A review of hydrogen/diesel fuel blends in internal combustion engines

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Abstract. A hydrogen fuelled internal combustion engine has great advantage on exhaust emission in comparison with a conventional engine from fossil fuel. Despite diesel engines are indispensable for the transport sector, the decreasing emission regulations limit values in recent years’ force researches to find other alternative fuels to use in addition or straight without major engines modifications. A comprehensive review of the recent research activities on the use of hydrogen/diesel fuel blends is documented. Also the challenges and perspectives and main limitations are analysed in this paper.

1. Introduction
Since the introduction by the Rudolf Diesel in 1982 diesel engines are considered one of the most efficient types of engine used worldwide. The recent diesel scandal regarding the pollutant emissions have increase attention regarding the future of diesel engines. Many countries have limited the access of diesel cars in the next years forcing industry and researches to investigate and to research new alternatives. The use of hydrogen is prepared by the automotive manufacturers as a method to enhance performance and improve harmful emission. However, the production of hydrogen is still a very costly process and is expected that this obstacle to be overtaken in future years. The reduction of diesel emission could bring back diesel engine's reliability [1]. The energy content of hydrogen is one of the highest among the commonly used fuels providing at 1 kg almost three times more energy than petrodiesel fuels (diesel and gasoline). However, the low density specific to hydrogen restricts his use do to the storage space required for powering a car for an adequate driving range. Antunes et al. [2] investigated on a single cylinder diesel engine the hydrogen addition directly into a combustion chamber and reported an increase in peak power by 14% comparative with petrodiesel fuel. Miyamoto et al. [3] studied the 16% addition by volume of hydrogen in a direct injection, single cylinder diesel engine and found a reduction in HC and NOx emissions. Saravanan and Nagarajan [4] used three methods of hydrogen addition in a Kirloskar AV1 diesel engine and found that at 1500 rpm and 25%, 50%, 75% and 100% load conditions are no difference between injecting from port and injecting from manifold. The NOx emissions increase with 8% and 17% depending on the method used. Karagoz et al. [5] studied the effect of engine load to the performance of hydrogen addition 0-30% and found a decrease of BTE and an increase of BSFC with 8.4%. Wu and Wu [6] investigated the performance of a single cylinder diesel engine fueled with 20% hydrogen and found a reduction of NOx and smoke emissions compared with petrodiesel fuel. Szwaja et al. [7] studied the addition of 5% hydrogen by energy share to fossil diesel and found that combustion duration did not change significantly but the peak combustion pressure increased. In Table 1 are compared a few of the combustion properties of
hydrogen and diesel fuel. According to the data the high diffusivity and auto-ignition temperature of hydrogen make this fuel for compression ratio (CI) engine compared to gasoline engines [8].

Table 1. Important properties of diesel and hydrogen [8].

| Properties                                      | Diesel | Hydrogen |
|------------------------------------------------|--------|----------|
| Lower Heating Values (MJ/kg)                   | 43     | 120      |
| Stoichiometric air fuel ratio                  | 14.5   | 34.2     |
| Energy Density at 15 °C and 100 kPa, MJ/m³     | 35.8   | 10.3     |
| Autoignition temperature, K                    | 530    | 858      |
| Laminar burning velocity, m/s                  | 0.3    | 2.65 – 3.25 |
| Flammability limits (% volume in air)          | 0.7 to 5 | 4 to 75  |
| Density at 15 °C and 100 kPa, kg/m³            | 848    | 0.0083   |
| Diffusivity in air, cm²/s                      | 0.038  | 0.63     |

2. Effect of hydrogen addition on performance

2.1. Power output

The use of different ratios of hydrogen (e.g. 5 - 50% by volume) to the diesel engine and its effect on emission and performance was evaluated by various researchers. Shin et al. [9] investigated the hydrogen addition and found that the blend hydrogen/diesel improves the process of combustion and leads to the increase of engine power for all loads. Ghazal [10] investigated in his research the relation between air–fuel ratio and engine speed and hydrogen addition. He found for a ratio of 15 air–fuel (A/F) and a percentage of hydrogen between 5% and 10% for different speeds the maximum power output improves. At higher air–fuel ratio the hydrogen addition affects the engine maximum power if the proportion of hydrogen is over 30–40%. In Figure 1 it is observed an increase with 14% in power for all engine speeds comparative with petrodiesel fuel.

![Figure 1](image-url). The brake power versus A/F ratio for different H₂ concentrations at 1000 and 4000 rpm [10].

