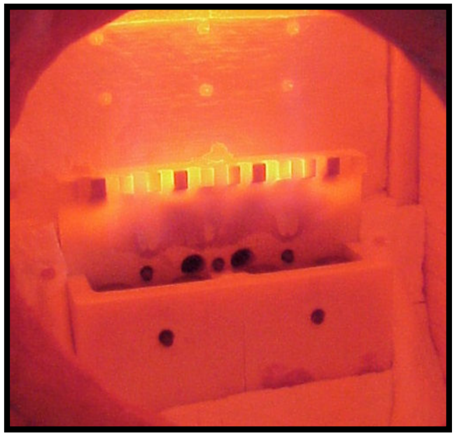
REI Profile

- Energy And Environmental Consulting Firm Specializing In:
  - » Combustion System Design and Performance Analysis
  - » Complex CFD Simulations
    - – Performance
    - – Emissions
    - – Operational Impacts
  - » Customized Software
  - » Specialized Equipment
  - » Proof-of-Concept Testing
- Strong Network of Experts

Objective: Solve Challenging Combustion Problems Using Specialist Talent & Technology

REI Modeling Strengths

- Modeling and Analysis Expertise
  - » Combustion, Fuel Conversion & Pollutant Emissions
  - » Unique, Proprietary Modeling Capabilities & Tools
    - – Ability to develop and apply advanced chemistry to CFD and process modeling tools
  - » "Qualified" Combustion Modelers
    - – Understand physics, chemistry, mathematics, software
    - – Industrial perspective
  - » Experience
    - – Over 200 Combustion Systems Modeled
- Network of Consultants
- Objective Analyses



Selected Industrial Applications & Clients

Applications

- Melting Furnaces
- Reheat Furnaces
- Blast Furnace Injection
- Flash Smelters
- Cement Kilns
- Phosphate Kilns
- CO Boilers
- Sulfur Recovery Units
- Process Heaters
- Cracking Furnaces
- Incinerators
- Thermal Oxidizers
- Burners
- Enclosed Flares

Selected Clients

- Bayer
- BHP
- BP
- Cadence
- Callidus
- Chemtrade
- Chevron
- China Steel
- Cominco
- ConocoPhillips
- CPC
- CPChem
- Dow
- Hexcel
- Holnam
- Huntsman Chemicals
- INCO
- Inland Steel
- John Zink
- LaFarge
- Lone Star
- Monsanto
- NOVA Chemicals
- PCA
- Persee Chemical
- Philip Morris
- Praxair
- Searles Valley Minerals
- Technip
- Solena
- Solutia
- SunCoke
- Thai Olefins

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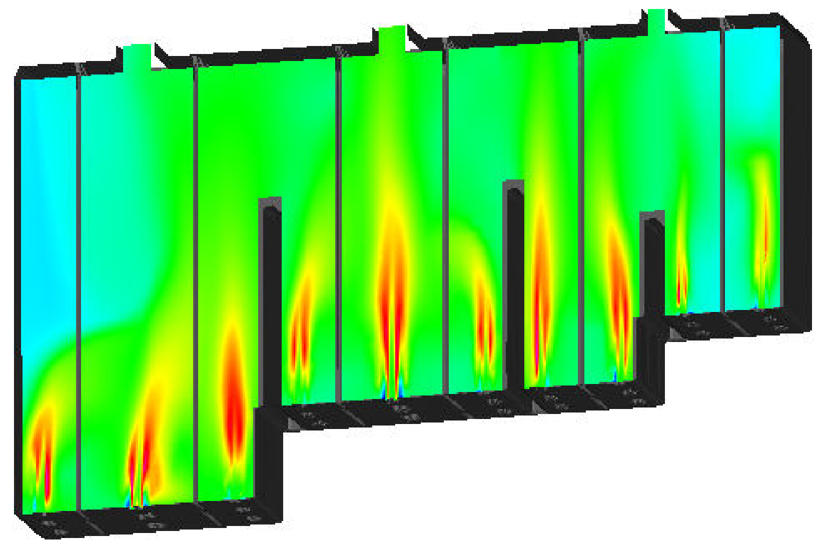
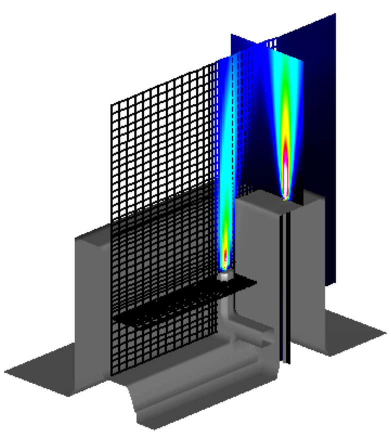
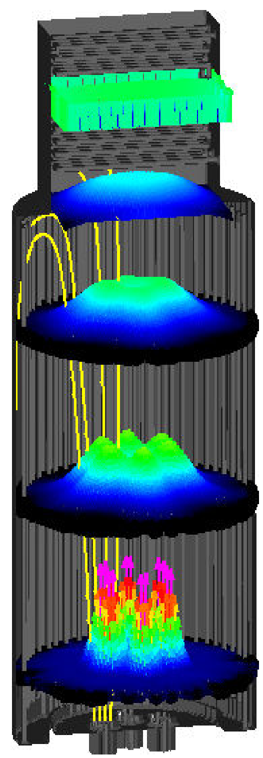
Chemical Process Applications



Systems

- Process Heaters
- Cracking Furnaces
- Thermal Oxidizers
- Incinerators
- Burners
- Flares





Applications

- Pollutant Emissions (NOx, CO)
- Waste Stream Disposal
- Tube Overheating
- Heat Flux & COT Uniformity
- Process Yield & Conversion
- Radiant Efficiency

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Why Use CFD Modeling?

Modeling is a cost effective approach for evaluating system performance, pollutant emissions, and operational impacts

- **Improve understanding**
- **Estimate performance**
- **Provide conceptual designs**
- **Identify operational problems**
- **Cheaper than testing**
- **More information than testing**

- **Does NOT make decisions for engineers, but does help them be more informed**

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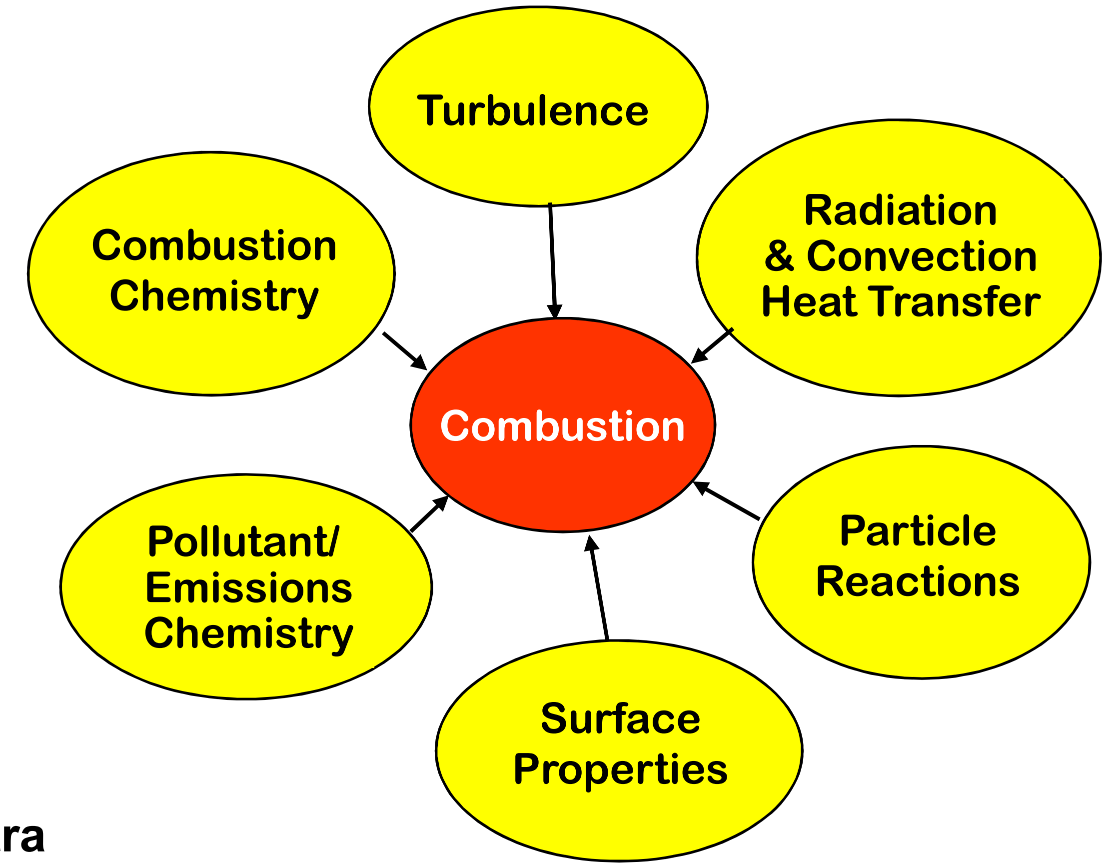
REI's Proprietary *CFD* Software

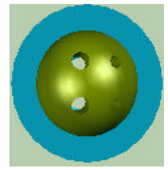
- ***BANFF & GLACIER***
  - 20+ years development and application
  - Targeted to gas, oil and coal-fired utility boilers
- ***ADAPT***
  - ~10 years development and application
  - Improved geometry resolution (adaptive mesh refinement)
  - Advanced chemistry
  - Improved turbulence-chemistry interaction
  - Targeted to gas-fired ultra low-NOx systems and premixed combustion



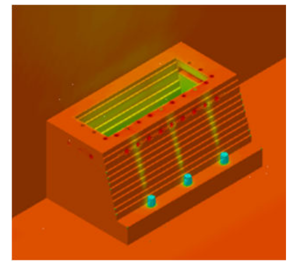
Chemical Furnace Modeling Challenges

- **Scales!**
  - » Geometric resolution
  - » Jet velocities
  - » Chemistry vs turbulent mixing
- **Input accuracy**
  - » Garbage-in garbage out
- **Trade-off between accuracy and turn-around time**
  - » What are most critical factors for problem of interest

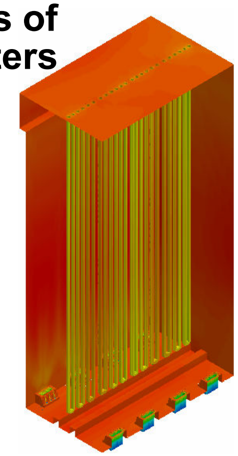
millimeter

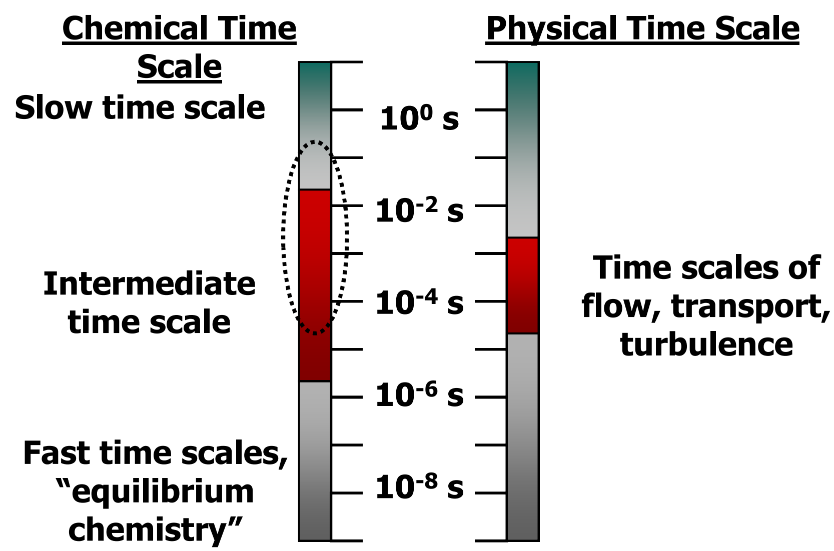


meter



tens of meters





Furnace Model Requirements

- Accurately represent furnace geometry and operation
- Sub-models for:
  - » Turbulent fluid mechanics
  - » Combustion chemistry
  - » Turbulence-chemistry interactions
  - » Finite-rate kinetics for ppm-level NOx, CO
  - » Surface properties
  - » Gas-wall-tube heat transfer (conduction, convection, radiation)
  - » Process chemistry

