Ammonia Plant Capacity Increase by Autothermal Reforming and Dual Pressure Synthesis

Dr. Klaus Noelker,
ThyssenKrupp Uhde GmbH
Dortmund, Germany
Introduction
Ammmonia Plant Capacity Increase

• **Advantages of capacity increase compared to the erection of a new plant:**
  – better adjustment to market growth and feedstock availability
  – lower overall investment
  – faster implementation
  ⇒ much smaller risk

• **Important aspects:**
  – determine the most economical extra capacity
  – select the best revamp concept
Introduction
Scope of the Presentation

• **Investigation:**
  - based on existing old ammonia plant
    (capacity at the time of the investigation: 1665 mtpd)
  - envisaged a 30 % expansion (500 mtpd)
  - covered areas:
    - entire process plant
    - steam system
    - focus on the synthesis gas generation section

• **Detailed comparison of three different expansion concepts:**
  I. Upgrading of existing steam reformer / secondary reformer
  II. Secondary reformer operation with enriched air
  III. Autothermal reformer (ATR) parallel to existing syngas generation
Basics of Capacity Increase
Economical Requirements

Three distinct ranges of capacity expansion:

1. utilization of built-in capacity reserves ⇒ no investment
2. debottlenecking of few units / items ⇒ low investment
3. substantial plant modification ⇒ high investment
## Basics of Capacity Increase

### Technical Requirements

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Action</th>
</tr>
</thead>
</table>
| Increased flowrates               | - compressor / driver improvement  
|                                   | - larger cross sectional areas                                        |
| Transfer larger amounts of heat   | - larger heat transfer surfaces  
|                                   | - better heat transfer coefficients  
|                                   | - increased temperature differences                                    |
| Maintain reaction conversions     | - larger catalyst volumes  
|                                   | - modified reaction temp. & press.                                     |
| Sustain separation of species     | - improved internals of separation units  
|                                   | - better solvents (solubility / selectivity)                           |
Compared Process Concepts
Concept I: Expansion of Primary Reformer

- air
- process air compressor
- natural gas
- pre-heating
desulphurization
- pre-heating
primary reformer
- secondary reformer
gas cooling
- CO₂ removal
methanation
- CO₂ removal
gas cooling
- LT shift
gas cooling
- HT shift
- BFW
- CO₂
- aux. gas cooling
aux. CO₂ removal
- aux. gas cooling
aux. gas cooling
- aux. gas cooling
steam
existing equipment / line
new / modified equipment / line

“Conventional concept”
Compared Process Concepts
Concept II: Secondary Reformer Operation with Enriched Air

- Natural gas
- Aux. gas
- Proc. air preheater
- Secondary reformer
- Gas cooling
- Raw syngas
- Steam
- Existing equipment / line
- New / modified equipment / line

Flowchart diagram showing the process flow with labels for each step and equipment.
Compared Process Concepts
Concept III: New ATR parallel to Existing Syngas Generation

- Natural gas
- Process air compressor
- Pre-heating
- Desulphurization
- Pre-heating
- Primary reformer
- Secondary reformer
- Gas cooling
- ATR
- Aux. pre-heating
- Enr. air preheat.
- Aux. gas cooling
- Existing equipment / line
- New / modified equipment / line
- Steam
- Raw syngas
- 370 °C
- ~ 550 °C
- ~ 950 °C
- Air separation compressor
- Air separation
- Oxygen
- Auxiliary process air compressor
- Air separation compressor
Compared Process Concepts

Concept III: New ATR parallel to Existing Syngas Generation

Uhde autothermal reformer design

- Oxygen inlet
- Combustion zone
- Manhole
- Catalyst
- Refractory
- Water jacket

Gas inlet → Gas outlet

- Process air
- Raw gas
- Existing equipment / line
- New / modified equipment / line

ATR

Uhde autothermal reformer design

ThyssenKrupp Uhde
Compared Process Concepts
Ammonia Synthesis

Ammonia synthesis expansion with Uhde dual-pressure concept:

- pre-heating
- OT reactor
- gas cooling
- NH₃ separation
- synthesis loop
- steam turbine or motor
- saturated HP steam
- BFW / saturated HP steam
- synthesis gas
- new / modified equipment / line
- existing equipment / line
- ammonia
- purge gas
Energy Consumption Evaluation
Methods

- Mass and energy balances in Aspen Plus
- For process plant and steam system
- Equipment characteristics included in the process models:
  - pressure losses: function of flowrate
  - compressor heads / eff.: function of flowrate, speed
  - heat transfer: function of mean log. temperature diff.
Energy Consumption Evaluation
Method

ammonia plant
(existing plant & expansion part,)

fuel gas
feed gas
electric power
MP steam

ammonia
purge gas

steam system
waste heat recovery system

Notes:
1) purge gas export is desired in this study because it is used in another plant
2) also including air separation unit where applicable
Energy Consumption Evaluation
Method

Lower heating value (LHV)
Conversion to equivalent natural gas for its production
Specific enthalpy

Notes:
1) Purge gas export is desired in this study because it is used in another plant
2) Also including air separation unit where applicable
Energy Consumption Evaluation

Results

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>Process Concept</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>I Enlarged SMR</td>
</tr>
<tr>
<td>Feed gas</td>
<td>GJ/t NH₃</td>
<td>22.83</td>
</tr>
<tr>
<td>Fuel gas</td>
<td>GJ/t NH₃</td>
<td>13.28</td>
</tr>
<tr>
<td>MP steam</td>
<td>GJ/t NH₃</td>
<td>2.07</td>
</tr>
<tr>
<td>Electricity (converted)</td>
<td>GJ/t NH₃</td>
<td>0.98</td>
</tr>
<tr>
<td>Purge gas export</td>
<td>GJ/t NH₃</td>
<td>-1.73</td>
</tr>
<tr>
<td>Overall</td>
<td>GJ/t NH₃</td>
<td>37.43</td>
</tr>
</tbody>
</table>

Result: ATR-based concept shows lowest overall energy consumption
Investment Cost Evaluation
Calculation of Capital Cost for Expansion Concepts

- Cost estimation for individual equipment items by scaling from reference data:
  \[
  \text{actual cost} = \text{reference cost} \left( \frac{\text{actual capacity}}{\text{reference capacity}} \right)^{\text{exponent}}
  \]

- Factors applied for cost for engineering, piping, instrumentation etc.

