New Technologies in Ethylene Cracking Furnace Design

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Technip Benelux

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1. Introduction

TechnipFMC
TechnipFMC in a Snapshot

A unique global leader in oil and gas projects, technologies, systems, and services that will enhance the performance of the world’s energy industry

- 2 Stock Exchange listings – NYSE and Euronext Paris
- 21 Vessels
- 48 Countries in which we operate
- 44,000 Employees
Three Major Operating Segments

A comprehensive and flexible offering from concept to project delivery and beyond

Subsea

Onshore/Offshore

Surface
Technip Benelux B.V.

- **Technology center for**
  - Ethylene + Hydrogen Technologies
  - SPYRO® (steam cracking simulation software)
  - Fast pyrolysis oil (biomass to oil)

- **Full EPC capabilities**
  - Strong front-end engineering capabilities
  - Advisory / Consulting services
  - Procurement, Expediting, QA/QC
  - Construction, Commissioning, Startup
  - Project Management

- **No. 1 in furnace revamp projects (200+)**

- **Alliances with DOW and Air Products**
Process Technology Centers Around the World

- Houston
- Claremont
- Boston/Weymouth
- Paris
- London
- Zoetermeer
- Rome
Supply of ~400 Cracking Furnaces

Liquid Furnaces
GK6®, USC-U® & SU®
> 200 furnaces

Gas Furnaces
SMK™, USC-M®
> 200 furnaces
2. Cracking Fundamentals

Characteristics
Cracking Furnace
SPYRO® simulation software
Worldwide Ethylene Capacity

- Current ethylene capacity 165,000 kta (2016)
- 271 steam cracking units in operation
- Plant capacity ranging from 30 to almost 2000 kta
- 54 countries
- Average growing ethylene capacity: 3.9% (recorded over the years)
- Capacity is increased by
  - New grassroots plants
  - Plant expansions

Ethylene is the largest chemical produced worldwide
Characteristics of Olefins Production

- Strongly endothermic process

**Ethane**
- Absorbed duty: $Q \sim 1.6 \text{ MW} / \text{ton of feed}$
- For 1500 kta cracker: fired heat $\sim 890 \text{ MW}$

**Naphtha**
- Absorbed duty: $Q \sim 1.4 \text{ MW} / \text{ton of feed}$
- For 1000 kta cracker: fired heat $\sim 790 \text{ MW}$
Cracking Reactions - Products

Example – ethane cracking

\[
\begin{align*}
\text{C}_2\text{H}_6 & \rightarrow \text{CH}_3^* + \text{CH}_3^* & \text{initiation reaction} \\
\text{CH}_3^* + \text{C}_2\text{H}_6 & \rightarrow \text{CH}_4 + \text{C}_2\text{H}_5^* & \text{hydrogen abstraction} \\
\text{C}_2\text{H}_5^* + \text{C}_2\text{H}_6 & \rightarrow \text{C}_2\text{H}_4 + \text{H}^* & \text{propagation} \\
\text{H}^* + \text{C}_2\text{H}_6 & \rightarrow \text{CH}_4 + \text{C}_2\text{H}_5^* & \text{termination} \\
\text{C}_2\text{H}_5^* + \text{C}_2\text{H}_5^* & \rightarrow \text{C}_2\text{H}_{10} \\
\text{H}^* + \text{C}_2\text{H}_5^* & \rightarrow \text{C}_2\text{H}_6 \\
\text{H}^* + \text{CH}_3^* & \rightarrow \text{CH}_4 \\
\text{H}^* + \text{H}^* & \rightarrow \text{H}_2
\end{align*}
\]