- Computationally efficiency (parallel execution)

Modeling Approach

- REI currently uses advanced *ADAPT* CFD software for process heaters/cracking furnaces
- Accurate modeling provides accurate flame shape, flow patterns, temperature profiles, major species profiles, heat transfer/heat flux profiles, tube temperatures, process fluid heat absorption
- Provides capability to analyze:
  - » New generation ultra-low NOx burners for new furnaces and revamps
  - » Burner spacing, distribution and burner-burner interactions
  - » Lower emissions (CO and NOx)
  - » Impacts of fuel changes
  - » Non-uniform heat flux profiles and surface temperatures
  - » Sources and fixes for process or convective tube overheating
  - » Test furnace to full-scale furnace scale-up

Sample Uses of Modeling

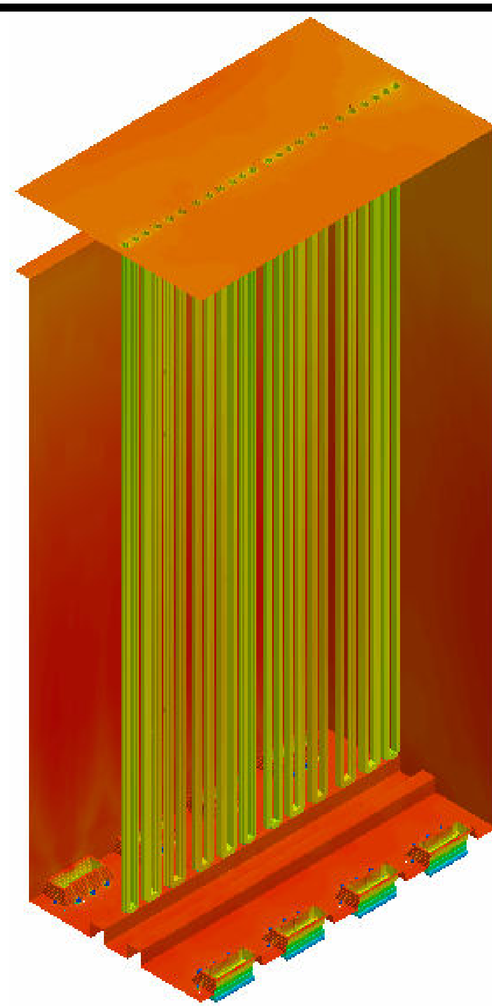
- Improved Performance
  - » Enhance furnace efficiency
  - » Lower emissions
  - » Study particulate behavior during de-coking process
- Reduce risk of new technology
  - » Evaluate burner designs and spacing for new furnaces
  - » Compare different burner designs for furnace revamps
  - » Assess impacts of fuel changes
  - » Evaluate coating impacts
  - » Scale burner performance from test furnace to full-scale furnaces
- Troubleshooting
  - » Identify causes and fixes for process or convective tube overheating
  - » Identify source of heat flux non-uniformities

Pyrolysis Furnaces

Example - Retrofit Burner Evaluation

Full-Scale Pyrolysis Furnace

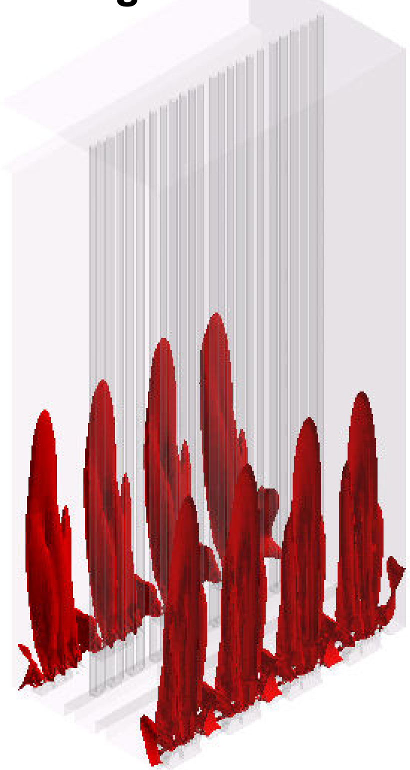
- Objectives
  - » Improve flame quality
  - » Maintain low NO_x emissions
- Compare retrofit burners
  - » Flame quality (no rollover)
  - » Low NO_x and CO emissions
  - » Heat flux profile
- Use ¼-furnace model
  - » Capture burner-burner interaction
  - » Capture tube heat flux profiles
  - » Maximize burner resolution



Retrofit Burner Evaluation

Isosurfaces of 5000 ppm CO

Original burner



Excess fuel between burners

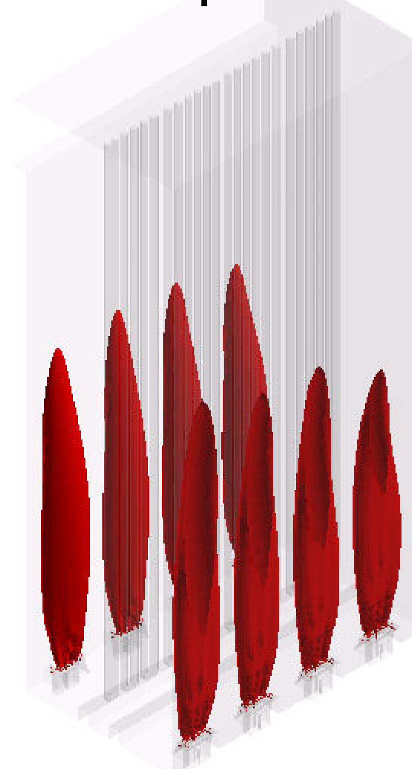
Option 1

Propensity for flame rollover

Option 2

Limited heat flux distribution

Option 3



Good combination of flame quality and heat distribution

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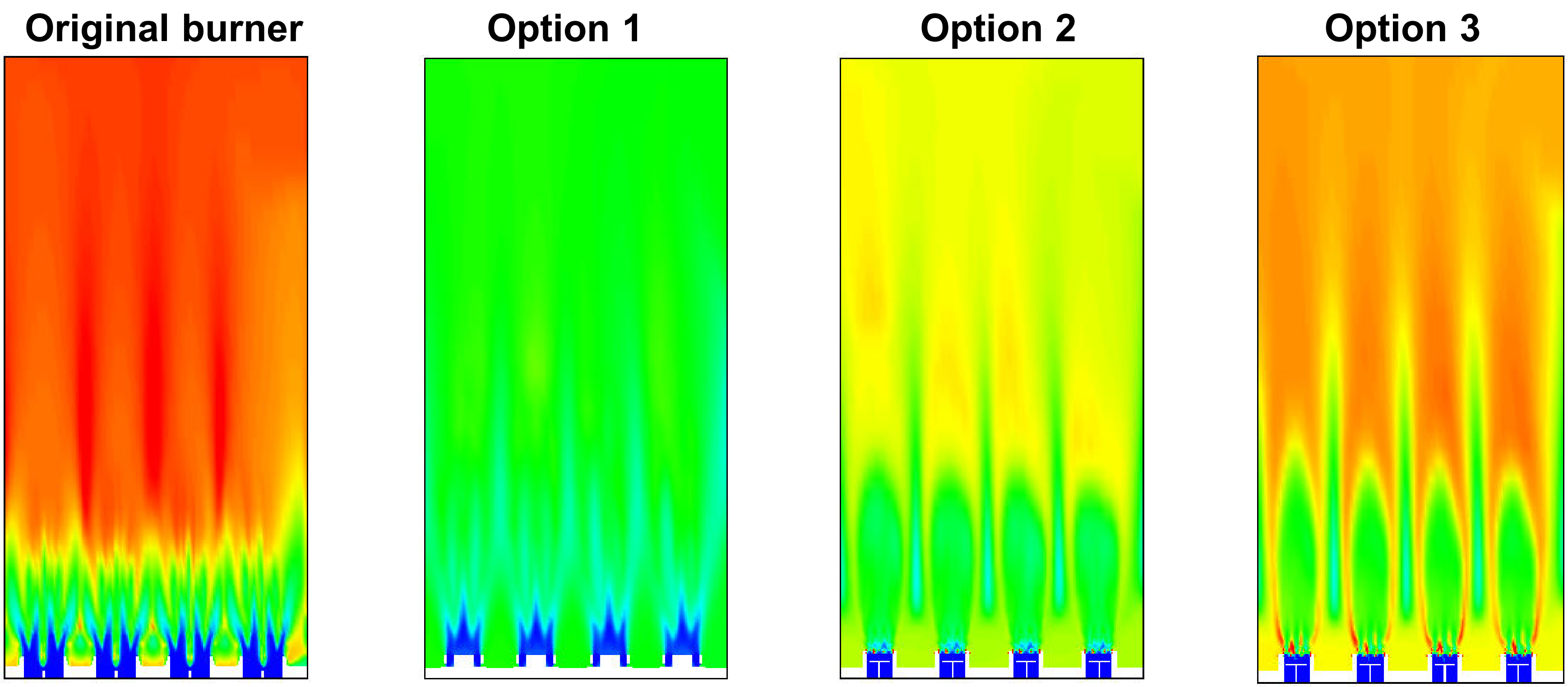
Retrofit Burner Evaluation

