Solid Oxide Cell Enabled Ammonia Synthesis and Ammonia based Power Production

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Haldor Topsøe A/S
We have been committed to catalytic process technology for more than 77 years

• Founded in 1940 by Dr. Haldor Topsøe
• Revenue: 700 million Euros
• 2400 employees
• Headquarters in Denmark
• Catalyst manufacture in Denmark and the USA
Topsøe Ammonia Catalyst Charges

- 248 current references worldwide
Topsoe ammonia plants
Since 2000

Number of plants: 60
Accumulated capacity, MTPD: 99,505
Topsoe ammonia process – alternative with prereformer

- Process steam
- Prereforming (optional)
- Reforming
- Natural gas
- Process air
- Stack air
- Purge gas
- Ammonia product
- Ammonia synthesis
- Methanation
- CO₂ removal
- Process cond.
SynCOR Ammonia™
Simplified process layout

Air separation unit

Hydrogenation
Sulfur removal
Preforming
Auto thermal reforming
Fired heater
Steam
Fired heater
Super heated steam
High temperature shift
High temperature shift

Air
Natural gas + hydrogen
Fuel

Super heated steam

Ammonia conversion
S-300
Ammonia product

Oxygen

CO₂ removal
Nitrogen wash
Process condensate

CO₂
Off gases
Nitrogen wash

Nitrogen wash

Nitrogen

Nitrogen product

Air separation unit

Steam

Super heated steam

High temperature shift
Fuel Cell and Electrolyser

SOFC

H₂ + O²⁻ → H₂O + 2e⁻

½O₂ + 2e⁻ → O²⁻

H₂O

½O₂

H₂

SOEC

H₂O + 2e⁻ → H₂ + O²⁻

O²⁻ → 2e⁻ + ½O₂

H₂O

½O₂

H₂

H₂ + CO + O₂ ↔ H₂O + CO₂ + electric energy (∆G) + heat (T∆S)
SOEC more efficient than present Electrolysers

Internal waste heat used to split water

Energy needed to evaporate water

Waste heat which can be utilised to split water

Minimum Electricity Input
Biogas upgrade by means of SOEC

$$\text{CH}_4 + \text{CO}_2 + 3\text{H}_2\text{O} + \text{El} \rightarrow 2\text{CH}_4 + \text{H}_2\text{O} + 2\text{O}_2$$
Biogas to SNG via SOEC and methanation of the CO$_2$ in the biogas
Biogas upgrading demonstration unit
Operating in Foulum, Denmark

- 50 kW SOEC unit for steam electrolysis
- Catalytic methanisation
- The CO$_2$ in the biogas is upgraded to pure methane with pipeline quality.
- High Exergy Efficiency of 80%
SOEC Operating temperatures as function of voltage and ASR

ASR = Area specific resistance

Source: O´Brien IMECE 2008
Synergy between SOEC and fuel synthesis

- Air
- SOEC
- Syn Gas
- Synthesis
- Ammonia
- H₂O
- Steam
Ammonia Synthesis Gas Generation by SOEC

Efficiency = 77 % on exergy basis – 71 % on LHV basis
Breakdown of power consumption in kWh per MT ammonia

Total energy: 7223 kWh/MT NH₃
Haber-Bosch Synthesis only 6.0 % !
Direct Ammonia SOFC

\[ 2 \text{NH}_3 \rightarrow 3 \text{H}_2 + \text{N}_2 \]

Same or better performance with ammonia as with H\(_2\)+ N\(_2\) mixture

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**750 °C**

- Hydrogen/nitrogen 3/1
- Ammonia

**850 °C**

- Hydrogen/nitrogen 3/1
- Ammonia
Direct use of Ammonia for SOFC
Electrical efficiency > 60 % LHV
Conclusions

• Haldor Topsøe A/S has been the market leader for both catalyst and ammonia technology for decades
• Recently introduced process scheme enables capacities above 6000 MTPD capacity based on auto-thermal reforming of natural gas
• New Solid Oxide Electrolysis based synthesis gas process eliminates air separation unit and have very high efficiency
• Ammonia is the perfect fuel for Solid Oxide Fuel Cells without the need for water addition or fuel processing
Thank You