Superior Performance Technology

AMOMAX® 10
Ammonia - The Molecule against Hunger

• One of the world's most valuable industrial & agricultural chemicals: Today’s population would be still around 3 billion without the production of Ammonia and artificial fertilizers

• World total fertilizer NH$_3$ demand 2014: 138 Mio t, main driver:
  - population growth, changing diets and to some extend climate change
  - biofuel production using cereals, sugar cane and oilseeds is another key driver

Top 18 Processes by Energy Use

Source: Technology Roadmap IEA / ICCA / DEHEMA, 2013
Energy Consumption of Ammonia Units

Historical Development – NH₃ Synthesis Catalyst

• Developed 1910 by A. Mittasch (more than 22,000 tests)
  ➢ Magnetite (Fe₃O₄) based catalysts promoted with non-reducible metal oxides (Al, K, Ca) proved to be superior to those prepared from other oxides.
  ➢ Catalytically active form: α-iron (Fe⁰)

• Further improvement was achieved by:
  ➢ Adding other structural and electronic promoters
  ➢ Optimizing the component ratio
  ➢ Conditions of preparation
  ➢ Catalyst particle size and form
Ammonia Synthesis Catalyst - Innovations

**Until today:**  Industrial catalysts closely related to original promoted magnetite

**Innovations only since approx. 15 years:**

<table>
<thead>
<tr>
<th>KAAP (KBR)</th>
<th>Ruthenium catalyst</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- Low pressure process (90 bar)</td>
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<td></td>
<td>- Extremely high raw material costs</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>AmoMax 10</th>
<th>Wustite catalyst - Award-winning innovation by Süd-Chemie</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- Very high activity at low temperature and pressure &amp; extreme stability</td>
</tr>
<tr>
<td></td>
<td>- Strongly growing commercial successes worldwide in short time</td>
</tr>
<tr>
<td></td>
<td>- Still based on the relatively cheap raw material iron</td>
</tr>
</tbody>
</table>
Main Features of AmoMax® 10 based on the iron (II) oxide wustite

- Significant change in ammonia synthesis after 100+ years!
- **Wustite** instead of **Magnetite**
- From »**Wustite**« to »**AmoMax® 10**« only through a tailor-made and optimized set of promoters!
  - Stabilization of small Fe crystallites
  - Significant increase of surface area

<table>
<thead>
<tr>
<th></th>
<th>MAGNETITE</th>
<th>WUSTITE</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHEMICAL FORMULA</td>
<td>Fe₂O₄[Fe²⁺/Fe³⁺]</td>
<td>FeO [Fe²⁺]</td>
</tr>
<tr>
<td>OXYGEN CONTENT</td>
<td>27.7%</td>
<td>22.3%</td>
</tr>
</tbody>
</table>
Unique Promoter System AmoMax® 10

- Classical »magnetite promoters« K, Al, Ca
- Also several other proprietary promoters like e.g. certain transition metal oxides
  - located in the inter-granular spaces (K, Al, Ca, …)
  - but some are incorporated in the Fe crystals
Benefits of AmoMax® 10 in comparison to standard catalysts

Higher ammonia concentration at converter outlet (up to 1% point more)

Faster start-up (1–2 days less)

ENERGY SAVINGS
(less recycle and lower loop pressure: up to 10 bar less)

LESS CONSUMPTION
of natural gas for catalyst reduction

INCREASED AMMONIA PRODUCTION
(if not limited by make-up gas and/or compressor curve)

EARLIER START
of ammonia production
Activity of AmoMax® 10 – Lab Investigations

- AmoMax® 10 is **42% higher active** than a standard magnetite catalyst
- AmoMax® 10 requires a **30% lower activation energy**

![Graph showing activity comparison](image)

\[
\text{Ln (Rate)} = 4.43x + 9.42, \text{ Magnetite} \\
\text{Ln (Rate)} = 3.07x + 7.67, \text{ Wustite}
\]