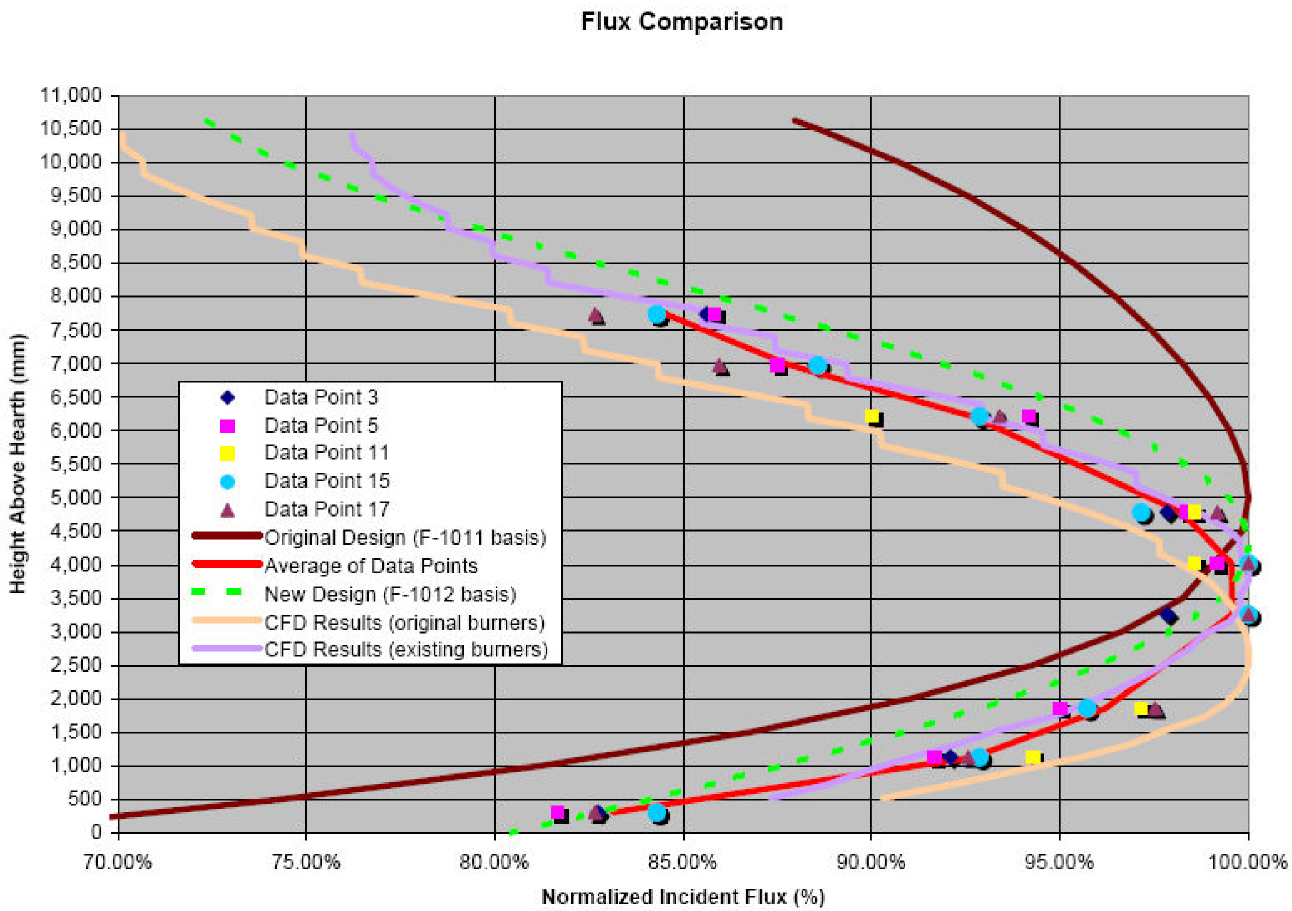
NO_x Profiles

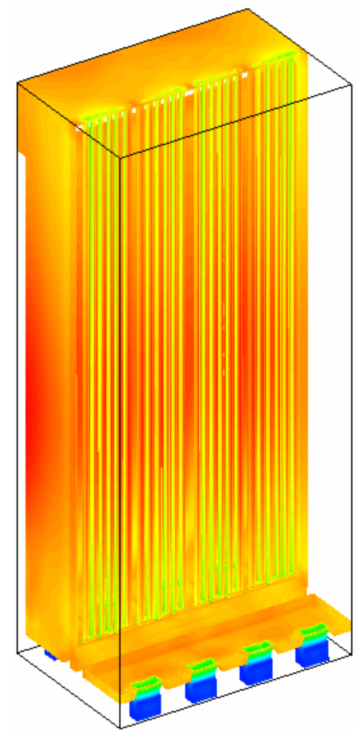


- **Option 3 improved flame quality and slightly lowered NO_x emissions**

Example – New Furnace

- **Identified improved burners for new ethylene cracking furnace, helped adjust heat flux design basis**





Incident Flux

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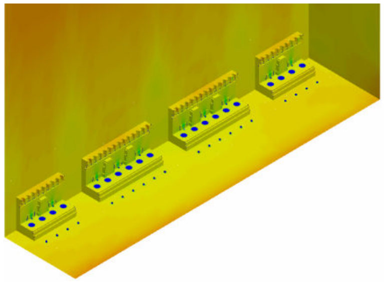
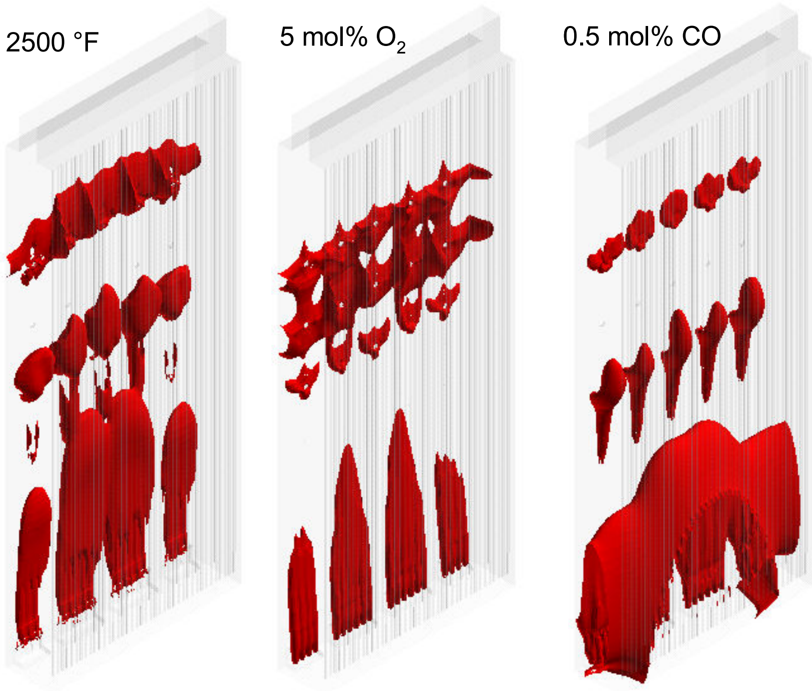
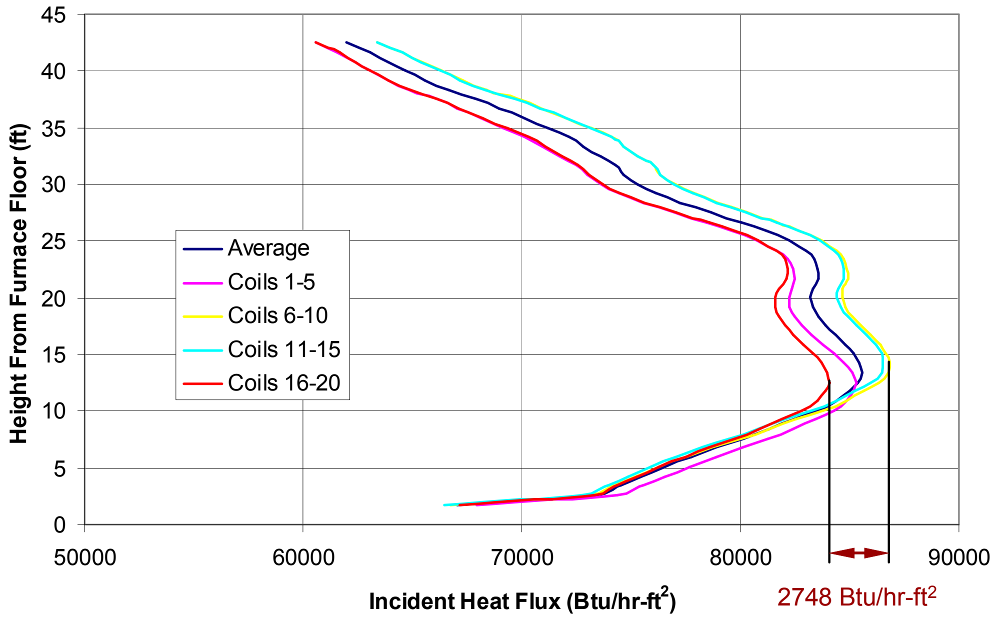
Example – New Burner

- **Evaluated new ultra low-NOx burner performance, helped guide burner spacing and port placement**







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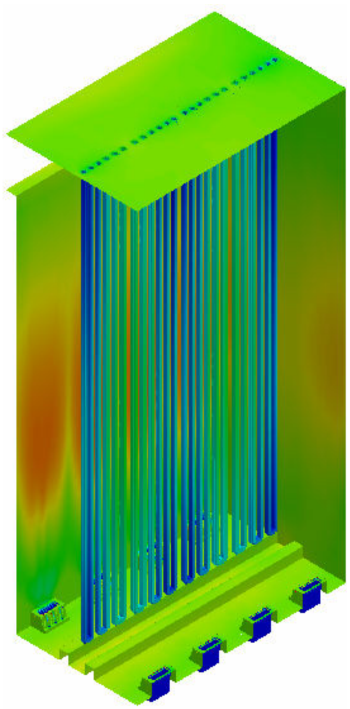
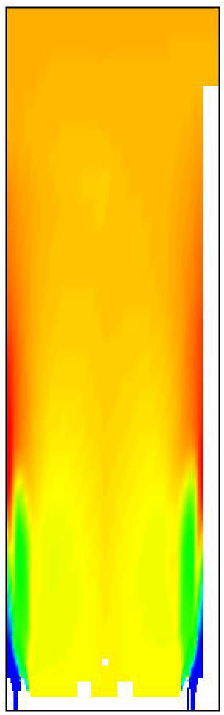
Example – Burner Retrofit

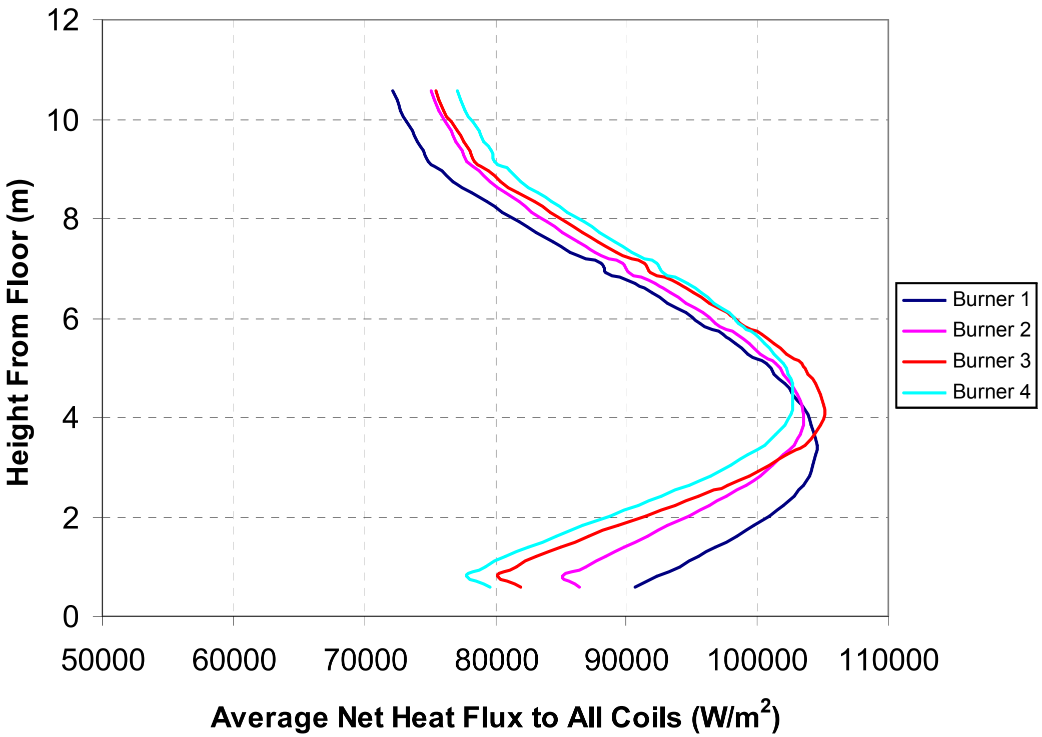
- Evaluated different burner designs to determine best flux profile and NO emissions for furnace retrofit



