Intensification of the Steam Cracking Process

Mohamed Ellob, Jonathan Lee, Arthur Gough
School of Chemical Engineering and Advanced Materials
University of Newcastle

Does Steam Cracking Need Steam
Introduction

Olefins demand in year 2005:
- Ethylene (107 million tons)
- Propylene (67.1 million tons)

Olefins demand growth during years (2005–2010):
- Ethylene about 4.3% per year
- Propylene about 5.4% per year

Olefins production capacity growth:
- Ethylene about 5.4% per year
- Propylene about 5.1% per year
Typical Steam Cracking Furnaces

- Total Number of cracking tubes about 600
- Total Reaction Volume about 45 m³
- Total firebox volume about 9,000 m³
- Residence Time 0.25 to 0.75 s
- Firebox Efficiency about 65%
Steam function and process limitation

- Enhance heat transfer
- Reduce coke formation and deposition
- Improve selectivity towards ethylene
- Operation purposes
- Coke deposition is the main process limitations due to:
  - High tube skin temperature
  - High pressure drop
Exothermic channel gas

Endothermic channel gas

Exothermic reaction catalyst

Thin plate

Endothermic reaction catalyst

Catalytic Plate Reactor
Velocys Device Fabrication

Advantages Of Catalytic Plate Reactor

- High Surface to volume Ratio
- Laminar flow Conditions
- High Heat transfer Coefficient
- Thin Catalyst Layer Minimize Diffusion Limitation
- Surface Temperature only few degrees above the process temperature
- Improved Safety and Environmental Impact
- Scale-up by Numbering –up
- Low Capital and operating Costs
Coke formation

- Metal-catalyzed coke
- Non-catalytic coke from tars
- Small chemical species (coke precursors) react with free radicals on the coke surface
Objectives

1- Study and investigate the possibility of intensifying the thermal cracking of propane to produce ethylene through the use of the catalytic plate reactors.

2- Reducing the coke formation and deposition.

3- Reducing the use of steam.

4- Modelling and simulation for propane cracking using Catalytic Plate Reactor.
Benefits

- Lower environmental and safety impacts. (NO$_x$, contaminated water, CO$_2$, H$_2$S)
- Improved energy efficiency.
- Lower capital cost.
- Improved overall plant economics
Experimental setup design criteria

- Allows for accurate coke measurement
- Constant and uniform temperature along the reactor
- Very fast cooling of reaction products
- Easy to change reactor size and material
Propane cracker showing flow paths during decoke

Manometer

Knock-out

To GCs

Vent
Experimental variables

- Reactor materials and internal coatings
- Reactor channel size
- Process variables (temperature, pressure, and flow rate)
- Run time length
Conversion at low and high operating parameters

Low flow rate

High flow rate
Coke yield vs Flow at 835 °C and 1.35 bar
Coke yield vs Temperature. at 3.5 l/h and 1.35 bar

Coke yield (mg/g-propane reacted) vs Temperature, °C
Coke yield vs Pressure at 3.5 l/h and 835 °C

Coke yield (mg/g-propane reacted)

Pressure, bar
Coke yield at low and high operating parameters

Low flow rate

Coke yield (mg/g-propane reacted)

High flow rate

Coke yield (mg/g-propane reacted)
UY of Ethylene at low and high operating parameters

**Low flow rate**

<table>
<thead>
<tr>
<th>Pressure</th>
<th>Temperature</th>
<th>UY of Ethylene, Weight %</th>
</tr>
</thead>
<tbody>
<tr>
<td>low</td>
<td>low</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>high</td>
<td>44</td>
</tr>
<tr>
<td>low</td>
<td>high</td>
<td>46</td>
</tr>
<tr>
<td>high</td>
<td>low</td>
<td>48</td>
</tr>
<tr>
<td>high</td>
<td>high</td>
<td>50</td>
</tr>
</tbody>
</table>

**High flow rate**

<table>
<thead>
<tr>
<th>Pressure</th>
<th>Temperature</th>
<th>UY of Ethylene, Weight %</th>
</tr>
</thead>
<tbody>
<tr>
<td>low</td>
<td>low</td>
<td>42</td>
</tr>
<tr>
<td></td>
<td>high</td>
<td>44</td>
</tr>
<tr>
<td>low</td>
<td>high</td>
<td>46</td>
</tr>
<tr>
<td>high</td>
<td>low</td>
<td>48</td>
</tr>
<tr>
<td>high</td>
<td>high</td>
<td>50</td>
</tr>
</tbody>
</table>

Ultimate Yield = \( \frac{\text{Mass Ethylene Produced}}{\text{Mass Propane In Feed}} \)

Assuming that the unreacted propane and the ethane produced by one pass through the reactor, are recycled to the feed
Conclusions

• Conversion of about 90% can be achieved in 2 mm internal diameter fused silica reactor without any significant pressure drop.

• Steam use can be reduced or possibly eliminated.

• High olefins yield can be obtained without steam.

• Low acetylene and $C_4^+$ yield.

• Run length of about 14 – 20 days was estimated to be possible before any decoking is required. This run length was achieved with no steam.
THANK YOU