Biomass based Sustainable Ammonia Production

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Sustainable Ammonia Production

Water Electrolysis + Air Separation + HB Process

Electrochemical formation

Biomass to ammonia processes

Bicer & Dincer (2017), ACS. Sust. Chem. Eng. 5(9), 8035-8043
Sanchez & Martin (2018), Sustain. Product. Consumpt. 16, 176-192
Biomass to Ammonia Process

Biomass (Switchgrass)

Gasification

Biomass Treatment

Digestion

Gas Clean-Up, Reforming and Upgrading

Ammonia Synthesis

Ammonia
Modelling Issues

A: Indirect Gasification

\[ X = a + bT + cT^2 \]

B: Direct Gasification \( \text{O}_2/\text{Steam} \)

\[ f_i = A + B \cdot P + C \cdot T + D \left( \frac{O_2}{\text{Feed C}} \right) + E \left( \frac{H_2O}{\text{Feed C}} \right) \]

C: Direct Gasification Air/Steam

Developed empirical model:

\[ Y_i = a_0 + a_1T + a_2T^2 + a_3ER + a_4ER^2 + a_5(S/B) + a_6(S/B)^2 + a_7OP + a_8OP^2 \]

D: Anaerobic Digestion

Experimental results + First Principles
$H_2S + ZnO \rightarrow H_2O + ZnS$

Complete conversion

Reforming Stage

Equilibrium conditions

$CH_4 + H_2O \rightarrow 3H_2 + CO$

$CO + H_2O \leftrightarrow H_2 + CO_2$

$C_nH_m + nH_2O \rightarrow nCO + \left( n + \frac{m}{2} \right)H_2$
Two temperature levels shift reaction

- High temperature: 573-773K
- Low temperature: 453-533K

\[ \text{CO} + \text{H}_2\text{O} \rightleftharpoons \text{CO}_2 + \text{H}_2 \]

Methanation

- Below 10 ppm CO
- Poison Ammonia Catalyst

\[ \text{CO} + 3\text{H}_2 \rightleftharpoons \text{CH}_4 + \text{H}_2\text{O} \]
Ammonia Synthesis

\[ N_2 + 3H_2 \rightleftharpoons 2NH_3 \]

Kinetics
Pressure drop
Energy integration
Chemical Equilibria

Bounds for the Optimization model
\( T, X_{\text{bed}}, \text{Flows} \)
Results

Operating Variables

Generated Steam: 2-6.5 kg Steam/kg NH₃

ATR processes generated more steam than SMR

Indirect cooling ammonia reactor processes generated more steam than the direct cooling alternative
Operating Variables

Needed Steam: 1-4 kg Steam/kg NH$_3$

More steam needed in the digestion processes

Cooling Water: 0.1-0.2 t Water/kg NH$_3$
Operating Variables

ATR processes more power consumption than SMR

Power: 1-4 MW/kg NH₃
Economic Results

Capital Costs

Indirect cooling reactor more investment due to the reactor’s heat exchangers

SMR lower investment than ATR
Economic Results

Production Costs

390-1284 €/t

Indirect Gasification, SMR and Direct Cooling is the best alternative

Digestion alternatives: low yield to ammonia
Results

Environmental Index

Current Processes: 3-4 kg CO$_2$/kg NH$_3$

Biogenic CO$_2$ is neglected
Sensitivity Analysis

Results

Different Biomass prices have been considered: 30-100 €/t
Conclusions

- Different path to produce ammonia from biomass have been evaluated

- Three gasification technologies and anaerobic digestion have been studied

- Two reformer alternatives and direct and indirect cooling reactors have been presented

- Indirect Gasifier with Steam Reforming and Direct Cooling is the most promising alternative in economic and environmental terms

- Digestion presents a worse performance in both index

- The influence of the biomass price and a scale analysis for the process is also presented