Fuel protonation as extra way to improve diesel engine efficiency

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Abstract. This paper presents a method for low-cost protonation (hydrogenation) of diesel fuel. Protonation reduces the estimated fuel consumption to 3.3 g/kWh by intensifying the combustion of diesels, which reduces the external loss of energy due to exhaust gas, as well as the internal losses that occur in the gas-turbine supercharger.

1. Statement of Problem.
Experimental studies [1] have proven inappropriate using hydrogen gas (H₂) as an additive to a fresh diesel-fuel charge due to lower fill factor, backfiring, and detonations.

Somewhat better results were attained [2,3] by experimentally using hydrogen gas (H₂) as an additive to diesel fuel, whereby the gas-fuel emulsion was generated in the mixing accumulator of an experimental injector. Fuel consumption and the toxicity of exhaust gases were positively reduced by injecting a gas-fuel emulsion with an H₂ content of 0.1% of fuel weight. Note that the only factor behind such positive results was the higher combustion temperature of the added hydrogen gas (H₂).

The goal hereof is to prove feasible fuel protonation and to assess how it affects diesel engine performance.

2. Research Essentials.
The easiest and cheapest way to generate hydrogen ions (protons, H⁺) directly in the diesel fuel medium is to use ion exchange. This is advisable to due by a single-stage cation exchange method; instead of anion exchange, implement anion deposition on acceptors added to the cassette together with cationites in the form of chippings of active metals (Fe, Ni, etc.). This causes hydrogen ions (protons, H⁺) to be released in stoichiometric proportions to the amount of acceptor-deposited anions; these are deposited on the unused bonds of the non-saturated fractions of diesel-contained hydrocarbons, while surpluses merge into hydrogen molecules (H₂).

Without waterborne salts being dissociated into cations and anions, ion exchange is not possible, which is why protonation uses a “wet” technique [4]. To enforce cation exchange that will generate H⁺, it is advisable to use cationites with H⁺ counterions.

It is also necessary to inject a salt, e.g. Ca (HCO₃)₂, which provides both dissociation and corrosion-inhibiting effects, to the cassette. The process results in cations Ca²⁺ being exchanged to counterions H⁺.
Table 1 provides the experimental readings from a 4ЧН12/14 diesel engine running at different loads for a standard fuel (1) vs protonated fuel (2) comparison.

| Parameters | Ne, kWh | pc, Pa | Тc, K | pc, Pa | Тc, K | pc, Pa | Тc, K |
|------------|---------|--------|--------|---------|--------|---------|--------|
| Nе=1.0    | 72.9    | 134,143| 337.2  | 131,200 | 915    | 876.2  |         |
|            | 72.9    | 133,643| 336.6  | 130,700 | 801    | 864.5  |         |
| 0.908      | 66.2    | 130,343| 333.4  | 127,400 | 871    | 815    | 724    |
|            | 66.2    | 129,543| 329.5  | 126,600 | 815    | 808    | 719    |
| 0.8176     | 59.6    | 129,000| 329.5  | 123,600 | 815    | 808    | 719    |
|            | 59.6    | 127,300| 324.5  | 122,500 | 724    | 705.7  | 695    |
| 0.6365     | 46.4    | 126,000| 315    | 116,100 | 695    | 705.7  | 695    |
|            | 46.4    | 122,000| 315    | 114,500 | 695    | 705.7  | 695    |

Table 1. 4ЧН 12/14 diesel engine parameters at different loads, n = 1,800 min⁻¹

Apparantly, while the diesel engine power is the same, using protonated fuel somewhat reduces the supercharger pressure. This is due to lower turbine power, which is attributable to both the lower pre-turbine gas pressure $p_t$ and lower pre-turbine gas temperature $T_t$. Lower $p_t$ can be attributed to lower exhaust, which is due to lower supercharger pressure.

Lower $T_t$ (and $T_{dis}$) can be due to better indicative process.

Figure 2 shows a reduced volume of the working medium when using protonated fuel, see lower air amount $G_a$ and lower hourly fuel consumption $B_h$.

What proves a better indicative process is the lower fuel consumption $B_h$ at $N_e=const$ despite somewhat lower excess air factor $\alpha$.

After all, Figure 2 shows that using protonated fuel reduces the effective fuel consumption by 3...4 g/kWh at any load.

Figure 3 shows the diagram of the tested combined internal combustion engine (CICE). The legend is as follows: C stands for supercharger, S stands for inlet manifold, PE stands for piston engine (the diesel engine itself), O stands for outlet manifold, and T stands for gas turbine.

$H_o$, $H_c$, $H_s$, $H_t$, $H_{dis}$ are the respective enthalpy values of the working medium flow: $H_\alpha$ and $Q_x$ are the fuel enthalpy and the heat released due to fuel combustion; $N_o$ and $N_{ro}$ are the values of supercharger drive power and gas turbine power; $\sum Q_i = Q_o + Q_{oil} + Q_{oil} + Q_{env}$ is the total of heat dissipated by water, oil and into the environmental off the engine walls; $N_e$ is the effective diesel engine power.
Figure 1. Parameters of the diesel-engine working medium at different loads, original vs protonated fuel.
As shown in Figure 3, the CICE energy balance is as follows:

\[ H_{\text{env}} + N_c + H_{\text{fl}} + Q_x = N_c + H_{\text{dis}} + N_{\text{it}} + \sum Q_l, \]  

(1)

while the thermal balance is as follows:

\[ Q_x = N_c + Q_{\text{gas}} + Q_{\text{w}} + Q_{\text{e}} + Q_{\text{res}}, \]  

(2)

where \( Q_{\text{gas}} = H_{\text{dis}} - H_{\text{env}} - H_{\text{fl}}. \)

**Figure 2.** Basic diesel engine readings plotted against load.
Table 2 presents the relative thermal balance values for standard (1) and protonated (2) fuel, where:

\[ q_x = \eta_e + q_2 = \eta_e + q_{\text{gas}} + \sum q_i. \]  

Table 2. Thermal balance at different loads

| Notation | 1.0 | 0.908 | 0.8176 | 0.6365 |
|----------|-----|-------|--------|--------|
|          | 1   | 2     | 1      | 2      | 1      | 2      | 1      | 2      | 1      | 2      |
| \( q_x \) | 100 | 100   | 100    | 100    | 100    | 100    | 100    | 100    | 100    | 100    |
| \( q_{\text{gas}} \) | 38.00 | 37.73 | 37.80 | 36.57 | 37.00 | 36.57 | 37.10 | 36.20 |
| \( \sum q_i \) | 27.50 | 27.31 | 27.90 | 28.61 | 28.79 | 29.20 | 29.58 |
| \( q_2 \) | 65.50 | 65.04 | 65.70 | 65.17 | 65.80 | 65.36 | 66.30 | 65.78 |
| \( \eta_e \) | 34.50 | 34.96 | 34.30 | 34.80 | 34.15 | 34.66 | 33.70 | 34.20 |

For any load, \( q_{\text{gas}} \) and the total \( q_2 \) is lower for protonated fuel than for its standard counterpart, which is the enabling factor behind greater engine efficiency \( \eta_e \).

3. Conclusions.
Hydrogenation or protonation of diesel fuel by means of ion exchange does reduce the estimated fuel consumption to 3.3 g/kWh by intensifying the combustion of diesels, which reduces the external loss of energy due to exhaust gas, as well as the internal losses that occur in the gas-turbine supercharger.

References
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