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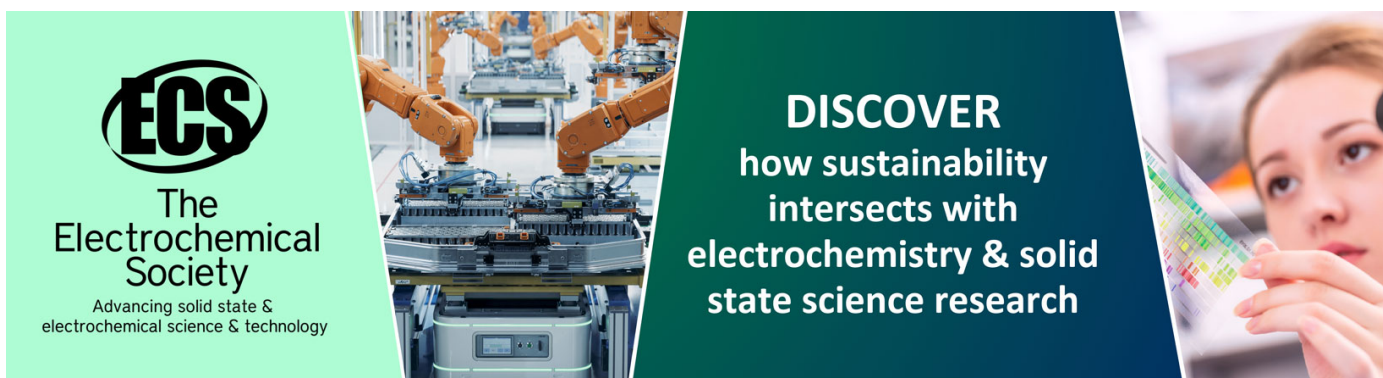
Test bench for studying the effects of water injection inside an internal combustion engine

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Test bench for studying the effects of water injection inside an internal combustion engine

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Abstract. Under the increasingly drastic conditions imposed on motor vehicles, in terms of pollution, manufacturers and researchers are looking for solutions to reduce pollutant emissions, especially emissions of nitrogen oxides (NO_x) dissipated in the atmosphere. The problem of polluting emissions in the field of transport is becoming increasingly stringent, the pollution rules are becoming stricter, so there is a general interest in finding solutions to reduce pollutant emissions and fuel consumption. A possible solution to this problem can be achieved by direct or indirect water injection (through the valve port) inside the cylinder of an internal combustion engine. In this paperwork we present the test bench and we analyzed the effect of water injection inside a cylinder of an internal combustion engine. The water injection is made upstream of the throttle valve by single injector mounted on the intake. The injection timing and amount of water injected inside the engine have been controlled by CompactRIO hardware device and in-house algorithm implemented in LabView. The engine used for measurements is a 1.6 liter engine, manufactured by Daewoo Motor Company and for the moment it's running on wasted spark configuration. So in order to have water particles in all the cylinders, the water is injected two times at each rotation of the crankshaft. The main goal of this research was decreasing of nitrogen oxides (NO_x) by reducing the combustion chamber temperature.

1. Introduction

The increase of thermal efficiencies obtained by an internal combustion engine is mainly the reason of increasing the compression ratios. However, the use of high compression ratios leads to higher combustion temperatures and creates favorable conditions for the formation of nitrogen oxide (NO_x) emissions.[1] Additionally, the higher compression ratios used in internal combustion engines leads to higher temperature in the later stages of the compression stroke and a higher temperature in the earlier stage of the combustion and expansion stroke, resulting in a rapid NO_x formation reaction rate. Minimizing NO_x is a well-known problem and it has been studied by many researchers.[2]

The method of implementing a water injection system would be one of the perfect solutions to inhibit NO_x formation. The heat is absorbed during the combustion stroke by the vaporization of water at high temperature which will form hydroxide and hydrogen. Besides the absorption of the heat during water vaporization, water provides oxygen for the burning process. The injected water also reduces the local temperature of the combustion flame and thus leads to lower NO_x emissions.[3], [4]

Fundamentally, water injection in the spark-ignition engine helps in controlling the temperature and pressure of the combustion process, thus giving an improvement in the volumetric efficiency of an engine and its power output.



Wu et al. [5] presented a new concept for combining the water injection process with an oxy internal combustion engine cycle for improving the thermal efficiency. The water injected into the cylinder after it was heated by passing it through the engine coolant and exhaust systems. Results showed that the thermal efficiency reached values from 53-67% when the water injected into the cylinder was at 120-200°C, moreover, the indicated thermal efficiency increased from 32.1% to 41.5%.

Boretta [6] used water injection in combination with a turbocharger, having ethanol as a fuel to explore the possibility of reducing the tendency to knock, increasing the charge efficiency and controlling the temperature of the air flowing into the turbine.

Cesur et al. [7] investigated the possibility of the engine using higher compression ratios and boost pressures and involved investigations of an original engine in combination with water injection.

Mingrui et al. [8] used water injection in combination with direct gasoline injection. Various tests with different water mass ratios were injected directly into the cylinder at the later part of the compression stroke. The optimum water ratio was determined at 15% for a certain cyclic dose, in terms of engine performance and emissions, the NO_x emissions were reduced by 34.6%. These conclusions were drawn from the comparison of the results obtained from the measurements of a water injection engine with those obtained from the measurements of a standard gasoline engine.

Kohketsu et al. [9] studied a new water injection system applied to a diesel engine, and by using an optimal combination of water and fuel concluded that total NO_x and particulate matter (PM) were reduced by 50% and respectively 25%, without an increase of fuel consumption.

The main purpose of direct water injection is the reduction of inlet temperature as a direct consequence of water vaporization, which results in a large decrease of temperature inside the combustion chamber at the latter stages of the compression stroke.