Surface Temperature

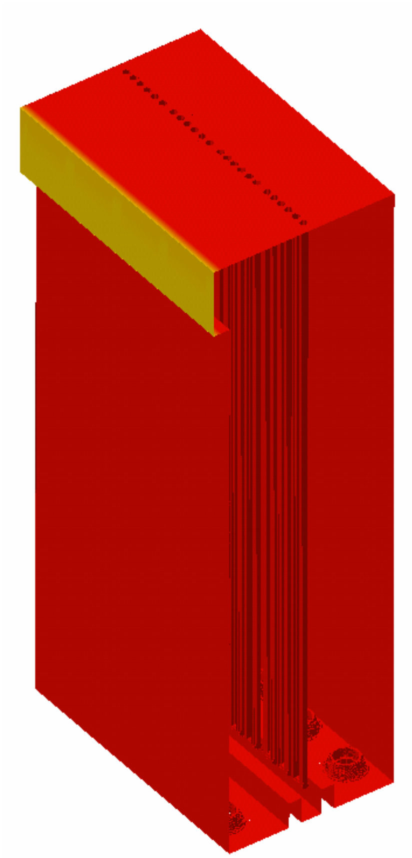


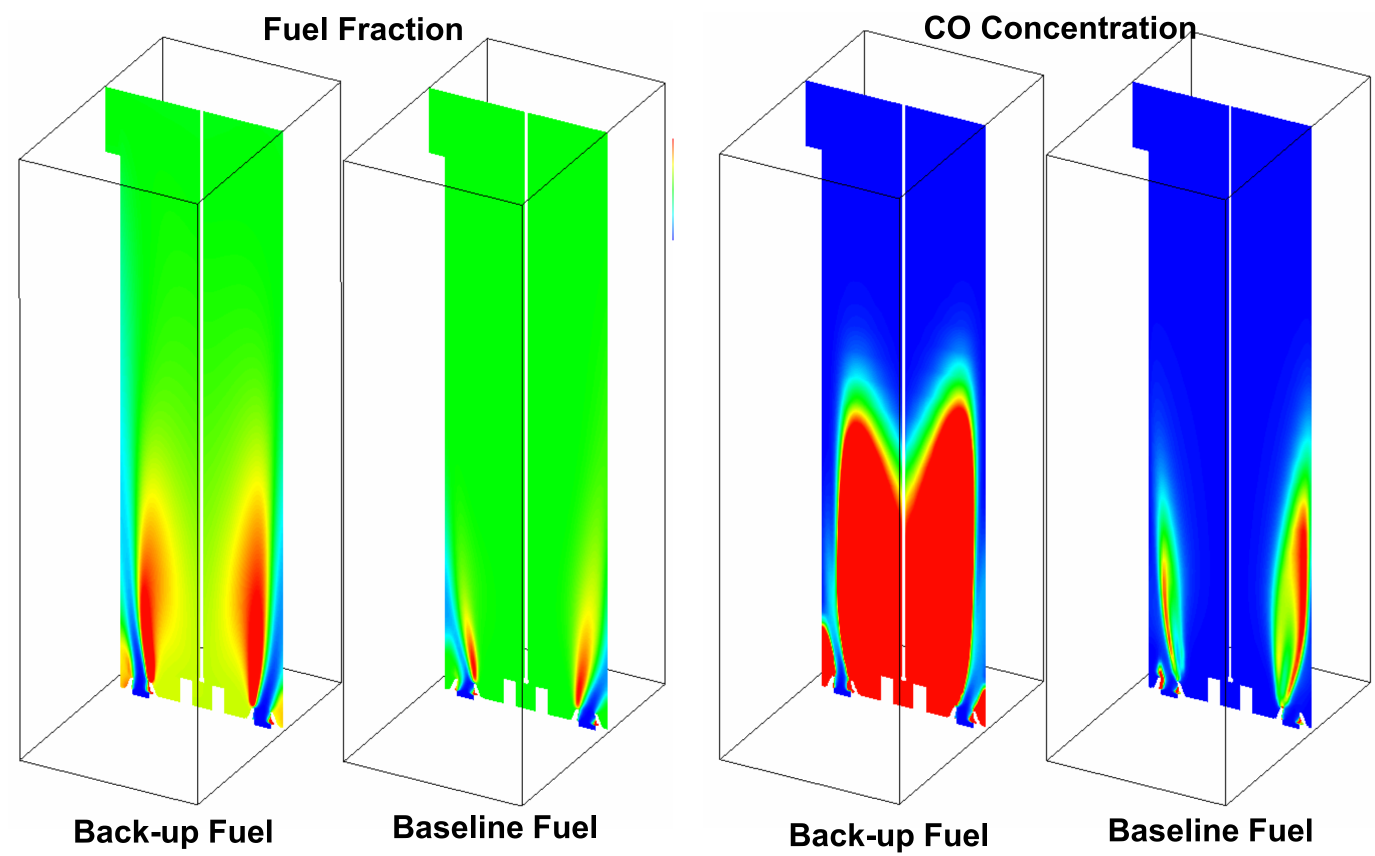
NO Concentration



Example – Fuel Change

- Evaluated performance of back-up fuel with new burners

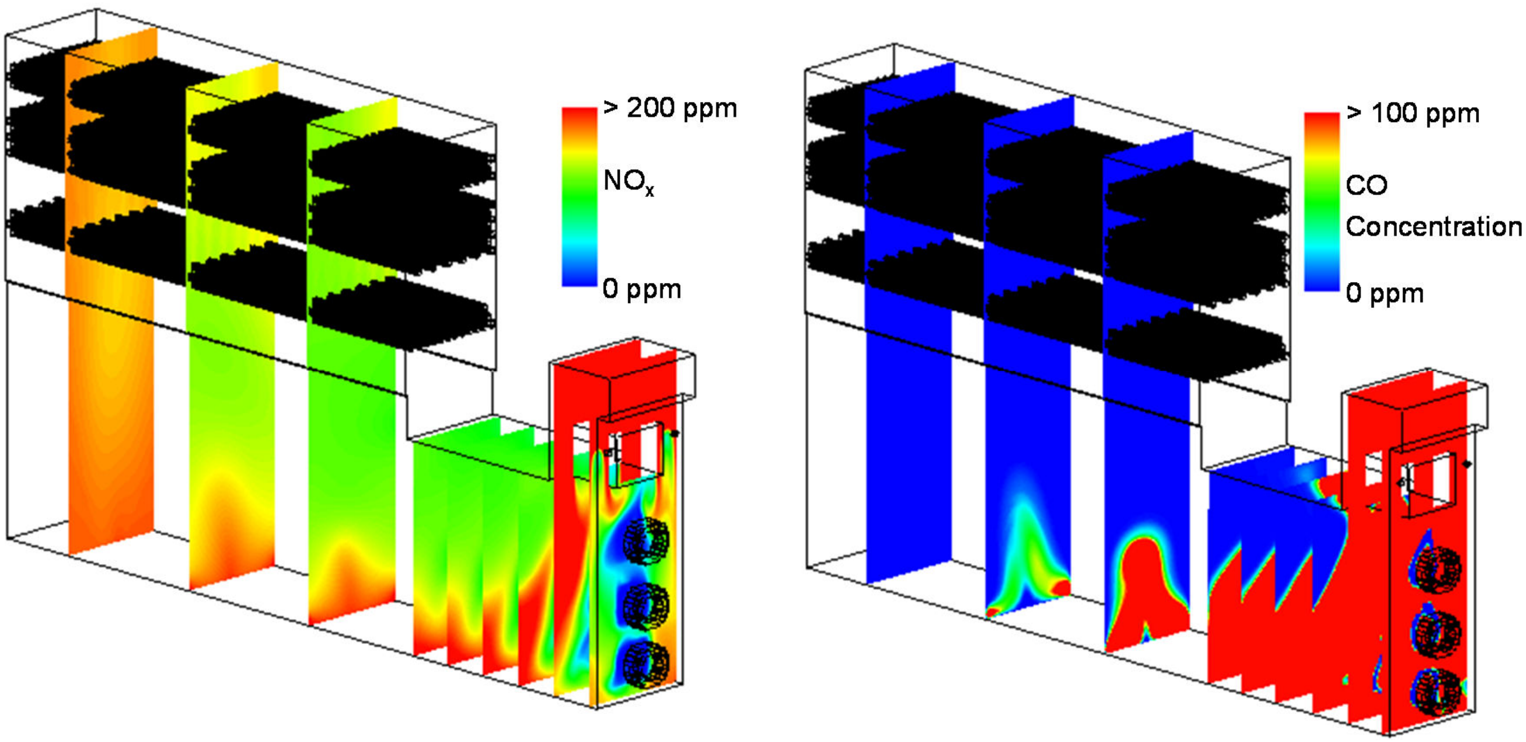




Industrial Furnaces

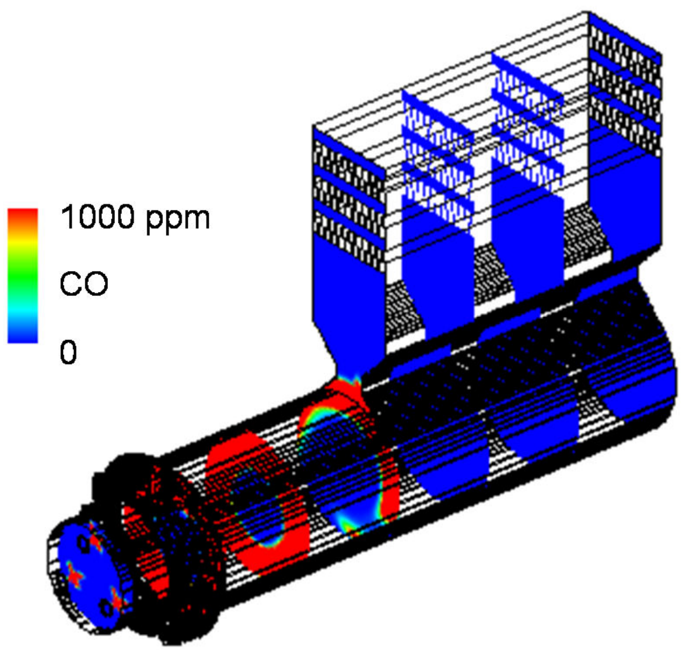
CO Boiler

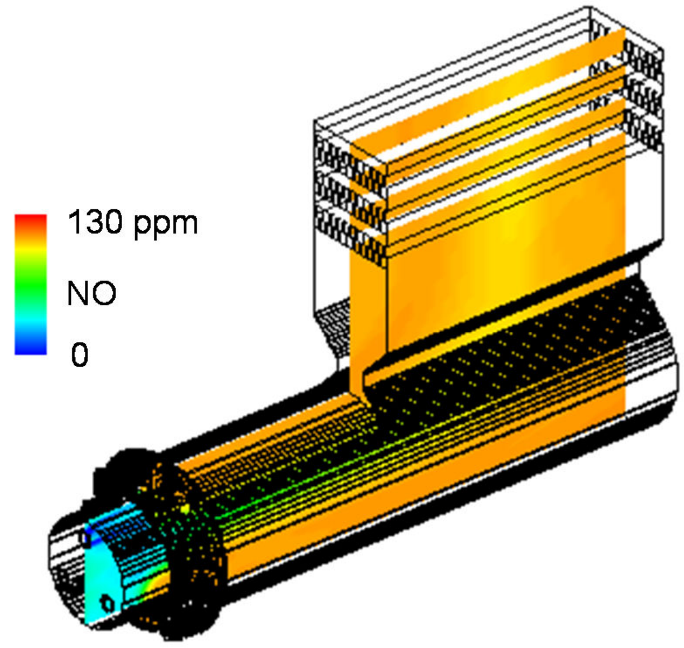
- **Simulation of a CO boiler with process tubes for heating crude oil. CO plenum was simulated to predict the mixing of injection air into the CO plenum to account for impacts of non-uniform air and CO mixing**



