Modeling Combustion In Pyrolysis Furnaces With Next Generation Low NOx Burners

Brad Adams, Qing Tang, Jinliang Ma
Reaction Engineering International

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Ethylene Cracking Furnaces

• Ethylene is major building block in petrochemicals (75 million metric tons per year)

• Key furnace performance issues:
  – Availability
  – Efficiency
  – Emissions (NOx, CO)

• Furnace performance depends on burner performance
  – Burners becoming more complex
  – Often a trade-off between low emissions and flame ‘quality’

• CFD can help evaluate new burner technologies
Key Furnace Combustion Elements

• **Burners**
  – Staged diffusion flames and/or lean premixed flames
  – Multiple fuels and firing rates (turn down)
  – Low NOx emissions (30-60 ppm)
  – Flame profile and emissions are key

• **Process coils**
  – High radiant efficiency (~45%)
  – Heat flux profile and heating uniformity

• **Refractory**
  – Limited heat loss (~2-4%)
  – Variable temperature & emissivity
Cracking Furnace Modeling Challenges

- **Scales!**
  - Geometric resolution
  - Jet velocities
  - Chemistry vs turbulent mixing

- **Input accuracy (GIGO)**

- **Trade-off between accuracy and turn-around time**
  - Grid refinement
  - Chemistry accuracy
  - Convergence
Furnace Model Requirements

• **Grid resolution** (for detailed burner geometry, fuel jets, multiple fuel mixing zones, process tube heat transfer)

• **Sub-models for:**
  – Fuel-lean, premixed, turbulent combustion
  – Turbulence-chemistry interactions
  – Finite-rate kinetics for ppm-level NOx, CO
  – Variable surface properties
  – Gas-wall-tube heat transfer
  – Fire-side - process-fluid thermal coupling

• **Computationally efficiency** (for optimal run-time and memory usage)
REI Software Evolution

1991
- Zone-type model with radiative heat exchange

1992
- BANFF models with 200,000 computational cells (flame quality, radiation, no NOx)

1995
- BANFF models with 500,000 computational cells (flame quality, radiation, some NOx)

2001
- Fluent-BANFF and BANFF-BANFF hybrid models with 1M + 800,000 cells (flame quality)

2004
- ADAPT code with 1M+ computational cells

2007
- Refined ADAPT code (chemistry, mixing models, turbulence-chemistry models, efficiency)

2008+
- “More-refined” ADAPT code
Laboratory-Scale Gas Burner

2004 Calculations

Sandia Piloted-Jet Methane Flame (http://www.ca.sandia.gov/TNF)
LPMF* Hearth Burner

- Lean Premix
- Fuel Staging
- Quasi-Flameless

*Lean PreMix Flat Flame (LPMF)*

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Test Furnace with LPMF Burner

- Heat Release ~ 6.5 mmBtu/h (as shown)
- Firebox Temp ~ 2,250°F
- NOₓ~ 0.02 lb/mmBtu (~17 ppmvd)
Lean Premixed Burner

Lower Port

Firing wall

Cooling wall

Port B

Exp.
EDC_9_species
PDF_9_species
EDC_19_species
PDF_19_species

Port B

Exp.
EDC_9_species
PDF_9_species
EDC_19_species
PDF_19_species

Port B

Exp.
EDC_9_species
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EDC_19_species
PDF_19_species

Port B

Exp.
EDC_9_species
PDF_9_species
EDC_19_species
PDF_19_species
Lean Premixed Burner

Upper Port

![Graphs showing temperature and emissions profiles for Port G with various species models and experimental data.](image-url)
PTTCH Application
(Next Generation System)

- JZ Solar Technology™
- Combustion System
  - CFD crucial
  - Not just burner technology
- First Application Outside US Gulf Coast
- 0.035 lb/mmBtu guaranteed
  - HHV basis
  - Corresponds to 32 ppmvd
PTTCH Furnace Model

- LPMW-SF
- LPMW
- RFS nozzles
- LPMF floor burners

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Purpose of CFD at PTTCH

- To determine optimal furnace performance
  - For different burner layouts
  - For different burner configurations
- Based on predictions of
  - Flame shape
    - from velocity, CO concentrations and gas temperatures
  - Furnace CO and NO\textsubscript{x} emissions
  - Furnace exit temperature
  - Heat transfer to process coils
  - Heat flux profiles to process coils
Study 1: Burner Layout

Initial design had poor heat release patterns

Revised design improved heat release patterns

Velocity

70 ft/s

Gas Temp.

3000 °F

500 °F
Study 2: Process Coil Heating Uniformity

Height From Furnace Floor (ft)

Incident Heat Flux (Btu/hr-ft²)

Average
Coils 1-5
Coils 6-10
Coils 11-15
Coils 16-20

5568 Btu/hr-ft²
Study 2: Improve Heating Uniformity

Improve uniformity by optimizing burner configuration (fuel distribution)

Case 2: 5568 Btu/hr-ft²
Case 3: 3114 Btu/hr-ft²
Case 4: 2748 Btu/hr-ft²
Model-Furnace Data Comparison

NOx Emissions
- CFD predicts 21 ppm @ 3% O₂
- Tests measured 17-21 ppm @ 3%
- CO <1 ppm in both cases

Furnace passed warranty and regulatory testing
Why Use CFD Modeling?

- **CFD is a vital design tool**
  - Improves understanding
  - Compared to testing
    - Better for flux profile
    - Better for ‘flame quality’
    - Almost the same for $\text{NO}_x$
    - Cheaper
    - More data
  - Validates designs
  - Avoids operational problems
Conclusions
(industry perspective)

• New ADAPT CFD software is a powerful tool for modeling next generation low NOx firing systems
  – Not a sledgehammer
  – Requires capable modeling engineers

• Successful application requires full collaboration and commitment from
  – CFD specialist
  – Licensor/ furnace designer
  – Burner manufacturer
  – Producer/End User

• Still challenges ahead
  – Validity of results limited by
    • Computational power
    • Budget and schedule constraints
Thank You

adams@reaction-eng.com