Review of ammonia as an electrofuel for Internal Combustion Engines

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Electrofuels/ammonia
Examples:

- Liquid fuel production: methanol
- Biogas enrichment
- Hydrogen
- Ammonia! (if no carbon source is available)
Ammonia Production
Ammonia application today: mainly industry
Possibilities: peaker plants, IC engines
Substitution of: natural gas, HFO
Ammonia distribution and storage
## Pipelines:

<table>
<thead>
<tr>
<th></th>
<th>Efficiency*</th>
<th>Capacity°</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural gas</td>
<td>97%</td>
<td>1,464MW</td>
<td>-</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>87%</td>
<td>1,207MW</td>
<td>0,5-3,2 $/kg</td>
</tr>
<tr>
<td>Ammonia</td>
<td>99%</td>
<td>2,251MW</td>
<td>0,034 $/kg</td>
</tr>
</tbody>
</table>

*: conditioned for vehicle application purposes  
°: based on a 12-inch nominal pipeline
<table>
<thead>
<tr>
<th></th>
<th>Energi content (LHV) [MJ/Kg]</th>
<th>Energi content (LHV) [MJ/L]</th>
<th>Octane</th>
<th>Cetane</th>
<th>Laminar Flame velocity [m/s]*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel</td>
<td>45.6</td>
<td>38.6</td>
<td>~50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gasoline</td>
<td>46.4</td>
<td>34.2</td>
<td>92-95</td>
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<tr>
<td><strong>Liquified Ammonia</strong></td>
<td>18.6</td>
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<td>&gt;130</td>
<td>0.015</td>
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<td><strong>Liquified Hydrogen</strong></td>
<td>120</td>
<td>8.491</td>
<td>&gt;130</td>
<td>3.51</td>
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</tr>
<tr>
<td>Methane</td>
<td>49.6</td>
<td>20.3</td>
<td>120</td>
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<tr>
<td>Methanol</td>
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<td>60</td>
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*) Stoichiometric combustion

For compressed hydrogen divide by 2-4!
Storage:
Ammonia stored at 17 bars: 13,8 MJ/l
Liquid hydrogen at -253°C: 10,0 MJ/l

Vessel storage:
Ammonia (typical capacity): 15-60.000 t
Hydrogen (with current techn.): <900 t
Ammonia as an IC engine fuel
Cetane – Octane Comparison

100 High Octane

50 High Cetane

Diesel fuel must burn faster. Cetane is a measure of ignitability and rapid combustion (ignition quality).

Gasoline must burn evenly. Octane is a measure of a fuel’s ability to resist detonation (pre-ignition).

Ammonia?
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<tr>
<td>Methane</td>
<td>49.6</td>
<td>20.3 (LNG)</td>
<td>120</td>
<td></td>
<td>0.34</td>
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*) Stoichiometric combustion
Ammonia

**Barriers:**
Low flame speed
Additional fuel/ign. improver needed (CI application)
Poisonous
Materials
Heat of vaporization
Emissions unknown (N$_2$O?)
<table>
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<tr>
<th>Ammonia</th>
<th>Additional fuel</th>
<th>Result</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>None</td>
<td>😞 ☹ ☹ ☹</td>
<td>High compression needed (CR 35:1) to achieve combustion</td>
</tr>
<tr>
<td>Gaseous in intake</td>
<td>Hydrogen in intake</td>
<td>☺ ☺ ☺</td>
<td>Applied in SI engine, 5 vol-% hydrogen achieves good combustion – only tried at limited operating conditions, NOx and N2O? (SCR needed)</td>
</tr>
<tr>
<td>Gaseous in intake</td>
<td>Gasoline DI</td>
<td>☹ ☹ ☹</td>
<td>Difficult at many operating conditions (low flame speed), Low BSFC, Fuel NOx high</td>
</tr>
<tr>
<td>Dissolved in gasoline</td>
<td>Gasoline</td>
<td>☹ ☹ ☹</td>
<td>Higher power with moderate ammonia concentrations, but not much info</td>
</tr>
<tr>
<td>Gaseous in intake</td>
<td>Diesel DI</td>
<td>☺ ☹ ☹</td>
<td>Possible but high BSFC, high fuel NOx production at lower loads, N2O? (SCR needed), higher CO and HC</td>
</tr>
<tr>
<td>Gaseous in intake</td>
<td>Biodiesel DI</td>
<td>☺ ☹ ☹</td>
<td>As above with even higher NOx</td>
</tr>
<tr>
<td>DI</td>
<td>DME DI</td>
<td>☹ ☹ ☹</td>
<td>Cyclic variations, higher CO HC and NOx</td>
</tr>
</tbody>
</table>
SI engine application

[Graphs showing NO, NH₃, and N₂O emissions as a function of excess air ratio (λ) for different compression ratios and ignition timings.]

SCR Necessary!
CI engine application

Fig. 15. NOx emissions for various fuel mixtures.

Ammonia emissions seems to be much higher in CI engines!

Fig. 16. Ammonia emissions for fuel mixtures containing ammonia.

SCR Necessary!
Ammonia injected into the air stream

DI of diesel fuel

However, poor engine efficiency for ammonia due to cyclic variations!

Very high emissions of unburned ammonia!

Fig. 15. Measured engine power using “diesel fuel only” (dashed line) and various combinations of ammonia/diesel fuel (solid line).

Fig. 18. Ammonia concentration in the exhaust, ppmV, for corresponding engine torque using combinations of ammonia/diesel fuel.
CI engine application

100%DME, SOI = 10 BTDC,

60%DME–40%NH₃, SOI = 20 BTDC.

(b) BMEP=0.21 MPa

(c) BMEP=0.35 MPa

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Conclusions:

• Ammonia cannot be applied as the only fuel
• Different concepts have been studied
  • SI engine application with hydrogen is most promising so far
• Fuel NOx production is a new issue to consider
• N2O emissions have to be addressed
• BSFC is quite poor in CI engines
• SCR is needed to reduce NOx
Thank you for your attention!