CO Boiler

- **Simulation of CO oxidation and NOx formation in a CO boiler to assess flue gas properties in the boiler that would impact SNCR design.**





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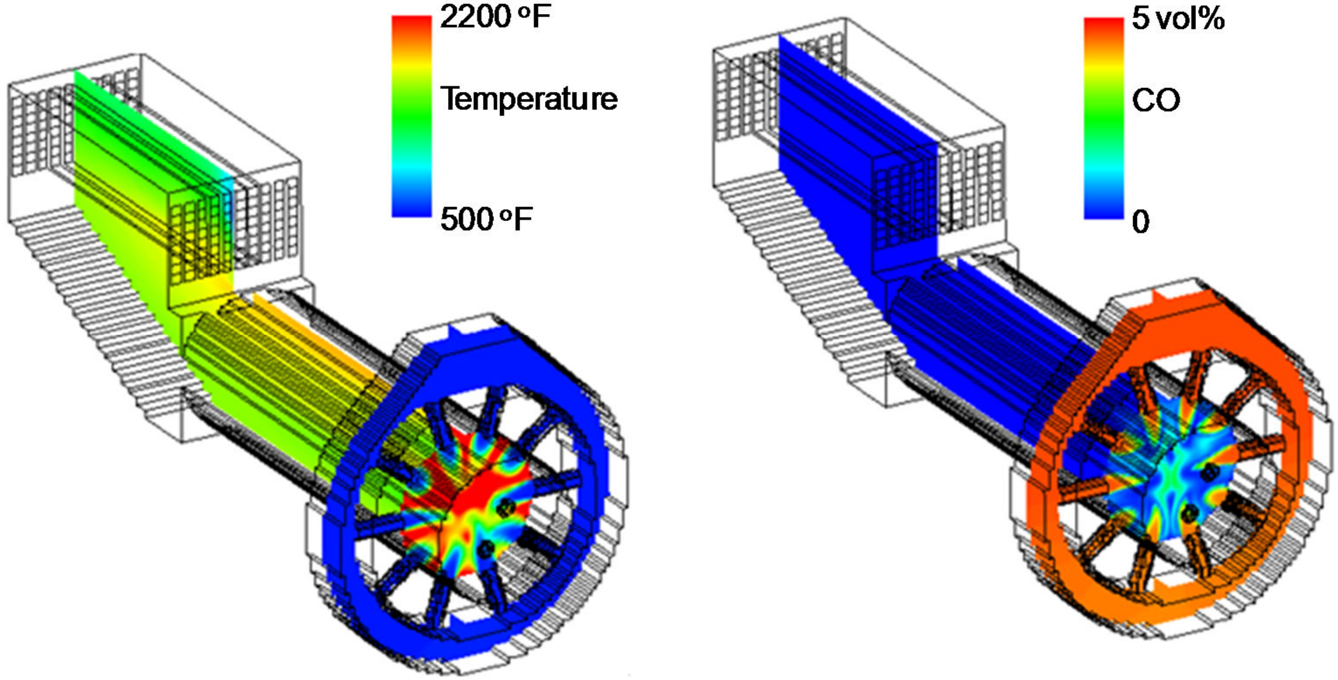
CO Boiler

- **Simulation of flue gas flow, gas temperature, CO, and NOx distributions in approximately 10 different waste-heat recovery CO boilers augmented by natural gas combustion for assessment of SNCR for NOx control.**



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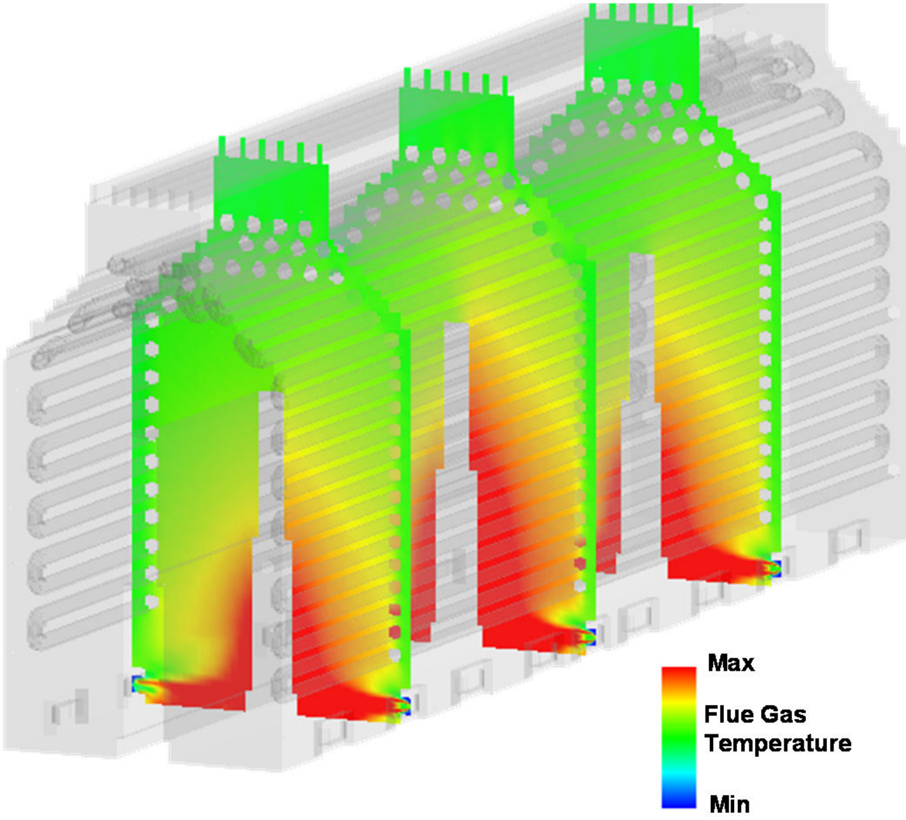
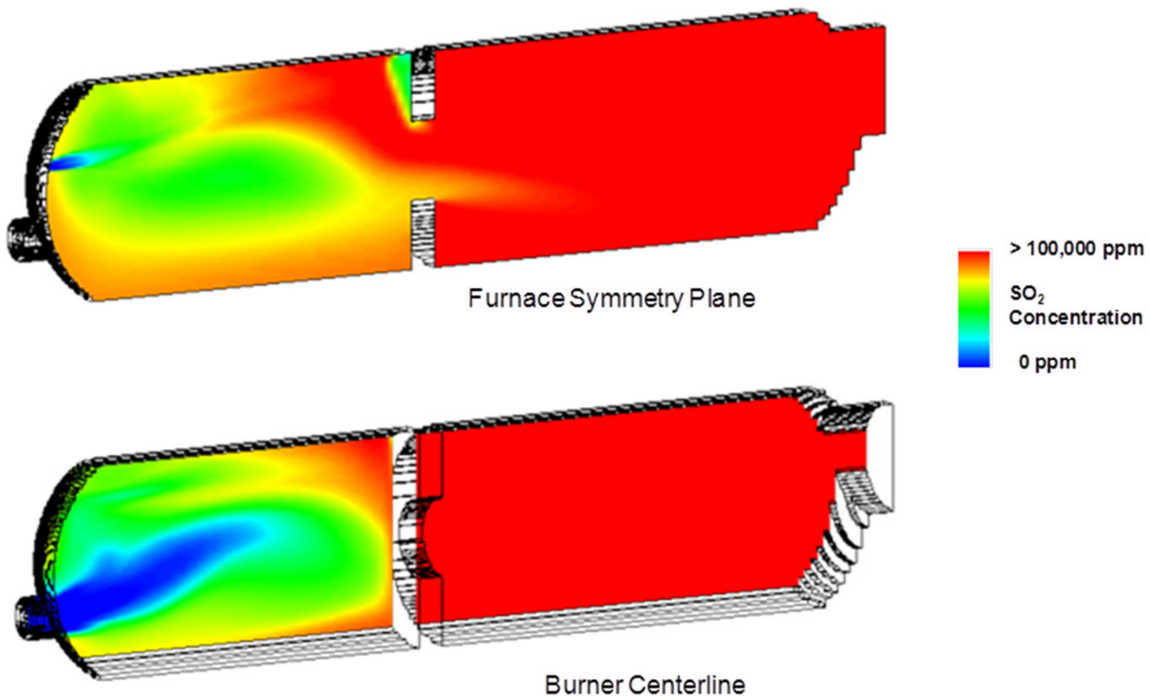
Refinery Process Heater

- **Simulation of a refinery process furnace for evaluation of impacts of modifications of process tube arrangement to mitigate tube overheating.**



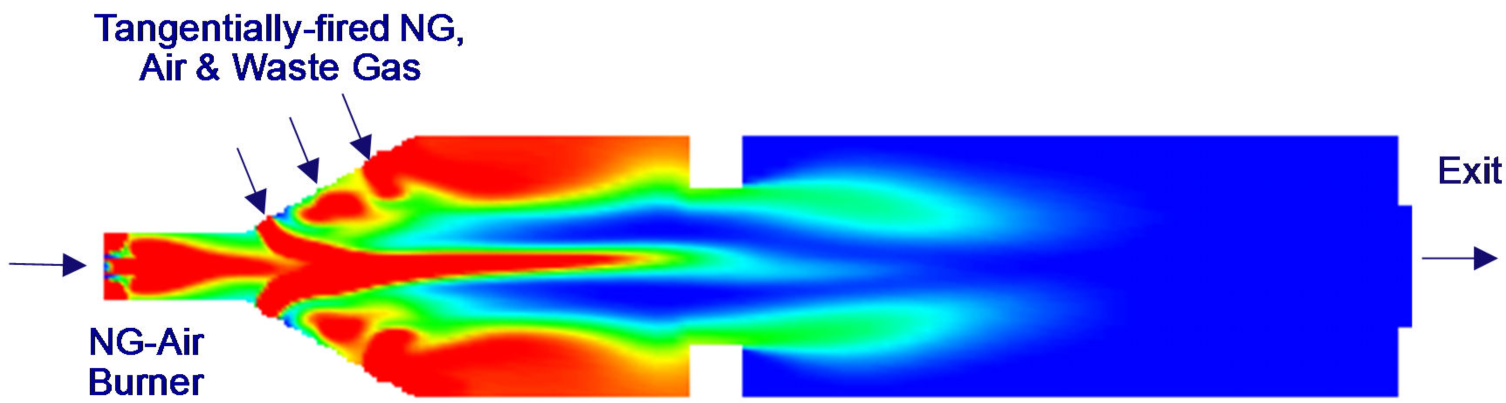
Spent Acid Furnace

- Simulation of a spent acid furnace fired by fuel oil. Modeling used to verify adequate fuel burnout and aqueous spent acid vaporization achieved with limited droplet impaction on walls



