Low Energy Consumption Ammonia Production
Baseline energy consumption, options for optimization
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Overview

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○ Minimum realistic energy consumption of conventional processes
○ Examples for energy saving measures
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  – High efficiency energy conversion
  – Use of high efficiency turbo-machinery
  – Reduced pressure drop
○ Comparison of consumption figures
○ Summary
Introduction
Why think about energy consumption?

- Economical point of view:
  Natural gas is not a cheap by-product of oil production any more – prices are increasing all over the world.
  - Many fertilizer plants already lost the ability to produce competitively due to rising energy cost
  - Value of energy savings increases with gas price
  - Example: energy saving of: \(0.1 \text{ Gcal/t}_{\text{NH}_3}\) corresponds to net present value: \(8.7 \text{ million USD}\)

  Conditions: plant size: 2,000 mtpd  
gas price: 3 USD / MMBTU  
time horizon: 15 years  
interest rate: 5%

- Ecological point of view:
  A considerable portion of the ammonia-production related \(\text{CO}_2\) emission may at first be fixed in urea, but it will be released to the atmosphere upon urea decomposition.
Introduction

History of energy consumption

- Energy consumption was significantly reduced in the 1970s
- No obvious trend since about 1990, consumption figures ranging in between of 6.7 and 7.4 Gcal/t NH₃

Stagnation due to low gas cost or for physical reasons?
Minimum realistic energy consumption
Chemical baseline and reason for heat rejection

- Input for NH₃ production from CH₄, air and steam: 4.98 Gcal/tₙH₃ (from reaction stoichiometry)
- Energy in ammonia product (expressed as LHV): 4.44 Gcal/tₙH₃

CH₄
4.98 Gcal / tₙH₃ (LHV)

ammonia process

NH₃
4.44 Gcal / tₙH₃ (LHV)

min. heat rejection
0.53 Gcal/tₙH₃

- Higher heat rejection in the real process due to process requirements:
  - selected temperature and pressure levels
  - energy recovery by steam cycle: limited efficiency
  - dissipational effects (friction)
  - overstoichiometric process steam... and other
Minimum realistic energy consumption
Analysis of actual energy flows

- Energy flows of actual modern ammonia plant – showing loss streams and areas for improvement

Net consumption: 6.92 Gcal/t
Minimum realistic energy consumption
Analysis of actual energy flows

- Example from modern ammonia plant: 64% of the energy consumption ends up in the product

NG (feed and fuel) + imports
- exports
6.92 Gcal / t (LHV)

ammonia process

NH₃
4.44 Gcal / t (LHV)

64%
Minimum realistic energy consumption

- Approaches for reducing the energy consumption:
  - Reduce heat release from process ⇒ lower energy input
  - Increase efficiency of steam system ⇒ more value from waste heat

- Practical limits:
  - Limitations for heat release from the process:
    - Loss to water coolers cannot be avoided because there is waste heat present at a low level not favourable for recovery
    - Reformer stack temperature preferred above 100 °C
  - Steam system: optimisation to 40 % efficiency assumed

- Result: baseline at approx. 6.5 Gcal per ton of ammonia
  - Lower consumption only with high efforts
  - Not identical to the economic optimum
Options for saving energy (1)
Minimised direct heat release to environment

- e.g. flue gas at stack, synthesis waste heat to cooling water, ...

- exemplary measures:
  - extended use of primary reformer flue gas heat to lower the stack temperature:
    - combustion air preheating
    - higher preheating temperatures of feed/steam and process air
    - optional: integration of a pre-reformer with re-heating in flue gas duct
      ... all to utilize waste heat for process requirements
  - raise more HP steam and minimize heat loss to cooling systems:
    - 2 converter, 2 boiler synthesis loop
    - lower temperature difference in synthesis gas/gas heat exchanger
Options for saving energy (2)
Extended physical desorption in CO₂ removal unit

- Regeneration of solvent (here: aMDEA) is typically done with:
  - 2-stage physical desorption (HP/LP flash) for semi-lean solution
  - stripper column for lean solution
- Better regeneration by lower pressure possible, but:
  LP flash pressure optimized for CO₂ compressor suction pressure
- Insert atmospheric flash vessel below LP pressure for overall energy saving by:
  - lower solution circulation rate
  - lower reboiler duty
  - mechanical vapour compression
Options for saving energy (2)
Extended physical desorption in CO\textsubscript{2} removal unit

