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Comparative study of oxihydrogen injection in turbocharged compression ignition engines

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Abstract. This document proposes for analysis, comparative study of the turbocharged, compression-ignition engine, equipped with EGR valve, operation in case the injection in intake manifold thereof a maximum flow rate of 1l/min oxyhydrogen resulted of water electrolysis, at two different injection pressures, namely 100 Pa and 3000 Pa, from the point of view of flue gas opacity. We found a substantial reduction of flue gas opacity in both cases compared to conventional diesel operation, but in different proportions.

1. Introduction

Some main directions of study and points of view from the literature related to the studied phenomenon is presented in the introduction chapter:

Notes that in the case of naturally aspirated diesel engines, the hydrogen injection into the intake manifold can reach a maximum of 15% energy [1]. And the fact that in the case of medium load testing, an energy share of 10% hydrogen in diesel blends can reduce the smoke index by up to 50% and, in the case of maximum loading regimes, up to 17%.

In the review paper White et al. [2] stated the importance of studies on the use of internal combustion engines adapted to hydrogen-exclusive operation, both with compression ignition and spark ignition with applications in various areas of technology. They have highlighted some of the issues that require resolution to ensure that the H2ICEs engines can be safely exploited in everyday human activities. The various aspects are encountered such as detonation , wide range of flammability, combustion rate, supercharging, pollution problems with nitrogen oxides, use of flue gas recirculation valves to reduce thermodynamic cycle temperatures, maintaining the engine's specific power, achieving good filling efficiency, efficiency of Real Thermodynamic Cycle, Direct Injection of hydrogen and others.

Gomes et al. [3] conducted the experiments on the one-cylinder diesel engine and show that it is possible to operate the hydrogen-powered engine by producing an air preheat system, to obtain sufficiently high temperatures at the end of the compression phase as the air- Hydrogen mixture might self-ignites. They claimed the achievement of the satisfactory mechanical parameters, and a very low pollution level even with nitrogen oxides. The engine operated with an excess of air of 6, achieving a 45% efficiency. The increase of the final pressure in the cylinder at values exceeding those of the diesel engine operation, thus limiting the operation to high loading regimes.

Swaja et al. [4] presented the operation of diesel engines with a hydrogen-rich blend. They have shown that it is possible to operate them with 17% energy substitution rate. In the case of small substitution percentages of up to 5%, it reduces the delay time for self-ignition of the mixture, with reduction of the pressure gradient in the cylinder. It favors a smoother operation of the engine and thus a higher durability.

In the case of high power diesel engines [5], there is a decrease in total fuel consumption by approximately 12.6% at the engine supply with the 60 l/min H_2/O_2 fuel mixture and respectively a reduction in the level of pollutant compounds in the flue gas composition with 9.5% HC, 7.2% CO, 4.4% CO2, 19.3% particles, respectively an increase in the NOx level by 9.9%.

Considering the multitude of results obtained by the researchers, with conclusions that confirm the different tendencies of variation of the mechanical parameters of the diesel engines as well as the variation of the level of pollutants in the flue gases, the measurements have been made in which we can observe the variation of the opacity of flue gases according to the amount of oxyhydrogen induced in the engine mainfold at two different injection pressures and with the same amount of HHO.

2. The experimental setup

In Figure nr 2 the Block diagram of experimental installation is presented.

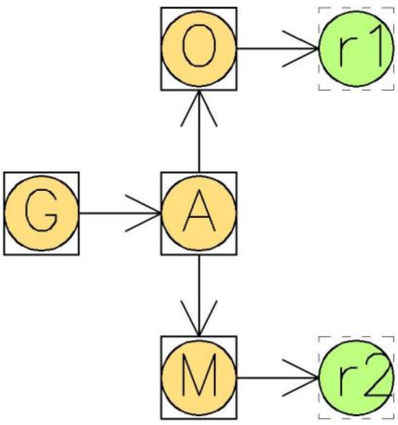

Figure 1. The schematic presentation of the experimental setup[6]:
A - Test used vehicle;
G - Oxyhydrogen gas generation equipment;
O - Laptop used for OBDII plug data acquisition;
M - Dynamometer MAHA LPS 3000 Roller type R100;
r1 - DDT2000 OBDII data acquisition (Timing angle, fuel consomption, air flow, egr psition, Load value);
R2 - MAHA LPS 3000 data acquisition (Wheel Power, Torq, smoke opacity).