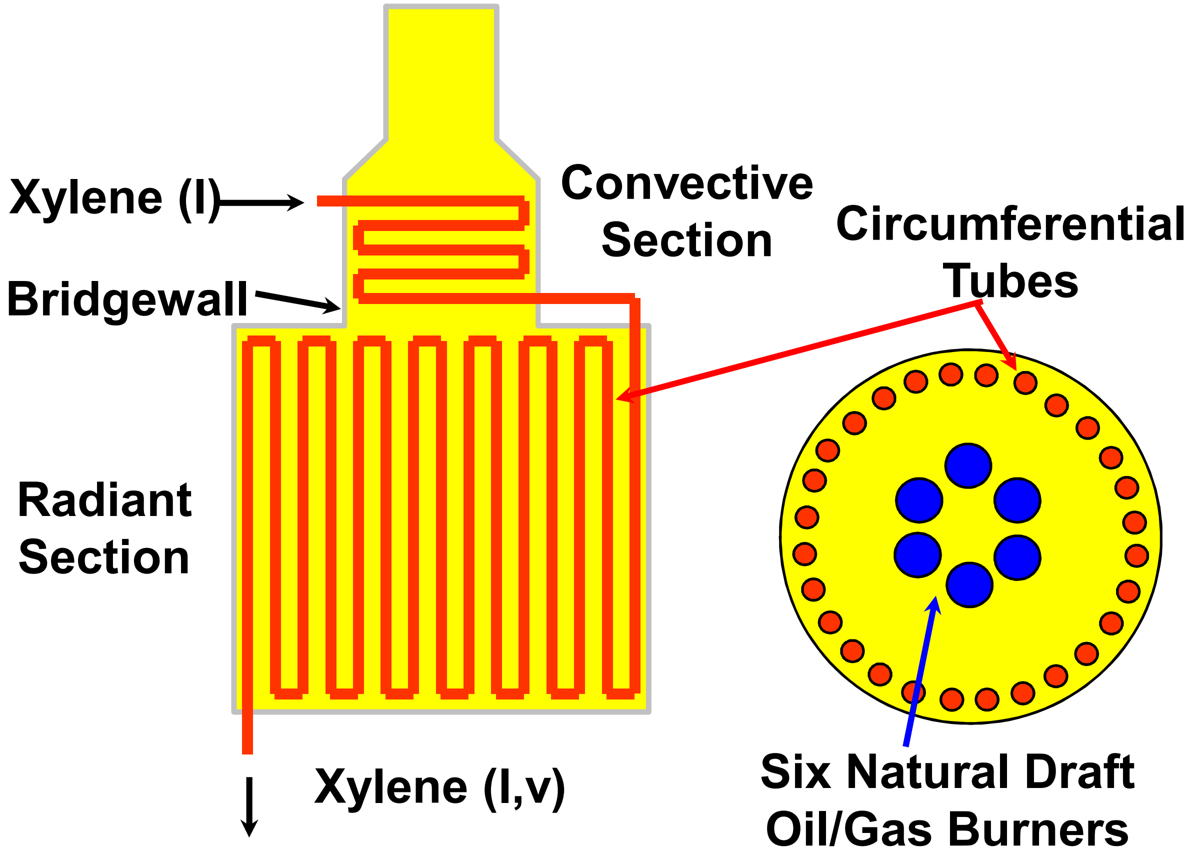
Thermal Oxidizer

- Simulation of an absorber off-gas oxidizer. Simulations were conducted in order to optimize burnout of the waste gas while minimizing NOx formation.



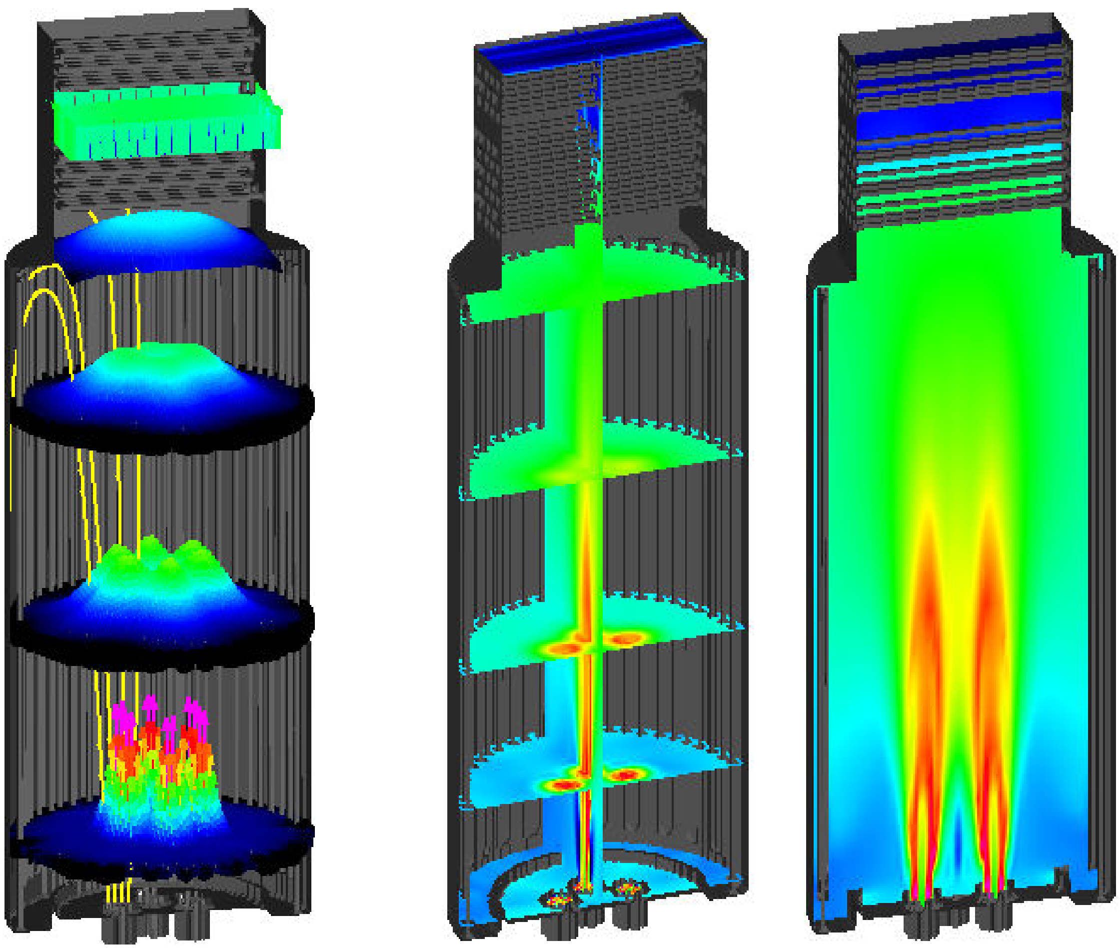
Detailed Example – Xylene Reboiler

- Xylene Splitter Reboiler (XSR)
- 52.5 MMBtu/hr Firing Rate
- 95/5% Oil/Gas
- 20% Excess Air
- 4 Process Tubes



- Radiant Tubes Hottest At 1/3 Height (why?)
- Bridgewall Temperatures Too Hot (measurement system reliable?)
- Convective Tube Localized Overheating (how to fix?)

Flow and Temperature Patterns

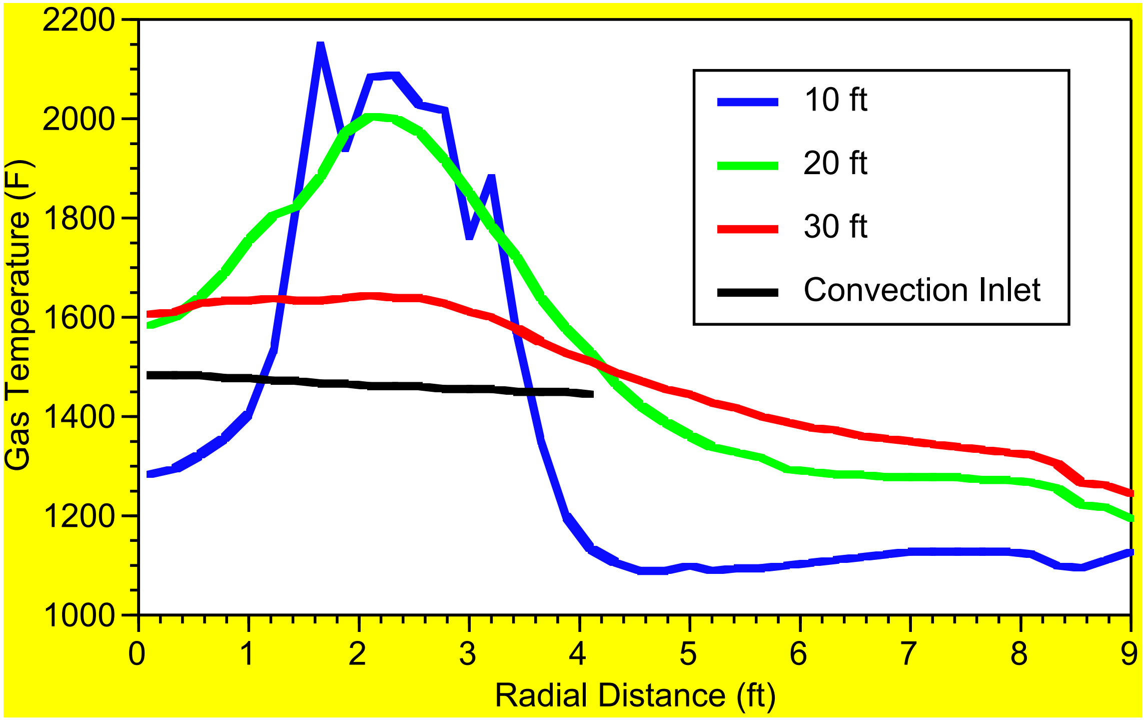


Flow Velocity   Temperature   Temperature

- **Recirculating Flow Field**
- **Long Flames Mix Slowly**
- **CO & O_2 Have Similar Profiles**
- **Flames Highly Emissive**

Temperature Profiles

Radial Gas Temperature Profiles



Profile Impacts:

- **Flame Emission**
- **Tube Heat Flux & Temperatures**
- **Bridgewall Temperatures**
- **Convective Tube Temperatures**