-35\% effect on total energy consumption:
≈ -0.05 Gcal/t NH\textsubscript{3}

Typical flowsheet of amine-based CO\textsubscript{2} removal

-30\% lean solution
-10\% semi-lean solution

HP/LP-Flash vessel
Atmospheric flash vessel
Stripper column
Absorber column

Purified gas
Raw gas
Options for saving energy (3)
Optimum efficiency energy conversion

- Steam reforming process must release some waste heat
- Raising HP steam is a good option to utilize this heat for power generation (lower steam pressure means lower efficiency)
- Remaining power demand can be provided by:
  - enlargement of the steam cycle duty by:
    - extra reformer firing
    - steam from auxiliary boiler
cycle efficiency: ~30%
  - combined cycle power plant (incl. gas turbine) serving the whole plant complex with steam and electric power:
    - cycle efficiency: >40% (up to 60% in large scale power plants)
    - energy saving:
      - advantage of $0.25 \text{ Gcal/t}_{\text{NH}_3}$ in exemplary NH$_3$ plant (due to changed energetic value of steam and power)
      - similar savings in the rest of the complex (urea and utilities)
Options for saving energy (4)
Use of energy-efficient machinery

- Recent proposal data from reputable vendors (same project):

<table>
<thead>
<tr>
<th></th>
<th>Vendor 1</th>
<th>Vendor 2</th>
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</thead>
<tbody>
<tr>
<td><strong>Synthesis gas compressor turbine</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HP steam inlet</td>
<td>250,400 kg/h</td>
<td>250,400 kg/h</td>
</tr>
<tr>
<td>MP steam extr.</td>
<td>181,700 kg/h</td>
<td>190,100 kg/h</td>
</tr>
<tr>
<td>∆ MP steam</td>
<td></td>
<td>+ 8,400 kg/h</td>
</tr>
<tr>
<td>∆ consumption figure *1</td>
<td>+ 8,400 kg/h</td>
<td>- 0.08 Gcal/t</td>
</tr>
<tr>
<td><strong>Refrigeration compressor turbine</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MP steam inlet</td>
<td>34,900 kg/h</td>
<td>31,824 kg/h</td>
</tr>
<tr>
<td>∆ MP steam</td>
<td></td>
<td>+ 3,076 kg/h</td>
</tr>
<tr>
<td>∆ consumption figure *1</td>
<td></td>
<td>- 0.03 Gcal/t</td>
</tr>
</tbody>
</table>

*1: MP steam rating: 3300 kJ(prim. energy) / kg(steam)

- Selection of machinery is also a question of energy consumption
Options for saving energy (5)
Reduced pressure drop

○ Pressure drop from outlet steam reformer
to inlet synthesis gas compressor usually ranges from 6 to 9 bar

○ Loss is to be compensated by synthesis gas compressor
Example:

\[
\text{pressure drop of 1 bar corresponds to about } 0.007 \text{ Gcal/t}_{\text{NH}_3} \text{ primary energy cons. or to a net present value of } \sim 600,000 \text{ USD}
\]

Conditions as on slide no. 3

○ Effect on the overall consumption figure is small

○ Consequently, it makes sense to find the optimum pressure drop with
respect to total cost (capex + opex)
Comparison of consumption figures

Checklist

- Energy consumption: important parameter to assess the economic value of a plant
- Just comparing numbers of energy consumption might be misleading because of:
  - Climatic conditions: lower energy consumption can be the consequence of lower ambient temperature, not of a “better” process
  - Selection of boundary: for different projects, the boundary can be selected differently – recommendation: include
    - condensate stripper
    - BFW pump power
    - refrigeration power for process
  - Credits for import / export streams: sometimes handled differently

See paper for more examples
Energy consumption of a typical modern plant is already rather low:
- >60% of energy consumption converted into product
- losses difficult to reduce

Some potential in:
- minimization of heat losses (e.g. reformer flue gas heat)
- extended physical desorption in CO$_2$ removal unit
- high efficiency supply of mechanical power
  (combined cycle for producing steam and electric power)
- efficiency of machinery
  - etc. ...

Be suspicious in case very low consumption figures are stated without obvious process improvements
- is the balance correct? (boundary, valuation of import / export, ...)

Lowest energy consumption is **not** the economical optimum:
consider capex + opex
Thank you for your attention!

Questions?

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