Comparison of synthesis gas generation concepts for capacity enlargement of ammonia plants

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Capacity enlargement of ammonia plants

Contents:

- Introduction
- Basics of capacity enlargements
- Compared process concepts
- Energy consumption evaluation
- Investment cost evaluation
- Overall CAPEX / OPEX comparison
- Summary
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Advantages of capacity enlargements compared to the erection of a new plant
- better adjustment to market growth
- lower overall investment
- faster implementation
⇒ much smaller risk

The success of a revamp is not independent of
> the chosen revamp concept
> the amount of additional capacity

It is therefore of prime importance
⇒ to select the best overall revamp concept and
⇒ to determine the most economical extra capacity
Presentation reports the results of a detailed comparison of three different expansion concepts

Investigation
- was based on an existing older ammonia plant
  (reference plant capacity at the time of the investigation ~1665 mtpd)
- envisaged a 30% expansion (~ 500 mtpd)
- mainly focused on the synthesis gas generation section
- covered the entire process plant and the steam system

Compared synthesis gas generation expansion concepts
I. Upgrading of existing steam reformer / secondary reformer
II. Secondary reformer operation with enriched air
III. Stand-alone autothermal reformer (ATR) parallel to existing syngas generation
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Basics of capacity enlargements (1)

Economical requirements

- Capacity expansions can usually be assigned to 3 distinct ranges
  1. utilization of built-in capacity reserves
  2. debottlenecking of limited numbers of process units / equipment items
  3. substantial plant modifications

⇒ Specific production costs of the additional capacity show significantly different characteristics in these 3 ranges

⇒ Maximum economical capacity depends on the
  → reserves originally built into the individual process units
  → plant location (feedstock cost and availability)
  → market situation
In general, a detailed investigation is required to determine the situation of a plant and the most suitable expansion capacity.
## Basics of capacity enlargements (3)

### Technical requirements

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Countermeasures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase flowrates through process flowpath</td>
<td>- compressor / driver improvement</td>
</tr>
<tr>
<td></td>
<td>- larger cross sectional areas</td>
</tr>
<tr>
<td>Transfer larger amounts of heat</td>
<td>- larger heat transfer surfaces</td>
</tr>
<tr>
<td></td>
<td>- better heat transfer coefficients</td>
</tr>
<tr>
<td></td>
<td>- increased temperature differences</td>
</tr>
<tr>
<td>Maintain reaction conversions</td>
<td>- elevated reaction temperatures &amp; press.</td>
</tr>
<tr>
<td></td>
<td>- larger catalyst volumes</td>
</tr>
<tr>
<td>Sustain separation of species</td>
<td>- improved internals of separation units</td>
</tr>
<tr>
<td></td>
<td>- better solvents (solubility / selectivity)</td>
</tr>
</tbody>
</table>
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Compared process concepts (1)

Reference plant

Block flow diagram of the reference plant
Compared process concepts (2)

Ammonia synthesis

Ammonia synthesis expansion with Uhde dual-pressure concept
Compared process concepts (3)
Concept I: Expansion of primary reformer

- Natural gas
- Process air compressor
- Pre-heating
- Desulphurization
- Pre-heating
- Primary reformer
- Secondary reformer
- Gas cooling
- Steam
- Direct reduction of CO₂
- CO₂ removal
- Gas cooling
- LT shift
- Gas cooling
- HT shift
- Auxiliary process air compressor
- Auxiliary CO₂ removal
- Auxiliary gas cooling
- Auxiliary gas cooling
- Auxiliary gas cooling
- New/modified equipment
- Existing equipment

Purified synthesis gas
BFW
BFW
BFW
BFW
BFW
BFW
Compared process concepts (4)

Concept II: Secondary reformer operation with enriched air
Compared process concepts (5)

Concept III: New ATR parallel to existing synthesis gas generation

- Natural gas
- Pre-heating
- Desulphurization
- S/F pre-heating
- Primary reformer
- Secondary reformer
- Gas cooling
- ATR
- Enr. air preheat.
- Aux. S/F preheat.
- Aux. gas cooling
- Synthesis loop
- Existing equipment
- New / modified equipment
- Oxygen
- Process air compressor
- Air separation compressor
- Air
- Steam
- Proc. air preheater
- 370°C
- 550°C
- 950°C
- 370°C
## Compared process concepts (6)
### Main equipment items in the expansion concepts