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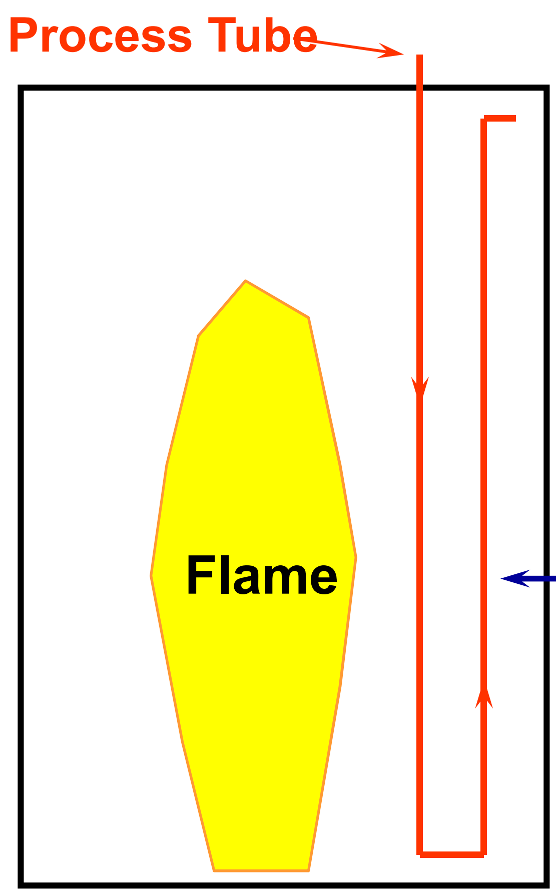
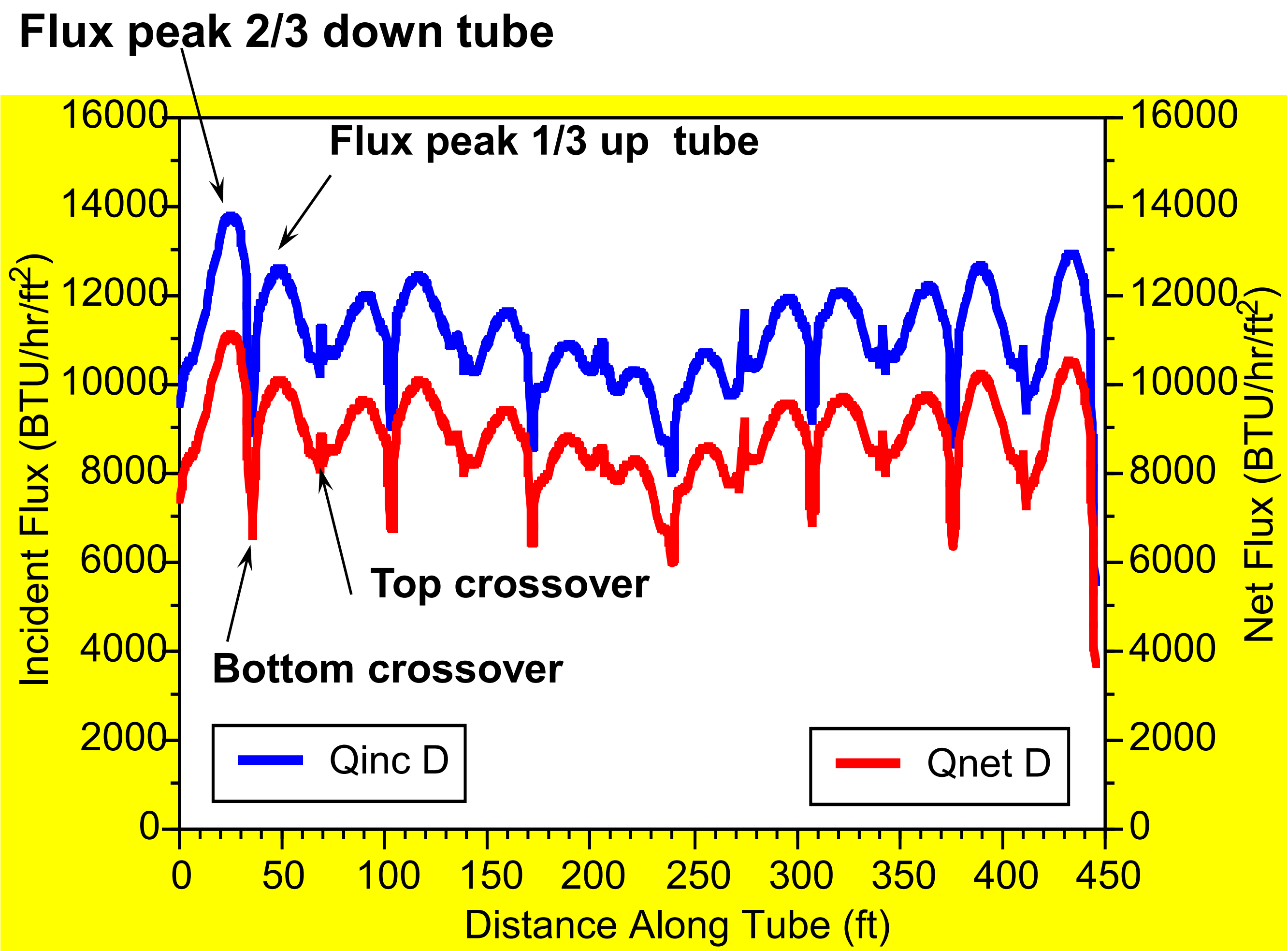
Flame Emission



- Emission Dependent on Temperature & Emissivity
- Peak Flame Emission ~1/3 Up Furnace
- Peak Incident & Net Flux at Same Height (~1/3 up)
- Peak Temp at Same Height; Location Agrees With Hot Tube Observation

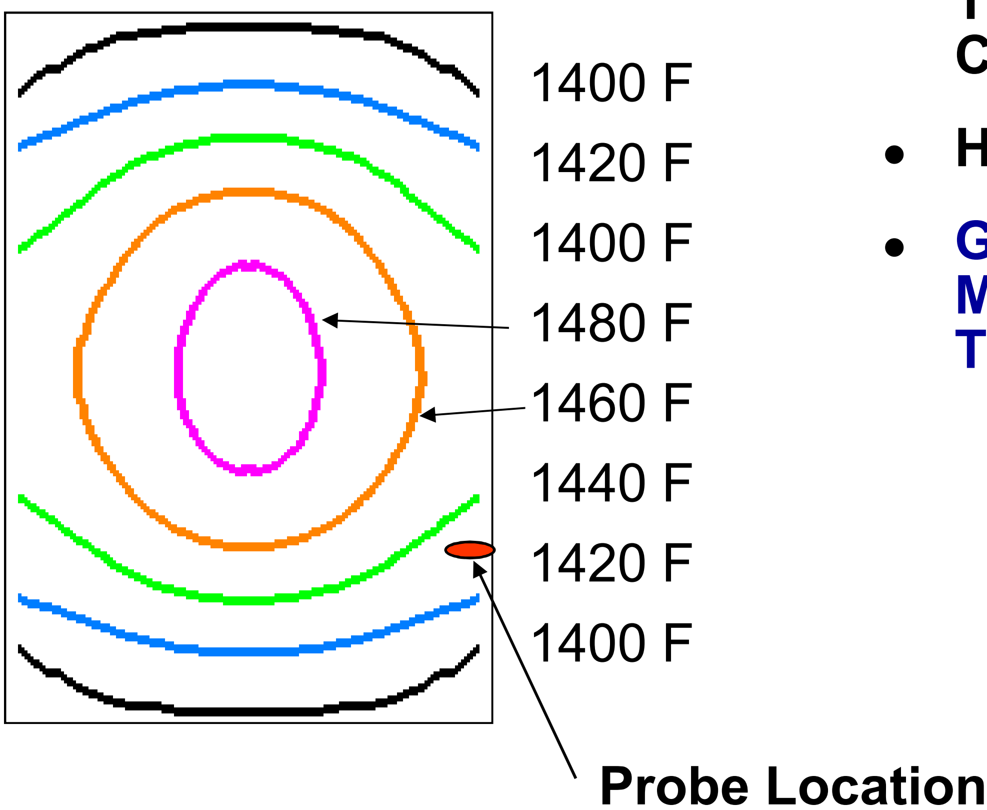
Radiant Section Tube Heat Flux Profiles



High Flux Locations Correlate with Hot Tube Temperatures

Bridgewall Temperatures

Temperature Contours



- **Probe Measures "Max" Temperature Entering Convective Section**
- **Hot Gas → Hot Tubes**
- **Gradient Impacts Measurement & Control of Temperature**

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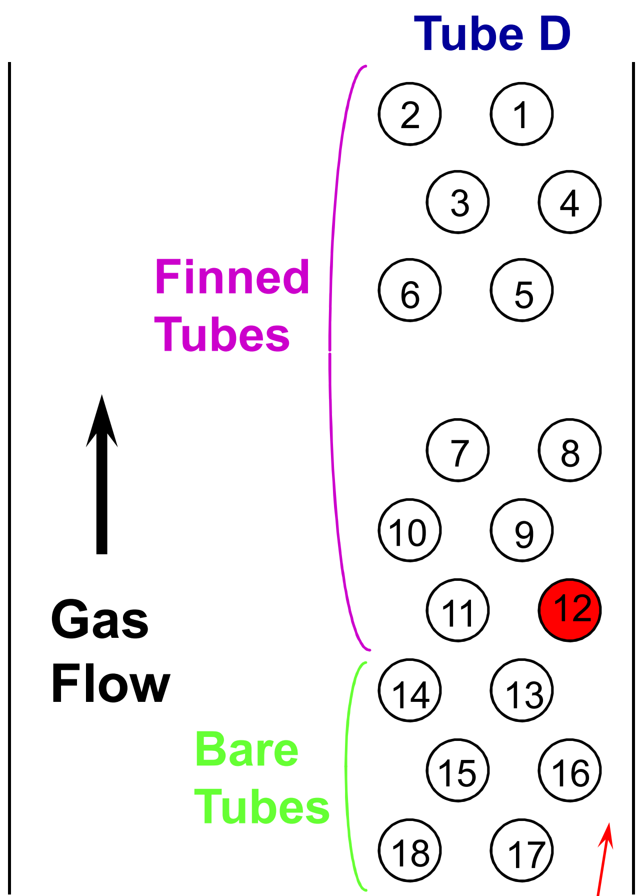
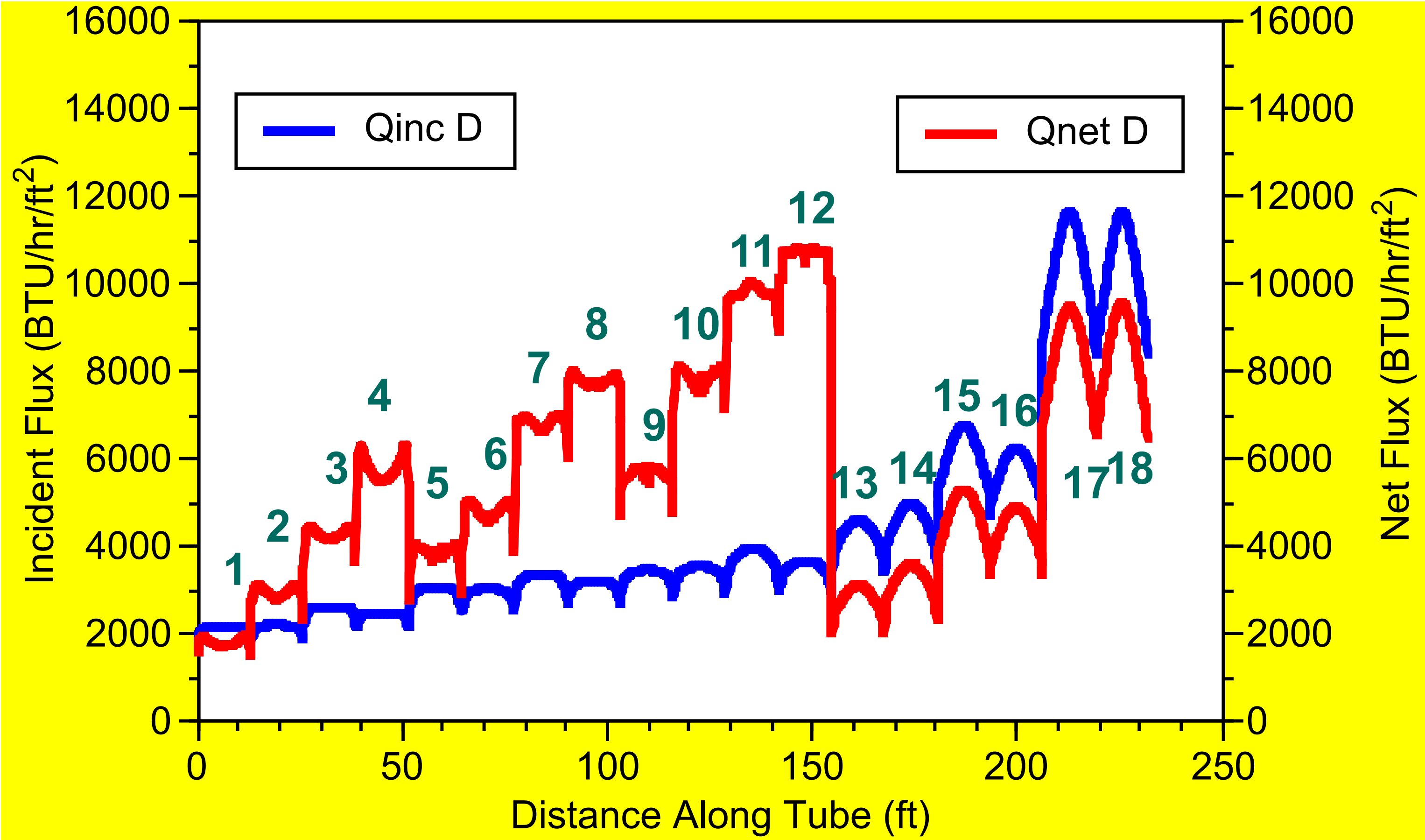
Convective Section