**Activity Evaluation Conditions**
- Pressure = 150 atm
- Temperature = 400 °C
- Feed Gas = H₂:N₂ = 3:1
- Space Velocity = 15,000/h
- Catalyst Size = 0.35–0.84 mm
- Catalyst Volume = 2.0 ml (based upon CBD)
AmoMax® 10 Catalyst Reduction – Lab Investigations

- Start-up temperature of AmoMax® 10 approximately 30 °C lower
- Leads to shorter reduction time and allows an earlier production start
Delhi, September 30, 2016
Worldwide AmoMax® 10 Users

MORE THAN 100 REFERENCES SINCE MARKET INTRODUCTION IN 2003

REPLACED CATALYSTS CHARGES

- KM-1: 7%
- AMax-110: 19%
- Alvigo: 38%
- New Plant: 15%
- BASF: 9%
- NH: 4%
- JMC: 2%
- Others: 6%
Clariant wins the 100th Global Reference for its AmoMax® 10 Catalyst

Award ceremony held August 26, 2015 in San Francisco at Clariant’s renowned »Defining the Future VII« conference.

»Catalyst improvements are paramount for the energy intensive ammonia industry. With AmoMax®-10, Clariant helps ammonia producers to attain their ambitious goals of maximizing their output while operating much more efficiently and making a positive impact on sustainability.«

—

STATEMENT STEFAN HEUSER
Senior Vice President & General Manager of the BU Catalyst at Clariant
Benefit Calculations and Value Creation for a typical ammonia plant (1600 mptd)

- Typical savings with AmoMax®-10: 20,000 kcal/MT
  - 170,000 USD/year (4.0 USD/mmBTU – 350 days of production)

- Total value creation (NPV basis – 15 years, discount factor 10%) compared to standard magnetite (in USD): 1.3 mio USD

- Additional savings due to quicker reduction time (1d) and faster restart time (3h)
Innovations contribute to a sustainable future

RESOURCE SAVING - AMOMAX®-10

Assuming that all global ammonia production facilities would apply AmoMax® 10, we could save significant amount of energy.

4000 GWH ANNUALLY

= ELECTRICITY CONSUMPTION OF 1.18 MILLION HOUSEHOLDS*

* 20.5 Million Households including described converter revamp
Source: World Energy Council / Enerdata; World average consumption per electrified household 3.386 kWh in 2013
Case Study 1 – One decade of AmoMax® 10 in China

SITUATION
- Location: China (Liaohe Chemical Fertilizer Co.)
- Converter type:
  - Original KBR design built in 1976
  - Converter revamped in 1988 by Casale (3-bed axial-radial design)
- Nameplate capacity:
  - 1070 mtpd
  - Frequently limited by insufficient gas supply
- First reference for AmoMax® 10, started-up in Dec. 2003

BENEFIT OF INSTALLING AMOMAX® 10
> STABLE ACTIVITY AND PRESSURE DROP FOR MORE THAN 12 YEARS

SPECIFIC CUSTOMER NEED
- Stable plant operation and a long catalyst lifetime despite of big variations in the gas supply
Case Study 2 – One decade of AmoMax® 10 in Russia

SITUATION

- Location: Russia
- Converter type:
  - Original KBR design built in 1981
  - Converter revamped in 1993 by Casale (3-bed axial-radial design)
- Nameplate capacity:
  - Designed 1360 mtpd
  - Debottlenecking to 1700 mtpd in 2010
- Started operation with AmoMax® 10 in Oct. 2004

BENEFIT OF INSTALLING AMOMAX® 10

- NH₃ concentration at reactor outlet has increased by more than 1%-pt.
- 11+ YEARS OF A SIGNIFICANTLY BETTER PERFORMANCE IN COMPARISON TO A MAGNETITE CATALYST