Moreover the relevant technical data of the test setup used in the experiments are shown in the table 1.

Table 1. Used test stand main technical data [6]

Equipment	Description		Notifications
Dynamometer MAHA LPS 3000 R100 (M)	LxWxH: Measurement Accuracy: Max Force: Max Wheel Power: Power:	3345x1100x625mm 2% 6000N 260kW 230V	Used to achieve power and torque measurement at vehicle wheel
Oxyhydrogen gas generation plant (G)	Nominal gas flow: Voltage/Current (nominal): Electrodes configuration (fig. 3): Electrode Surface: Used electrolyte solution:	1,0l/min 13,6V/15A -NNNN+NNNN- 140x185mm NaOH, 28% mass	Electrolyzer with multiple boards, with the function to perform electrolysis of water (Figure 3)
The vehicle used for the test (A)	Max Power: Speed of Max Power: Max Torque CEE: Speed of Max Torque:	48(65)[kW/CP] 4000 [rot/min] 160[Nm] 2000[rot/min]	Dacia Logan 1.5 DCI engine K9K 790 (Euro 3), DCM12 injection unit type, soft number 004C, soft version 0071, Calibration version 4845
Laptop (O)	Used for data acquisition through OBDII, including USB/VAG - KKL cable and software		

For an easier understanding of the operation of the HHO generator (Figure nr 2), we present below a drawing of the HHO generator (Figure nr 3), and a schematic diagram of the assembly of the setup.

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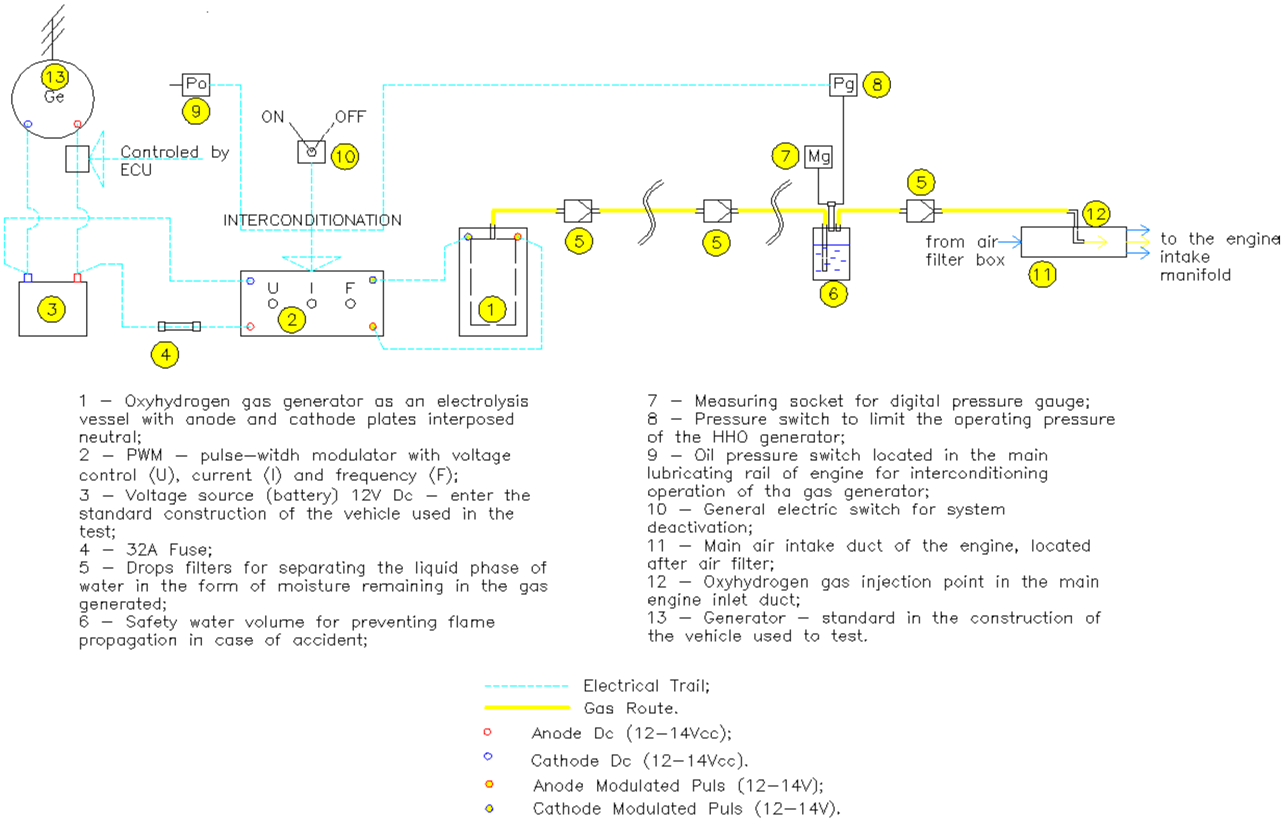

