Review of ammonia as an electrofuel for Internal Combustion Engines

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Publication date: 2019

Document Version
Peer reviewed version

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Citation (APA):
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5th International Conference on Smart Energy Systems
Copenhagen, 10-11 September 2019

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Technical University of Denmark
Electrofuels/ammonia
Electrofuels

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: $\text{NH}_3$

Haber-Bosch:

From air

$\text{N}_2 \rightarrow \text{NH}_3$

From natural gas/coal

$\text{H}_2$

70/30%
Ammonia distribution and storage
### Pipelines:

<table>
<thead>
<tr>
<th></th>
<th>Efficiency*</th>
<th>Capacity°</th>
<th>Cost</th>
</tr>
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<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>
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<tr>
<td>Ammonia</td>
<td>99%</td>
<td>2,251MW</td>
<td>0,034 $/kg</td>
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* conditioned for vehicle application purposes
° based on a 12-inch nominal pipeline
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<th>Energi content (LHV) [MJ/L]</th>
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<th>Cetane</th>
<th>Laminar Flame velocity [m/s]*</th>
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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
Ammonia?
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*) Stoichiometric combustion
Ammonia

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

SCR Necessary!

Danmarks Tekniske Universitet
CI engine application

Ammonia emissions seems to be much higher in CI engines!

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!
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

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!