<table>
<thead>
<tr>
<th></th>
<th>Magnetite</th>
<th>AmoMax® 10</th>
<th>AmoMax® 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>DATA FROM</td>
<td>09/03/2003</td>
<td>21/06/2005</td>
<td>11/03/2014</td>
</tr>
<tr>
<td>TIME ON STREAM</td>
<td>135 months</td>
<td>10 months</td>
<td>115 months</td>
</tr>
<tr>
<td>NH₃ Production [mtpd]</td>
<td>1340</td>
<td>1400</td>
<td>1720</td>
</tr>
<tr>
<td>NH₃ Concentration at reactor outlet</td>
<td>17.7%</td>
<td>19.1%</td>
<td>18.7%</td>
</tr>
<tr>
<td>Inert level (CH₄, Ar)</td>
<td>7.4%</td>
<td>9.7%</td>
<td>9.6%</td>
</tr>
<tr>
<td>Pressure at reactor inlet [kg/cm²]</td>
<td>227</td>
<td>220</td>
<td>245</td>
</tr>
<tr>
<td>ACTIVITY INDEX</td>
<td>100</td>
<td>189</td>
<td>165</td>
</tr>
</tbody>
</table>

SPECIFIC CUSTOMER NEED

- Highly active catalyst in order to support the plant capacity increase from 1360 to 1700 mtpd
Case Study 3 – Outstanding performance in Australia

**SITUATION**

- Location: Australia (Incitec Pivot Ltd, Gibson Island)
- Converter type: 6 individual reactors
- Designed capacity: 850 mtpd
- Plant was very skeptical about trying a »new« catalyst
- Commissioned a Study by the University of Queensland
  - **Very favorable to AmoMax® 10**
- Started operation with AmoMax® 10 in 2007

**SPECIFIC CUSTOMER NEED**

- Reliable and proven catalyst for a specific plant design in order to increase production and save energy

**BENEFIT OF INSTALLING AMOMAX® 10**

- Successful Startup:
  - Higher ammonia rates (up to 870 mtpd) than the design rate
  - 7 bar lower loop pressure
- Detailed case study presented at the NITROGEN + SYNGAS conference in 2008
Case Study 4 – Stability against CO and CO₂ poisoning

SITUATION
- Location: USA
- Converter type: Casale (3 bed axial-radial)
- Nameplate capacity: 1000 mtpd
- Started operation with AmoMax® 10 in Nov. 2005

SPECIFIC CUSTOMER ISSUE
- Problems with a heat-exchanger caused a significant temperature decrease at the inlet of both LTS and methanation reactor
  - CO out of HTS went unconverted in the ammonia synthesis converter
  - Accumulation of CO/CO₂ in the loop so that the reaction was drastically lost
- After repair work the ammonia synthesis converter was put back online
  - AmoMax® 10 recovered its original activity

BENEFIT OF INSTALLING AMOMAX® 10
- Fatal poisoning events can be prevented by the use of AmoMax® 10
- Lab results confirmed that AmoMax® 10 adsorbs considerably less CO₂ than a magnetite catalyst

ADSORPTION ISOTHERMS OF CO₂

<table>
<thead>
<tr>
<th>Pressure (bar)</th>
<th>mmol/g</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0.2</td>
<td>0.5</td>
</tr>
<tr>
<td>0.4</td>
<td>1.0</td>
</tr>
<tr>
<td>0.6</td>
<td>1.5</td>
</tr>
<tr>
<td>0.8</td>
<td>2.0</td>
</tr>
<tr>
<td>1.0</td>
<td>2.5</td>
</tr>
</tbody>
</table>

At 450 °C
Case Study 5 – Low light-off temperatures allow for fast restarts

SITUATION

• Location: Trinidad
• Converter type: KAAP
• Nameplate capacity: 1850 mtpd

SPECIFIC CUSTOMER NEED

Plant needs to restart production as quickly as possible

BENEFIT OF INSTALLING AMOMAX® 10

Light-off temperature of AmoMax® 10 at plant restarts significantly reduced in comparison to standard catalyst

- Lower light-off temperature allows for earlier production start
- Even in low pressure environments (60 bar/850 psig) at least 1 hour additional production can be gained at a fast 60 °C temperature increase per hour
Case Study 6 – Successful plant revamp