Figure 2. The general scheme of oxyhydrogen generator [6]

3. Experimental Procedure

The opacity tests have been made in 2 stage, the first stage for the standard diesel fuel mixed with HHO at the pressure p1 and in the second stage for the standard diesel fuel mixed with HHO at the pressure p2 (p2> p1), by applying the following procedure.

In the first phase, the instant but not brutal acceleration was made, up to a maximum speed limited by vehicle regulator, maintaining the speed for 2 seconds, then releases the accelerator pedal, leave a pause of a 2 seconds and repeat twice the same operation. The following phases have been employed: D_n – engine fed exclusively with diesel oil, P_i – engine fed with diesel oil and HHO mixture at 0,1 l/min, P_{i+1} – engine fed with diesel oil and HHO mixture at 0,3 l/min and P_{i+2} – engine fed with diesel oil and HHO mixture at 0,7 l/min, for Stage 1 and Stage 2.

At the same time the opacity measurements of flue gases have been made with the AVL opacimeter connected to the MAHA dynamometer and recording the available data series. The maximum supply pressure with HHO is $p_1 = 80$ Pa at stage 1 and $p_2 = 3000$ Pa at stage 2.

The recorded data are processed and the variation of the opacity of flue gases is plotted, depending on the oxyhydrogen flow rate induced in the two situations (for the pressure p_1 respectively p_2).

4. Results and Discussions

After carrying out the proposed experiments and tracing the variation of the flue gas opacity

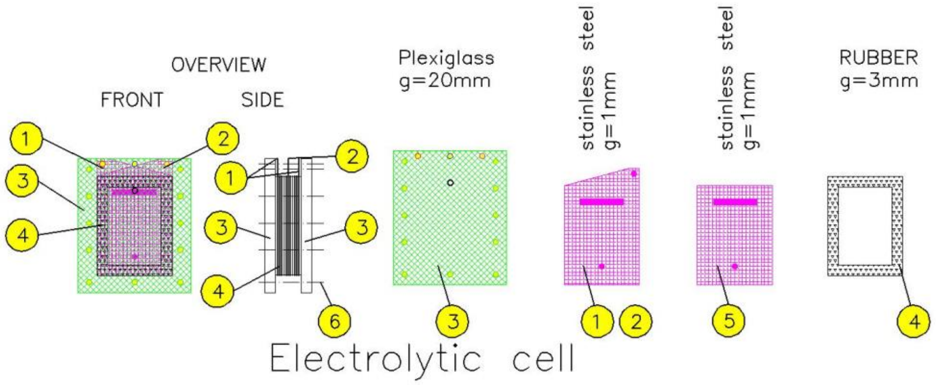

Figure 3. The components of the oxyhydrogen generator [6]

depending on the amount of HHO induced in the intake manifold, it can be clearly noticed that there is a tendency to reduce the opacity of the combustion gases for both p1 and p2 (Figure nr 4). This behavior might be explained by the reduction in the amount of diesel particles that is formed, due to a more complete burning, influenced by the presence of HHO. After the first flame cores occur, due to the self-ignition of the diesel fuel from the pilot injection, the entire mass of the mixture burns more quickly, more homogeneously and with a higher intensity. So the conditions at the beginning of the main injection will be more favorable, the combustion becomes even more homogeneous, and finally more complete.