2.2. Duration of combustion

Comparative with petrodiesel fuel hydrogen has a higher flame speed which affects the combustion process and engine performance. Liew et al. [11] showed that the addition of 2% hydrogen reduce the combustion duration revealing the effect of the fuel in the process of diffusion combustion. At a percentage of 6% a 23% was observed a reduction of combustion duration comparative with neat biodiesel (Figure 2). Grab-Logarinski and Szwaja [12] studied the hydrogen addition in a diesel engine in reduce proportion (maximum 5%) and found that hydrogen reduce ignition delay and improve performance of the engine. If the hydrogen addition exceeds 15% in energy ratios the diesel engine exhibits severe knock.
2.3. In cylinder pressure

At higher loads the hydrogen addition increases the pressure as is shown in Figure 3 due to the higher energy content. Saravanan and Nagarajan [4] found out that a percentage of 30% hydrogen at higher loads produce the best results. Masood et al. [13] show in his researches that the combustion process tends to increase as the percentage of hydrogen is higher due to higher flame velocities.

2.4. Heat release

The heat release rate is influenced by the addition of hydrogen. Figure 4 shows that the addition of hydrogen increases the heat release. It is observed a rapid rise of heat different that of highlighted diffusion combustion of diesel engines due to the high quantity of hydrogen used.

3. Conclusions

The high flammability range of hydrogen in comparison with all other fuels can allow to be combusted in engines over a wide range of fuel-air mixtures. The high flame speed is an order of magnitude higher (faster) than petrodiesel fuels meaning that hydrogen fuelled engines can approach thermodynamically ideal engine cycle. Also hydrogen is a desirable fuel for IC engines it can produce combustion anomalies such as rapid pressure rise, backfiring, pre ignition (surface ignition) and auto ignition. The power output of hydrogen internal combustion engine can increase with 15-20% more than gasoline or diesel engine depending of the method used for fuel injection. Due to the higher pressure and temperature associated with hydrogen usage the engine parts are solicited at higher values than petrodiesel fuels. Regarding the effects of hydrogen on engine parts its effects are the decrease in ductility and true stress at fracture.
Figure 4. Effect of H₂ addition on heat release process, 70% load [11].

References

[1] Pavlos D and Taku T 2017 A review of hydrogen as a compression ignition engine fuel, *International Journal of Hydrogen Energy* 42 pp 24470-24486

[2] Gomes A J M, Mikalsen R, Roskilly A P 2009 An experimental study of a direct injection compression ignition hydrogen engine, *Int J Hydrogen Energy* 34(15) 6516-6522

[3] Miyamoto T, Mikami M, Kojima N, Kabashima H and Urata Y 2009 Effect of hydrogen fraction in intake mixture on combustion and exhaust emission characteristics of a diesel engine, SAE Paper No. 2009-24-0086

[4] Saravanan N and Nagarajan G 2009 Experimental investigation on performance and emission characteristics of dual fuel DI diesel engine with hydrogen fuel SAE Paper No. 2009- 26-032

[5] Karagoz Y, Sandalci T, Yuksel L and Dalkilic A S 2015 Engine performance and emission effects of diesel burns enriched by hydrogen on different engine loads, *Int J Hydrogen Energy* 40 pp 6702–6713

[6] Wu H W and Wu Z Y 2012 Investigation on combustion characteristics and emissions of diesel/hydrogen mixtures by using energyshare method in a diesel engine. *Appl Therm Eng* 42(Suppl. C) pp 154–162

[7] Szwaja S and Grab-Rogalinski K 2009 Hydrogen combustion in a compression ignition diesel engine. *Int J Hydrogen Energy* 34 4413-21

[8] Priybrat S and Atul D 2018 Effect of hydrogen supplementation on engine performance and emissions, *Int J Hydrogen Energy* 43 pp 7570 – 7580

[9] Shin B, Cho Y, Han D, Song S and Chun K M 2011 Hydrogen effects on NOx emissions and brake thermal efficiency in a diesel engine under low-temperature and heavy-EGR conditions. *Int J Hydrogen Energy* 36 pp 6281–6291

[10] Ghazal O H 2013 Performance and combustion characteristic of CI engine fueled with hydrogen enriched diesel, *Int J Hydrogen Energy* 38 pp 15469–15476

[11] Liew C et al. 2010 An experimental investigation of the combustion process of a heavy-duty diesel engine enriched with H₂. *Int J Hydrogen Energy* 35 pp 11357–11365

[12] Adnan R, Masjuki H and Mahlia T 2012 Performance and emission analysis of hydrogen fueled compression ignition engine with variable water injection timing. *Energy* 43 pp 416–426