ACO™, The Advanced Catalytic Olefins Process

Michael Tallman

Evolution of the Modern Car

1800: Inventor Cugnot invents steam powered car

1870: 1st gasoline powered car

Early 1900’s, mass production of cars

Bigger cars fueled by oil

Hybrid cars, a response to a need

“Necessity is the mother of invention”

Plato 428BC-348 BC
**Evolution of Thermal Cracking**

- **1900’s**: investigations in thermal cracking for fuels
- **1920’s**: first steam cracker (Union Carbide)
- **1940-60**: advances in technology
- **1960-now**: revolutionary advances
- **2006**: Mega crackers
- **2010**: ACO

**Current State of the Art Thermal Cracking**

- Breaking and rearrangement of chemical bonds
- High temperatures required, >850°C
- Overall olefins yields decline with heavier feeds
- Propylene/ethylene (P/E) ratios ~ 0.4-0.6

<table>
<thead>
<tr>
<th>Steam Cracking Wt% Yield</th>
<th>Propylene</th>
<th>Ethylene</th>
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</thead>
<tbody>
<tr>
<td>Ethane</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>Propane</td>
<td>0.40</td>
<td></td>
</tr>
<tr>
<td>Butane</td>
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<tr>
<td>LL. Naph</td>
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<tr>
<td>Hvy. Naph</td>
<td>0.58</td>
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</tbody>
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Handling of Coke and Heavy Ends is Not a Fun Activity in Steam Cracking!

A Paradigm Shift – The ACO Process

- Development of a CATALYTIC route to ethylene and propylene
- Lower temperatures, ~600-700C
- Higher olefins yield with liquid feeds
- Very little coke production
- P/E ratios of ~1/1
- Utilize most common liquid feeds available (straight run naphtha and distillates)

Advanced Catalytic Olefins (ACO)
The Olefins Market

Ethylene
World Ethylene Demand Forecast
~4% overall growth

Propylene
World Propylene Demand Forecast
~5% overall growth

Steam cracking will NOT meet future propylene demand

Propylene Sources

54 KTA in 2000
Ethylene Plant 56%
Refriners 31%
Other 3%

66 KTA in 2005
Ethylene Plant 65%
Refiners 31%
Other 4%

89 KTA in 2010
Ethylene Plant 57%
Refriners 31%
Other 12%
Olefins Regional Issues

Regional Ethylene Growth

- Highest growth in Middle East
- Ethane feed makes little propylene
- Asia market also increasing

(Source: CMAI)
Olefins Regional Issues

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2004-12 Incremental Olefins Growth

- P/E Ratios: 0.77, 0.44, 1.5, 0.24, 0.85

What Does This All Mean?

- Ethylene growth lower than propylene growth
- Shift to lighter feeds will give lower P/E
- Alternative propylene technologies needed
- Steam Crackers will not meet propylene demand
- ACO can be a technology solution
ACO Process – Why Straight Run Feeds?

- The majority of global ethylene is produced from liquid feed
- Straight run naphtha is the predominant feed globally
  - Greater than 50% of ethylene made from naphtha
  - Widely available
- Most common feed in Asia (highest P/E ratio)

- Asia has very high P/E demand

ACO Process – Uses Naphtha Feeds

- Straight run naphtha is the predominant feed globally
  - Widely available
  - Greater than 50% of ethylene made from naphtha
- Naphtha is the most common feed in Asia
- Naphtha becoming more common in Middle East
ACO Process Key Features - Reactor

♦ Proprietary KBR FCC reactor features
♦ Propylene/ethylene (P/E) Product Ratio ~1/1
♦ Proprietary catalyst from SK Corporation
♦ All proven hardware and processes
♦ Robust and flexible, compared to other processes

ACO Process Key Features - Separation

♦ Product treatment and separation follows ethylene plant technology
  ▪ Compression
  ▪ Acid gas removal and drying
  ▪ Separation and fractionation to chemical or polymer grade products
♦ Proprietary expertise for trace impurities removal
♦ C4s and C5s can be recycled to reactor with no further treatment
♦ All proven technology
ACO Key Features – Summary

♦ Co-developed by SKenergy (Korea) and KBR
♦ Worldwide licensing rights by KBR
♦ SKenergy will become the first commercial user of ACO
  ▪ Plans underway to install ACO reactor at the SK complex at Ulsan, Korea
  ▪ ~2010 startup

SKenergy Background

♦ Large conglomerate
  ▪ ~$24 billion 2006 sales
  ▪ ~5.8 MM t/a products volume
♦ Very large olefins facilities
  ▪ 2 KBR steam crackers at Ulsan
  ▪ ~800 kta ethylene
♦ Regional need for propylene and high P/E
♦ SK plans to become the first adopter of ACO process by 2010
SKenergy Experience and Status

♦ Key to ACO is catalyst
  ▪ Developed by SK R&D
  ▪ Worldwide patents in progress
  ▪ High acid activity tailored to light olefins and LPG production
  ▪ High hydrothermal stability to high temperature steam

♦ Pilot testing conducted at SK R&D in Daejeon
  ▪ Fluidized bed reactor
  ▪ Fractionation recycle capability

KBR Experience and Status

♦ KBR Fluid Cat Cracking
  ▪ 50+ years
  ▪ Process/mechanical design
  ▪ More than 120 units worldwide

♦ Yield Predictions
  ▪ Development & modeling
  ▪ KBR in-house and client feed pilot studies

♦ Sasol SUPERFLEX Startup and Commercialization
Case Study

♦ Light Straight Run (LSR) Naphtha
♦ Case 1: Conventional Steam Cracker
   ▪ 1000 kta ethylene
   ▪ ~0.5 P/E ratio
♦ Case 2: ACO Process
   ▪ Maintain same feed rate as Case 1
   ▪ ~1/1 P/E ratio

ACO – Reaction Section
ACO Recovery Section

Steam Cracker Yields
Steam Cracker vs. ACO Overall Yields

Compared to Steam Cracker

- ACO has ~15-20% relatively higher olefins yield
- ACO has higher P/E of ~1/1
- ACO makes more 25% more BTX
- ACO can recycle all the C4s/C5 without additional treating

Steam Cracker vs. ACO Cost of Production (COP)

Case 1 Steam Cracker
Cost of Production = ~$730/MT Ethylene

Case 2 ACO
Cost of Production = $640/MT Ethylene
ACO Advantages

♦ Converts widely available feeds to ethylene and propylene
  - Straight run naphtha, distillates
♦ Higher total light olefins yields compared to steam cracker
♦ P/E ratio of 1/1 addresses propylene market
♦ More BTX for potential recovery, higher octane
♦ No C4/C5 processing required, all C4/C5 utilized in the ACO process
♦ Attractive ACO economics compared to steam cracking
♦ CO2 Emissions lower than the steam cracking case

Advanced Catalytic Olefins Process

♦ High growth rates for both ethylene & propylene
♦ Ethylene plants will not meeting propylene growth
♦ “Propylene On Purpose” technologies require niche feedstocks
♦ Consider ACO Process
  - Higher overall yields
  - 1/1 P/E ratio
♦ Commercialization plans by 2010 by SK
Thank you very much…

Questions?