Table 2. Measured values

	HHO feed pressure (p1, mmH2O)	HHO feed pressure (p2, mmH2O)	HHO volume flow rate (l/min)	Electrolysis Current (A)
D1	0.0	-	0.0	0.000
P1	3.5	-	0.1	2.400
P2	5.0	-	0.3	5.930
P3	8.0	-	0.7	12.66
D2	-	0.00	0.0	0.000
P4	-	167	0.1	2.400
P5	-	240	0.3	5.930
P6	-	300	0.7	12.66

5. Conclusion

Induction of oxyhydrogen in the intake manifold of turbocharged diesel engine, at low flow rates (up to 1 l/min), for 2 diferent HHO injection pressure are made. The following phenomena are observed:

The substantial reduction of flue gas opacity was found in both cases compared with conventional diesel operation;

Decrease the opacity of the flue gases with increasing amounts of added gas in both cases;

Flue gas opacity is lower in case of engine operation with diesel fuel enriched with HHO at 3000 Pa than 100 Pa.

At long-term use of an enriched fuel with HHO, the overall effect of reducing the opacity of the flue gases is observed for all cases considered.

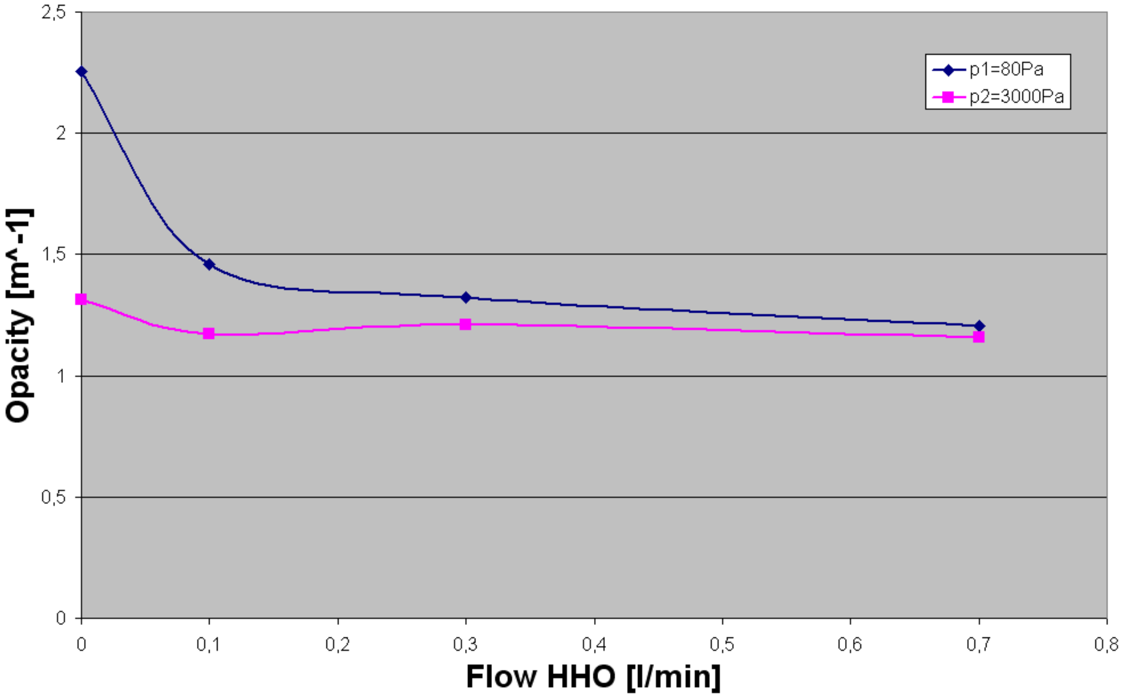

Figure 4. The smoke opacity variation for various flow of injected HHO

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