- Entire erection cost for each expansion concept: sum of adjusted equipment cost

- Production loss caused by shutdown time for tie-ins:
  - Concept III: tie-ins only in cold piping
  - Concept II: new secondary reformer ⇒ need one week more
  - Concept I: difficult work at reformer box ⇒ need four weeks more
## Investment Cost Evaluation

### Results – Importance of Shutdown Time

**Note:**
1) example: 400 USD/t sales price, 4 USD/MMBTU gas cost

**Result:** ATR-based concept is most attractive

<table>
<thead>
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<th>Item</th>
<th>Unit</th>
<th>Process Concept</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>I</td>
</tr>
<tr>
<td>Erection cost (process and steam sys.)</td>
<td>million USD</td>
<td>157.5</td>
</tr>
<tr>
<td>Lost profit(^1) by add’l shutdown time</td>
<td>million USD</td>
<td>15.7 (4 weeks)</td>
</tr>
<tr>
<td>Overall capital cost</td>
<td>million USD</td>
<td>173.3</td>
</tr>
</tbody>
</table>

\(^1\) Additional costs due to extended shutdown time.
Overall CAPEX / OPEX Comparison

Method

General aspects:

- All expansion concepts have the same annual production ⇒ specific production costs represent the economic ranking

\[
\text{specific production cost} = \frac{\text{annual CAPEX} + \text{annual OPEX}}{\text{annual production}}
\]

- Scenarios for cost evaluation:
  - annual interest rate: 4 or 10 %
  - required payback period: 5 or 15 years
  - specific energy cost: 1.0 or 4.00 USD/MMBTU (LHV)
  - operating days per year: 350
Overall CAPEX / OPEX Comparison
Method

OPEX Considerations:

- Costs / credits included in the OPEX calculation for all streams across B.L.:
  - gas
  - steam
  - electric power
  (same as for calculation of consumption figure)

- All other costs contributing to OPEX, e.g:
  - staff
  - maintenance
  - tax
  assumed to be same for all concepts ⇒ therefore excluded
### Overall CAPEX / OPEX Comparison

Resuling Specific Production Cost, based on CAPEX and OPEX

<table>
<thead>
<tr>
<th>Economic scenario</th>
<th>Production cost for process concept</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Enlarged SMR</td>
<td>SR with enriched air</td>
<td>Parallel ATR</td>
<td></td>
</tr>
<tr>
<td><strong>Energy cost</strong></td>
<td><strong>Annual interest rate</strong></td>
<td><strong>Payback period</strong></td>
<td><strong>I</strong></td>
<td><strong>II</strong></td>
</tr>
<tr>
<td>USD/MMBTU</td>
<td>%</td>
<td>years</td>
<td>USD/t</td>
<td>USD/t</td>
</tr>
<tr>
<td>1.0</td>
<td>4</td>
<td>15</td>
<td>128</td>
<td>129</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>5</td>
<td>307</td>
<td>309</td>
</tr>
<tr>
<td>4.0</td>
<td>4</td>
<td>15</td>
<td>231</td>
<td>234</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>5</td>
<td>404</td>
<td>412</td>
</tr>
</tbody>
</table>

**Result:** ATR-based concept shows lowest overall production cost, irrespective of energy cost, interest rate and payback period.
CO₂ Production
Comparison

CO₂ emission:
• CO₂ containing streams emitted by the ammonia plant and its utilities:
  – flue gas from reformer stack (ISBL)
  – flue gas from boiler stack (OSBL)
  – vent from CO₂ removal unit

approx. 10 % CO₂, ambient pressure

approx. 99.5 % CO₂, 1.3 – 1.7 bar abs.: easily available for urea production
**CO₂ and Urea Production**

Comparison

CO₂ and urea production after revamp at 2,180 t/d ammonia production:

<table>
<thead>
<tr>
<th>Stream</th>
<th>Unit</th>
<th>Process Concept</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>I</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Enlarged SMR</td>
</tr>
<tr>
<td>Total CO₂ generation</td>
<td>t CO₂ / t NH₃</td>
<td>2.10</td>
</tr>
<tr>
<td>CO₂ available for urea</td>
<td>t CO₂ / t NH₃</td>
<td>1.16</td>
</tr>
<tr>
<td>Max. urea production</td>
<td>t/d</td>
<td>3,449</td>
</tr>
</tbody>
</table>

**Result:** Concepts II and III offer more CO₂ to be used for urea, less CO₂ emission.
Summary

- Investigation on economics of ammonia plant production increase
- Focus on synthesis gas generation – three options compared
- \( \text{NH}_3 \) synthesis: same concept for applied to all cases
- Result: economic ranking between the concepts, based on CAPEX and OPEX data

Conclusion:
A stand-alone ATR parallel to the existing syngas generation:
- is a very competitive alternative
- requires minimum interference with the existing plant
- is the superior solution if full implementation costs (shutdown time, risks) are taken into consideration
- makes more \( \text{CO}_2 \) available for urea production compared to conventional concept
Thank you for your attention!

Questions?

Comments?

Suggestions?

klaus.noelker@thyssenkrupp.com
www.uhde.eu