<table>
<thead>
<tr>
<th>Mass, dry%</th>
<th>ethane</th>
<th>Naphtha</th>
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<tbody>
<tr>
<td>Hydrogen</td>
<td>4.1</td>
<td>0.8</td>
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<tr>
<td>Methane</td>
<td>5.0</td>
<td>13.4</td>
</tr>
<tr>
<td>Acetylene</td>
<td>0.4</td>
<td>0.3</td>
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<tr>
<td>Ethylene</td>
<td>52.8</td>
<td>27.7</td>
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<tr>
<td>Ethane</td>
<td>32.6</td>
<td>3.8</td>
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<tr>
<td>\text{C}_3\text{H}_4's</td>
<td>0.03</td>
<td>0.6</td>
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<tr>
<td>Propylene</td>
<td>1.2</td>
<td>16.4</td>
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<tr>
<td>Propane</td>
<td>0.2</td>
<td>0.5</td>
</tr>
<tr>
<td>sum \text{C}_4's</td>
<td>1.9</td>
<td>11.2</td>
</tr>
<tr>
<td>sum \text{C}_5s</td>
<td>0.4</td>
<td>5.9</td>
</tr>
<tr>
<td>sum \text{C}_6's</td>
<td>0.9</td>
<td>8.1</td>
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<tr>
<td>sum \text{C}_7's</td>
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<td>4.1</td>
</tr>
<tr>
<td>sum \text{C}_8's</td>
<td>0.1</td>
<td>2.2</td>
</tr>
<tr>
<td>sum \text{C}_9's</td>
<td>0.01</td>
<td>1.4</td>
</tr>
<tr>
<td>sum \text{C}_{10}'s</td>
<td>0.2</td>
<td>3.4</td>
</tr>
</tbody>
</table>
Cracking - Coke formation

Hydrocarbons $\rightarrow$ Olefins + other products + coke

- Coke coats the inside surface of radiant tubes
- Pressure drop increases
  - Reduce yield
- TMT increases, limiting furnace runlength (availability)
- Increase energy consumption
- Increase carburization
  (reduce coil lifetime)
Cracking - Coke formation

- Coking mechanism:
  - Catalytic (Ni, Fe)
  - Free radical
  - Condensation
Cracking – Coil failure mechanism

Carburisation

- Internal Carbide formation in carbonaceous atmospheres at high temperatures (>900°)
- Effects tube characteristics by impact on creep properties, ductility, thermal fatigue, thermal expansion coefficient

Creep ductility exhaustion

- Each cycle small amount of creep until creep ductility reached

radiant coil has a limited lifetime
Cracking Furnace layout

- Hydrocarbon Feed: 60°C
- Boiler Feed Water: 140°C
- Dilution Steam
- Convection Section: Heat recovery
- Desuperheater: BFW
- VHP Steam: 115 bara, 515°C
- Flue Gas to stack
- Radiant Coil: 120°C
- Radiant Section: Cracking reactions, combustion
- Radiant efficiency: 40-42%
- Overall efficiency: 93-95%
- Steam Drum: 119 bara, 324°C
- FPH
- ECO
- HTC-1
- HPSSH-1
- HPSSH-2
- HTC-2
- TransferLine Exchanger
- 350°C
- 620°C
- 850°C
- Burner
Cracking Furnace layout

- Fluegas ID Fan
- Steam Drum
- TransferLine exchanger
- Convection Section
- Quench Oil Fitting
- Radiant wall burners
- Radiant box - radiant coils
- Bottom burners
Furnace before Modernization
New Radiant Coil in Transport
Lifting New Radiant Coil
Facts / Parameter ranges

- Cracking reaction is non catalytic and not selective
- Cracking reaction is highly endothermic
- Inlet temperature: 550-700°C
- Outlet temperature: 750-900°C
- Selectivity sensitive for residence time, lower is better
- Selectivity sensitive for pressure, lower is better
- Furnace outlet pressure at TLE: 0,5 – 1,5 barg
- Dilution steam is required; ratio between 0,25 – 1,0
- Radiant coil material: 25/35 and 35/45
Facts / Limitations

- Coking rate
  - Coke layer increases TMT
  - Coke layer increases pressure drop over radiant coil

- Run length determined by:
  - Maximum allowable TMT (Outlet tube)
  - Coil pressure drop (critical flow venturi stays critical)

- Run length, typically 40-75 days

- Decoke with steam/air after EOR; 1-3 days duration

- Operation modes: SOR, MOR, EOR, Hot standby to fractionator, Hot standby to decoke system, Decoke
The Magic of Cracking

Optimization of:
- Coil selection
- Coil sizing

against:
- Yields
- Runlength
- Feedstock flexibility
- Operating cost
- Investment cost

• SPYRO® steam cracking simulation software is used by most cracking furnace operators
Radiant coil - metallurgy

GK6 radiant coil - typical

- Two pass
- Outlet tube highest temperatures
  - Highest process temperature
  - Coke formation

<table>
<thead>
<tr>
<th>Tube</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>25Cr35NiNb Micro-alloy</td>
<td>35Cr45NiNb Micro-alloy</td>
</tr>
<tr>
<td>DT</td>
<td>1080 °C</td>
<td>1115 °C</td>
</tr>
<tr>
<td>DP</td>
<td>3.9 barg</td>
<td>3.5 barg</td>
</tr>
<tr>
<td></td>
<td>4.9 barg</td>
<td>4.6 barg</td>
</tr>
</tbody>
</table>
Radiant coil - Development