hotter high velocity flue gas due to more open flow area

- **Tube Has 2 Passes in Each of 9 Rows**
- **Upper 6 Rows Have Fins, Lowest 3 Rows Are Bare**
- **Radiant Load Highest at Lowest Tubes**
- **Tube 12 Overheating**

Convective Section Tube Heat Flux Profiles



Observation - Net Flux Changes w/ Finned Tubes

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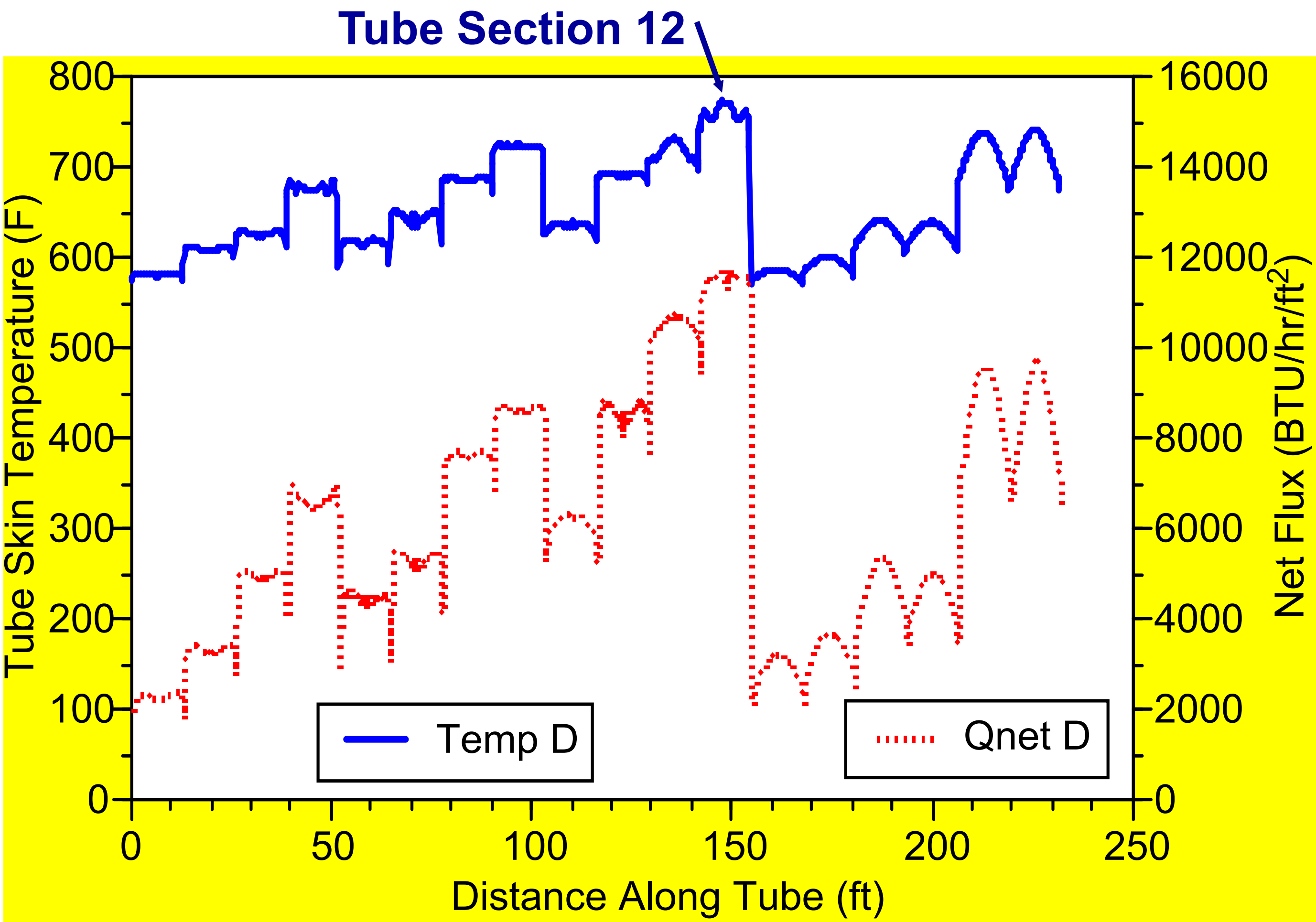
Convective Section Tube Temperature Profile



High Tube Temperatures Correlate w/ High Net Fluxes

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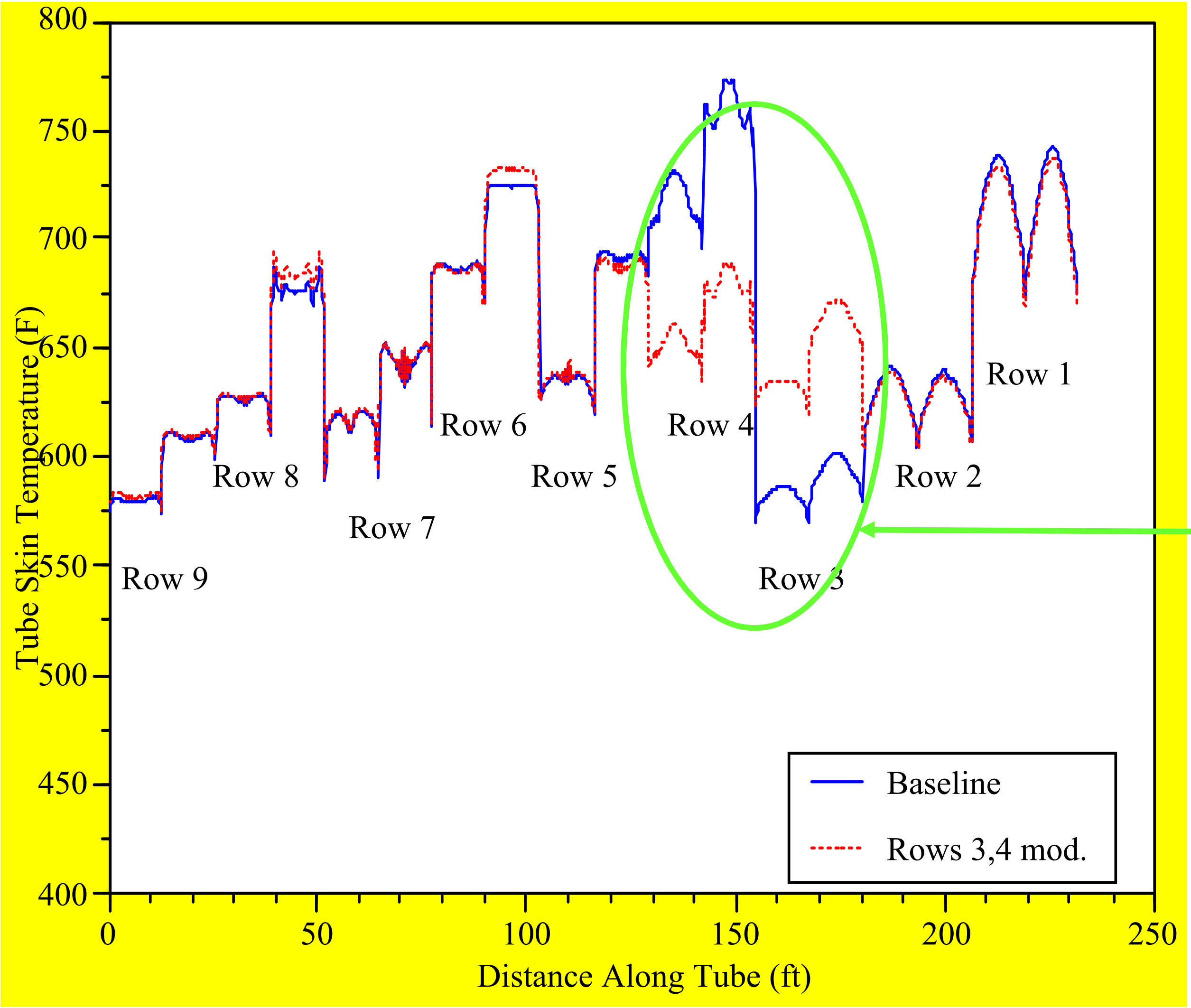
Recommended Modification



- **Reduce Row 4 Fins**
- **Add Row 3 Fins**
- **Evens Out Net Flux & Tube Skin Temperatures**

XSR Modeling Conclusions

- **Modeling Useful For Furnace Evaluation**
  - » **Recirculating Flow with Long, Highly Emissive Flames**
  - » **Radiant Furnace Tube Temperatures Reflect Flame Emission & Match Observation**
  - » **Long Flames Create Gradients at Bridgewall**
- **Modeling Useful For Furnace Troubleshooting**
  - » **Temperature Gradient at Bridgewall Impacts Measurements & Control**
  - » **Convective Tube Temperatures Reflect Net Flux Change with Finned Tubes**
  - » **Design Modification Identified to Minimize Convective Tube Hot Spots**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