COMPARISON OF AMMONIA / GASOLINE AND AMMONIA / ETHANOL MIXTURES

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Background and Motivation

- We wish to use ammonia as a primary transportation fuel.
- Ammonia works well at high engine loads but a combustion promoter is needed at lower loads.
- Gasoline has previously been shown to be a good combustion promoter.
- What about ethanol? Ethanol can be grown locally, can be carbon neutral, etc…
- It would be very difficult or impossible to produce enough ethanol to displace all of the gasoline that we use. But we could produce enough to use it as a combustion promoter.
- But is ethanol a good ammonia combustion promoter?
Overview

- Experimental Engine
- Comparison of Ethanol and Gasoline Characteristics
- Ethanol/Ammonia Fuel Mix
- Comparison of Gasoline/Ammonia and Ethanol/Ammonia Fuel Mix Maps
- Comparison of Rough and Knock Limits
- Comparison of Thermal Efficiency
- Conclusions
## Comparison of Ethanol Gasoline Properties

<table>
<thead>
<tr>
<th>Properties</th>
<th>Gasoline</th>
<th>E85</th>
</tr>
</thead>
<tbody>
<tr>
<td>RON</td>
<td>92</td>
<td>101</td>
</tr>
<tr>
<td>Density (g/cm³)</td>
<td>0.74</td>
<td>0.79</td>
</tr>
<tr>
<td>Heat of combustion (MJ/kg)</td>
<td>42.4</td>
<td>32.6</td>
</tr>
<tr>
<td>Latent heat of vaporization (KJ/kg)</td>
<td>420</td>
<td>845</td>
</tr>
<tr>
<td>Stoichiometric Air Fuel Ratio</td>
<td>14.3</td>
<td>9.0</td>
</tr>
</tbody>
</table>
Characteristics of Ethanol

- Ethanol has a high antiknock quality due to its high octane number.
- Ethanol has a high latent heat of vaporization.
  - Advantage: Decreases the compressed gas temperature during the compression stroke.
  - Disadvantage: Property influencing cold start ability.
Experimental Investigations

- **Roughness Limit**
  - There are various methods to determine the cycle to cycle variability which determines the vehicle drivability.
  - Pressure related parameters, burn rate related parameters, flame front position parameters.
  - Pressure related quantities are the easiest and the efficient way to determine the cycle to cycle variability.
  - The IMEP$_n$ derived from the pressure data is expressed as
    \[
    \text{Rough Limit} = \text{COV(IMEP}_n) = \frac{\sigma_{\text{imep}}}{\text{IMEP}_n} \times 100
    \]

- **Knock Limit**
  - The maximum gasoline fraction used to avoid knock

- **Efficiency**
  - It is the ratio maximum work output to input.
Cooperative Fuel Research Engine (CFR)
83.4 mm bore diameter, 114.3 mm stroke, 625 cc swept volume displacement
The fraction of required promoter input decreases drastically as load is increased.

The required promoter input (%) is the same for both gasoline and ethanol mixtures at the roughness limit.
Promoter Density at Spark at Rough Limit

Compressed NH$_3$ Density @ Spark (kJ/l)

Compressed Promoter Density @ Spark (kJ/l)

- 8:1, Gasoline/NH$_3$
- 10:1, Gasoline/NH$_3$
- 8:1, E85/NH$_3$
- 10:1, E85/NH$_3$
The promoter input (%) decreases as compressed NH$_3$ density at spark increases.
Minimum gasoline requirement at spark = 1.36
Minimum E85 requirement at spark = 1.57
Both the fuels require almost the same energy/volume at the spark!!
Promoter Density at Spark at Rough Limit

8:1 and 10:1, Gasoline/NH$_3$ and E85/NH$_3$

\[
y = -0.1512x + 1.4252
\]

NH$_3$ Density @ Spark (kJ/l)

Promoter Density @ Spark (kJ/l)

1000 RPM

1300 RPM

1600 RPM

\(y = -0.1512x + 1.4252\)
Is Ammonia a Good Fuel?

The required promoter input decreases slightly as load is increased, showing that ammonia as a fuel having a slighter positive or neutral effect when used with both gasoline and ethanol at the rough limit.
How Does Promoter Input Vary with Speed?

- Specific Promoter Input @ NH3 cut-in point

8:1 E85
10:1 E85
12:1 E85
14:1 E85
8:1 gas
10:1 gas
12:1 gas

Speed
Knock Limit

Knock Limit LHV Basis (% Promoter)

8:1 E85/NH3
10:1 E85/NH3
12:1 E85/NH3
14:1 E85/NH3
8:1 Gasoline/NH3
10:1 Gasoline/NH3
12:1 Gasoline/NH3
14:1 Gasoline/NH3
Knock and Rough Limit Crossover – Gasoline

- %Gasoline decreases as total fuel input increases.
- At some point there is a crossover between roughness limited minimum gasoline fraction and knock limited maximum gasoline fraction. The crossover occurs at 12:1 Compression Ratio.
The Crossover occurs at 13.5:1 Compression Ratio.
Thermal Efficiency At Rough Limit

**Gasoline**

![Graph showing thermal efficiency for gasoline at various IMEPn values, with lines for 8:1, 10:1, and 12:1 fuel ratios.]

**E85**

![Graph showing thermal efficiency for E85 at various IMEPn values, with lines for 8:1, 10:1, and 12:1 fuel ratios.]

Net Indicated Thermal%, All speeds
Summary of Ethanol/NH3 Combustion

Fuel Mix Sweep at 1600 RPM, 10:1 and IMEP_n ~ 550 kPa.
Conclusions

- The knock and rough limit crossover occurs at ~13.5:1 for E85 and ~12:1 for gasoline.
- E85/NH3 has higher knock limit and allows for a higher maximum compression ratio and thermal efficiency.
- Gasoline/NH3 has a lower roughness limit and allows for a slightly more fuel mixture flexibility.
- The roughness limited promoter fraction is found to be almost the same for both (Ethanol & Gasoline) when used with Ammonia as the primary fuel.
- The fuel blend does not change much with speed.
- E85 is an attractive combustion promoter, like gasoline, when used with ammonia as the primary fuel.
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