**SITUATION**
- Location: USA
- Converter type: Isothermal Converter design was chosen from Casale
- Capacity: Increase from 1550 stpd (1406 mtpd) to 1800 stpd (1633 mtpd)
- AmoMax® 10 RS was chosen as catalyst for the following reasons:
  - Predicted improved converter performance with AmoMax® 10
  - Lower Light-off temperature for Isothermal Converter

**SPECIFIC CUSTOMER NEED**
- Plant was highly interested in energy savings and capacity expansion
- Upgrade options and Casale modeled energy reductions (vs. Base Case A):

<table>
<thead>
<tr>
<th>Case</th>
<th>Description</th>
<th>Δ =</th>
<th>MMBtu/ST</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CASE B</strong></td>
<td>New load of Magnetite catalyst</td>
<td>-0.52</td>
<td>MMBtu/ST</td>
</tr>
<tr>
<td><strong>CASE C</strong></td>
<td>New load of AmoMax®-10 catalyst</td>
<td>-0.66</td>
<td>MMBtu/ST</td>
</tr>
<tr>
<td><strong>CASE D</strong></td>
<td>Converters revamping and new load of Magnetite catalyst</td>
<td>-1.14</td>
<td>MMBtu/ST</td>
</tr>
<tr>
<td><strong>CASE E</strong></td>
<td>Converters revamping and new load of AmoMax®-10 catalyst</td>
<td>-1.20</td>
<td>MMBtu/ST</td>
</tr>
</tbody>
</table>
Case Study 6 – Successful plant revamp

ACTUAL REVAMPING RESULTS / BENEFIT OF INSTALLING AMOMAX® 10

- Targeted capacity **1800 STPD** and energy savings of **1.2 MMBtu/ST** were achieved
- The plant is **saving over $160,000 per year** by installing AmoMax® 10
- After 2 years in service, AmoMax® 10 continues to perform well at the plant

<table>
<thead>
<tr>
<th>DATE</th>
<th>CATALYST</th>
<th>PRODUCTION RATE, STPD</th>
<th>105-D INLET, NH3 MOL%</th>
<th>105-D OUTLET NH3%</th>
<th>1105-D OUTLET NH3%</th>
<th>105-D INLET PRESSURE PSIG</th>
</tr>
</thead>
<tbody>
<tr>
<td>09/14/2013</td>
<td>AmoMax® 10 RS</td>
<td>1766</td>
<td>2.6</td>
<td>18.15</td>
<td>20.70</td>
<td>1860</td>
</tr>
<tr>
<td>11/11/2014</td>
<td>AmoMax® 10 RS</td>
<td>1867</td>
<td>2.38</td>
<td>17.69</td>
<td>21.30</td>
<td>1956</td>
</tr>
<tr>
<td>04/28/2015</td>
<td>AmoMax® 10 RS</td>
<td>1790</td>
<td>2.83</td>
<td>17.81</td>
<td>20.90</td>
<td>1926</td>
</tr>
</tbody>
</table>
Conclusions

• Clariant offers a superior ammonia synthesis catalyst, **AmoMax® 10**, which is based on the iron oxide wustite in combination with the special set of promotors

• AmoMax® 10 has been installed in **more than 100 references** world wide

• AmoMax® 10 shows a significant **higher activity** compared to a standard magnetite catalysts

• The main benefits for users in commercial plants are:
  
  **ENERGY SAVINGS** at less recycle flow and lower loop pressure due to a higher ammonia concentration at the converter outlet

  **FASTER CATALYST REDUCTION** leading to less consumption of natural gas for catalyst reduction and to an earlier start of ammonia production

  **FASTER RE-START TIMES** after shut-downs due to low light-off temperatures

  The total value creation over the catalyst lifetime **EXCEEDS THE PURCHASE PRICE FOR AMOMAX® 10**
Thank you.
QUESTIONS?

what is precious to you?