<table>
<thead>
<tr>
<th>new or modified main equipment item</th>
<th>enlarged SMR</th>
<th>sec. ref. with enriched air</th>
<th>ATR</th>
</tr>
</thead>
<tbody>
<tr>
<td>auxiliary air compressor</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>air separation unit</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>steam reformer oven box expansion</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>combustion air fan</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>flue gas fan</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>secondary reformer replacement / modification</td>
<td>o</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>autothermal reformer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>fired heater</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>process air preheating</td>
<td>o</td>
<td></td>
<td>o</td>
</tr>
<tr>
<td>combustion air preheating</td>
<td>o</td>
<td></td>
<td>o</td>
</tr>
<tr>
<td>feed / steam preheating coil</td>
<td>o</td>
<td></td>
<td>o</td>
</tr>
<tr>
<td>natural gas preheating coil</td>
<td>o</td>
<td></td>
<td>o</td>
</tr>
<tr>
<td>waste heat boiler &amp; steam drum</td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>auxiliary synthesis gas compressor</td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>once-through (OT) synthesis</td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>CO$_2$ absorber</td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
</tbody>
</table>

x  new equipment  o  modified equipment
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Energy consumption evaluation (1)

Methodology

Relevant utilities and balanced plant sections
Energy consumption evaluation (2)

Methodology

- Calculation of individual utilities consumptions via Aspen Plus-based material and heat balances
- Calculations contained entire process plants and steam systems
- Equipment characteristics included in the process models
  - pressure losses \( := f(\text{flowrate}) \)
  - compressor heads / eff. \( := f(\text{flowrate; speed}) \)
  - heat transfer \( := f(\text{mean log. temperatur difference}) \)

Transformation of utilities consumptions into equivalent energy consumptions:

- feed and fuel gas \( \Leftrightarrow \) lower heating values (LHV)
- steam \( \Leftrightarrow \) specific enthalpy
- electric power \( \Leftrightarrow \) 30% overall eff. from nat. gas to el. power
- purge gas ammonia synthesis \( \Leftrightarrow \) lower heating value
### Energy consumption evaluation (3)

#### Results

Individually energy consumption figures of the expansion concepts

<table>
<thead>
<tr>
<th>utility</th>
<th>unit</th>
<th>enlarged SMR</th>
<th>sec. ref. with enriched air</th>
<th>ATR</th>
</tr>
</thead>
<tbody>
<tr>
<td>feed gas</td>
<td>Gcal / t\textsubscript{NH\textsubscript{3}}</td>
<td>5,45</td>
<td>5,80</td>
<td>5,77</td>
</tr>
<tr>
<td>fuel gas</td>
<td>Gcal / t\textsubscript{NH\textsubscript{3}}</td>
<td>2,76</td>
<td>2,42</td>
<td>2,39</td>
</tr>
<tr>
<td>imported MP steam</td>
<td>Gcal / t\textsubscript{NH\textsubscript{3}}</td>
<td>0,50</td>
<td>0,41</td>
<td>0,38</td>
</tr>
<tr>
<td>electrical power</td>
<td>Gcal / t\textsubscript{NH\textsubscript{3}}</td>
<td>0,23</td>
<td>0,28</td>
<td>0,27</td>
</tr>
<tr>
<td>overall spec. cons.</td>
<td>Gcal / t\textsubscript{NH\textsubscript{3}}</td>
<td>8,94</td>
<td>8,91</td>
<td>8,81</td>
</tr>
</tbody>
</table>

**Result:** ATR-based concept shows lowest overall energy consumption.
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Investment cost evaluation (1)
Calculation of capital cost for each expansion concept

- Scaling of individual equipment cost via

\[
\frac{C_{rc,i}}{C_{bc,i}} = \left( \frac{V_{rc,i}}{V_{bc,i}} \right)^\alpha
\]

- Cost for engineering, piping, instrumentation etc. accounted for through cost escalation factors to individual equipment cost

- Entire erection costs for each expansion concept derived as sum of adjusted equipment cost
Capital cost evaluation (3)
Importance of tie-in time

Expansion concepts are associated with significantly different tie-in time spans → considerable differences in lost production revenues

