On identification of ammonia synthesis technology based on process energy requirements

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Why is ammonia important?

- farming
- chemical industry & biotechnology
- household
- refrigerant
How is ammonia produced?

3H₂ + N₂ ⇌ 2NH₃

1) Steam reforming
2) Cryogenic distillation
3) Ammonia synthesis
Ammonia synthesis

- Haber-Bosch process
- High temperature and pressure
- Exothermic chemical reaction
- Optimal temperature regime

Higher temperature
- faster reaction

Lower temperature
- higher yield
Two technologies

Multi-bed reactor with inter-stage cooling:

a) Direct cooling (quench)

b) Indirect cooling (HE)

- Production rate is fixed
- Energy requirements are different

1 tone of ammonia:
≈ 0.61 MWh of electrical energy
≈ 1.87 MWh of heating & cooling
Direct cooling (quench)

Which technology requires less energy?

Indirect cooling (HE)
Simulation

**Input**
- Feed composition and flow rate
- Reactor pressure
- Fractional conversion
- HE outlet temperatures
- Equation of state
- Recycle ratio
- Split ratio

**Output**
- Composition and flow rate of all streams
- Outlet temperature from reactors
- HE duty
Optimization

**Variables**
- Fractional conversion
- Split fraction

**Constraints**
- Reactor outlet temperature
- Ammonia flow rate in the product stream

**Minimized values**
- Total heat duty
Optimization results

**Absolute value of heat duty for directly cooled system in kW**

- Q1: Before 80,000 kW, After 53,000 kW (Delta: 27,000 kW)

**Absolute value of heat duties for indirectly cooled system in kW**

- Q1: Before 70,000 kW, After 37,800 kW (Delta: 32,200 kW)
Heat Exchanger Networks

-73.3 MW

-86.6 MW
Heat Integration

Goal
Heat Exchanger Network
• Minimum costs
• 20 years lifespan

Basic – Utility streams
Target – HE & utility streams
Heat Integration - Results

Before 80.24 MW  After 66.39 MW

108.7 % bigger area of HE

Before 106.9 MW  After 66.3 MW

226.2 % bigger area of HE
## Costs

<table>
<thead>
<tr>
<th></th>
<th>Direct cooling</th>
<th>Indirect cooling</th>
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</thead>
<tbody>
<tr>
<td>Capital costs</td>
<td>+ 0.7 %</td>
<td>+ 89 %</td>
</tr>
<tr>
<td>Operational costs</td>
<td>- 14.6 %</td>
<td>- 150 %</td>
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<tr>
<td>Cost/s</td>
<td>0.2244</td>
<td>-0.0863</td>
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Conclusion

**Directly cooled system**  **Indirectly cooled system**

- Simplicity
- Doesn’t depend on HPS usage and sale

- Great potential for generation of HPS
- Usage or sale
- Cheaper even without selling HPS
Methodology review

- Fast and reliable analysis of the process
- Quick optimization
- Designed the target HENs
- Demonstrated the benefits of direct cooling through the cost estimates