Cracking furnaces
- 165 000 kta, +3.9% yearly
- Radiant coil
  - Expensive
  - Limited lifetime – consumables

Looking for
- Lower carburization rate – increase coil lifetime
- Lower coking rate – increase runlength, fewer coils

Developments
- Additives (DMDS)
- Cr-oxide forming alloys
- Al-oxide forming alloys
- Ceramics
- Finned / riffled tubes
- Coatings
- Multi lane
- SFT – enhanced heat transfer
3. Latest Applied Technologies in Furnace Design

- Multi lane radiant coils
- Swirl Flow Tube®
- Large Scale Vortex® Burner
Dual-lane GK6®

80+ furnaces & 7,000+ KTA ethylene produced with Dual-lane GK6® technology
Tripple-lane GK6®

Top view:

- Inlet tubes
- Outlet tubes

Tube positions optimized:
- Outlet tubes to the center lane
- Inlet tubes to the outside lanes
Triple-lane Features & Advantages

Inlet tubes at outside, facing burners & refractory
→ Heat is shifted to inlet tubes

Outlet tubes at inside, away from direct radiant sources
Uniform circumferential radiation combined with large tube-tube spacing
→ Reduced Peak to Average Heat-flux on outlet tube

Large tube-tube spacing
Same amount of tubes in 3 lanes vs in 2 lanes

Overall Impact
Improved heat flux profile & decreased maximum TMT
Improved performance
Biasing heat flux towards inlet tubes

Improved thermal utilization of radiant coil

Higher flux to inlet tubes

Lower flux to the outlet tubes

Heatflux

Coil length

3-Lane
2-Lane
Improved Circumferential Temperature Distribution Outlet Tubes

- **Dual-Lane**
  - All tubes peak at refractory side
  - All tubes dip at inter-lane side

- **Triple-Lane**
  - Inlets peak at refractory side
  - Inlet gradient similar to dual-lane
  - Outlet tube circumferential heat distribution very uniform
Maximum Tube Metal Temperature

Temperature Profile Comparison
At Point of Maximum TMT

- Maximum TMT
- Average TMT
- Process Medium

Maximum TMT reduced
Triple-lane 1-1 “U” Coil:
Swirl Flow Tube®

- Round tube
- Helical geometry
- Full line of sight
- No obstructions
- Improved heat transfer

Helical tubes of different amplitudes and pitches

* Veryan Medical Limited: BioMimics 3DTM
Relative Coking Rates

Substantially lower coking rates observed due to
- Lower wall temperature
- Increased turbulence

Footnotes:
(1) Data from Pilot Steam Cracker of Universiteit Gent
Requirements for Ultra Low NOx burners

- NOx emission in the range 50 … 100 mg/Nm3
- Safety: Burner shall be stable for all operating conditions
- Stable flame and no flame impingement
- Uniform heat flux profile resulting in uniform tube wall temperatures
- Optimized firebox efficiency
- Burner shall be suitable for revamp and new furnace design
- Ability to operate at a high firing intensity
- Low maintenance costs
- Sound pressure level <76 dB(A) @ 1 m.

The LSV burner meets these requirements
LSV® burner overview

- Simple robust design
- Uses a combination of techniques to prevent NOx formation
- Proven ultra low NOx performance
- Designed to have optimized heat release profile for the most optimal furnace design
- Suitable for furnace revamp and grass root furnace designs
Operational Experience

**LSV design data**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excess air</td>
<td>%</td>
<td>7 – 15</td>
</tr>
<tr>
<td>Flue Gas Temp (box temp)</td>
<td>°C</td>
<td>1030-1360</td>
</tr>
<tr>
<td>Combustion Air Temp</td>
<td>°C</td>
<td>Ambient-470</td>
</tr>
<tr>
<td><em>NOx Emission @ 3 % O2</em></td>
<td>ppmv</td>
<td>25 – 50</td>
</tr>
</tbody>
</table>
Operational Experience

- Excellent flame patterns and flame stability
- Very good heat distribution on coils
- High firebox efficiency
- Low NOx emission
- Proven design, trouble free operation
- Reported low maintenance cost
- Manufacturing by TechnipFMC

More than 1000 LSV burners have been applied