<table>
<thead>
<tr>
<th>subject</th>
<th>expansion concept</th>
<th>I</th>
<th>II</th>
<th>III</th>
</tr>
</thead>
<tbody>
<tr>
<td>tie-in situation</td>
<td>unit</td>
<td>enlarged SMR</td>
<td>sec. ref. with enriched air</td>
<td>ATR</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>reconstruction of steam reformer</td>
<td>replacement / modific. of sec. reformer</td>
<td>only non-critical tie-ins</td>
</tr>
<tr>
<td>add. downtime beyond regular maintenance shutdown</td>
<td>days</td>
<td>28</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>add. lost production revenue *)</td>
<td>Mio. USD</td>
<td>16,8</td>
<td>4,2</td>
<td>0,0</td>
</tr>
</tbody>
</table>

*) lost prod. revenue of 0,6 Mio USD/d assumed (400 USD/mt$_{NH3}$, 3,0 USD/MMBTU)
## Capital cost evaluation (4)

### Results

Capital cost of the expansion concepts in Mio. USD

<table>
<thead>
<tr>
<th>plant section / cost component</th>
<th>expansion concept</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
</tr>
<tr>
<td></td>
<td>enlarged SMR</td>
</tr>
<tr>
<td>synthesis gas generation</td>
<td>80,40</td>
</tr>
<tr>
<td>OT synthesis</td>
<td>71,20</td>
</tr>
<tr>
<td>steam system</td>
<td>2,10</td>
</tr>
<tr>
<td>reformer waste heat section</td>
<td>3,90</td>
</tr>
<tr>
<td>basic erection cost</td>
<td>157,60</td>
</tr>
<tr>
<td>lost production revenue</td>
<td>16,80</td>
</tr>
<tr>
<td><strong>total capital cost</strong></td>
<td><strong>174,40</strong></td>
</tr>
</tbody>
</table>

**Result:** ATR-based concept shows lowest overall investment costs
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Overall CAPEX / OPEX comparison (1)

Methodology

General

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

- Individual specific production costs are calculated according to

  \[
  \text{specific production cost} = \frac{\text{annual CAPEX} + \text{annual OPEX}}{\text{annual production}}
  \]
Overall CAPEX / OPEX comparison (2)

Methodology

**Operating expenditure (OPEX)**

- Costs / credits included in the OPEX calculation for
  - feed and fuel gas
  - steam
  - electrical energy
  - purge gas ammonia synthesis

- All other costs contributing to OPEX e.g. for
  > staff
  > maintenance
  > tax

assumed to be the same for all expansion concepts and therefore excluded.
Overall CAPEX / OPEX comparison (3)

Methodology

Capital Expenditure (CAPEX)

- Calculation of annual capital costs (annuity) via
  
  \[
  \text{annual CAPEX} = \frac{\text{plant capital cost} + \sum \text{interest (entire payback period)}}{\text{required capital payback period}}
  \]

- Equal interest rates for equity and loans

- Scenarios considered to illustrate the influence of capital and energy costs
  - Annual interest rates: 5 / 15 %
  - Capital payback period: 5 / 15 yrs.
  - Specific energy cost: 0,75 / 3,00 USD/MMBTU
## Results

Specific production costs of the expansion concepts in USD / t\textsubscript{NH3}

<table>
<thead>
<tr>
<th>spec. energy cost (USD/MMBTU)</th>
<th>annual interest rate [%]</th>
<th>capital payback period [yrs.]</th>
<th>enlarged SMR</th>
<th>sec. ref. with enriched air</th>
<th>ATR</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.75</td>
<td>5</td>
<td>15</td>
<td>128</td>
<td>130</td>
<td>123</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>5</td>
<td>329</td>
<td>336</td>
<td>316</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>15</td>
<td>212</td>
<td>210</td>
<td>203</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>5</td>
<td>412</td>
<td>416</td>
<td>395</td>
</tr>
</tbody>
</table>

- ATR-based concept shows lowest production costs in all cases, irrespective of energy cost, requested capital payback time and annual interest rate.

- Significant margins in all scenarios to cover costs not accounted for in this comparison.
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Summary

- Presentation reported the results of an investigation concerned with the economics of ammonia plant production expansion
- Main focus on the synthesis gas generation
  → Same NH₃ synthesis expansion concept applied for all revamp concepts
- Investigation established an economic ranking between the expansion concepts via a CAPEX + OPEX comparison

**Conclusion:**
A stand-alone ATR parallel to the existing syngas generation

⇒ is a very competitive alternative in general
⇒ requires minimum interference with the existing plant
⇒ is the superior solution if full implementation costs and associated risks are taken into consideration
Thanks for your attention

Questions

Comments

Suggestions