The present study presents preliminary experimental determinations using a four cylinder internal combustion engine, manufactured by Daewoo Motor Company connected to a water brake. The test bench and methodology is described in the next section.

2. Methodology and discussions

The test rig used for testing is presented below.

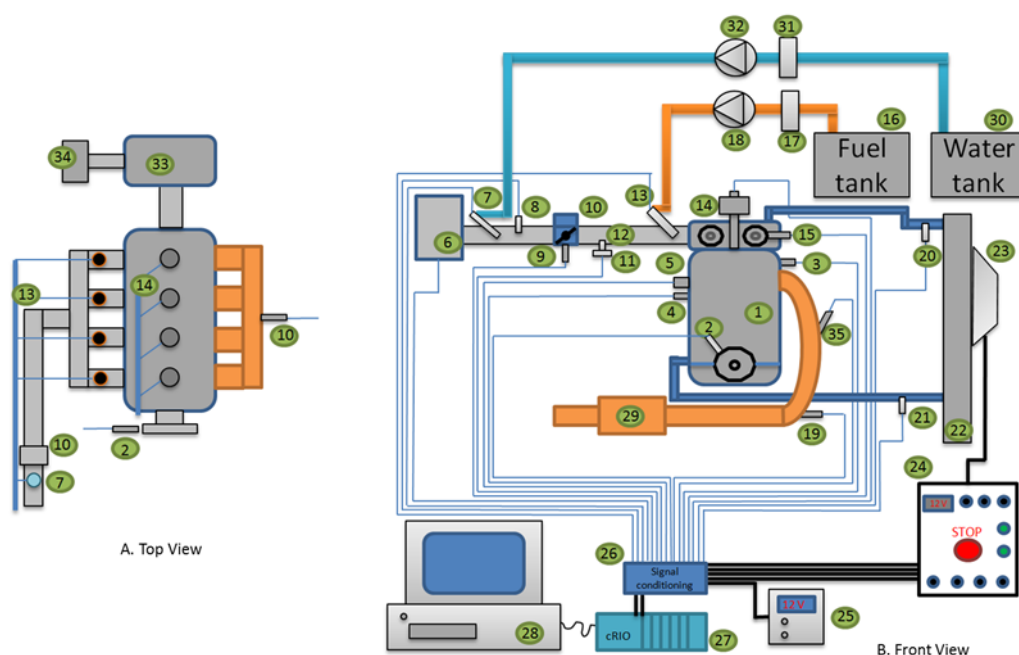


Figure 1. Schematic display of the experimental test bench

The system provides the possibility of using a standard fuelling and with the use of a single water injector mounted upstream of the throttle body as a function of the desired approach.

The experimental test engine has four cylinders and four valves per cylinder, and was manufactured by Daewoo Motor Company, with a power of 77kW and with a displacement of 1600cc connected to a water brake. The water brake 33 being set in motion by the water cooled internal combustion engine 1 which is started electrically by the startup system. The air enters in the internal combustion engine 1 through the intake manifold 12 after it passes the mass air flow sensor 6 and the throttle valve 10, and the exhaust gases are evacuated through the exhaust manifold 29. For controlling the air-fuel mixture, a plurality of sensors are used. The temperature of the air inside the intake manifold 12 is measured with the air temperature sensor 8, the pressure drop after it passes the throttle valve 10 is measured with a pressure sensor 11. The water temperature is measured in three locations, one at the exit of the cylinder head with the coolant temperature sensor 3, and two more temperature sensors mounted on the inlet 20 and outlet 21 of the heat exchanger 22. The air circulation through the heat exchanger is assured by the fan 23. The temperature of the exhaust gases is measured with the exhaust temperature sensor 19, the amount of oxygen in the exhaust gases is measured with a binary lambda sensor 35.

Engine operation is ensured by the fuel injectors 13 and ignition coils 14. Fuel is provided to the fuel injectors 13 from the fuel tank 16 by the aid of the fuel pump 18 through the fuel filter 17. The water injector 7, is placed upstream of the throttle valve which is provided with water from the water tank 30 by the aid of a water pump 32 through a water filter 31. The position of the crankshaft and camshaft is measured with two inductive sensors 2 and 15 mounted on two independent trigger wheels.

To prevent engine damage two important sensors are used, one for monitoring the oil pressure 4, and one for detecting knock 5.

For emergency situations the control panel 24 can be used to power on and off various subsystems like ignition, injection, fuel and water pumps, cooling fans, etc. All electric signals from the sensor and to the actuators are passing through the signal conditioning box 26. The controller 27 is a Compact RIO system made by National Instruments consisting of a real time power PC embedded controller for Compact RIO of 533MHz, with 2Gb storage and 256 Mb DRAM, a TTL digital module NI 9401 with 8-Channels, with a response time of 100 ns, and a 16-Bit analogic input module NI 9205 with 32-Channels having the input range of ± 10 V, and an acquiring frequency of 250 kS/s.

The internal combustion engine runs on an in-house algorithm implemented in LabView. The computer 28 is used for programming the cRIO system and for modifying and visualizing the working parameters. For powering the fuel pump 16, water pump 30 and the actuators (injectors and ignition coil) an external 12 V power supply 25 is used.[10]

Different loads are ensured by the water brake 33 and their power are quantified by the scale 34. For the case presented in the current study there, were made determinations using RON 95 gasoline as standalone fuel for the testing part.

Additionally we measure the pollutant emissions using a Capelec 3201 gas analyzer. This gas analyzer can measure the concentrations of hydrocarbons (HC), carbon monoxide (CO), and carbon dioxide (CO₂), Oxygen (O₂), nitrogen oxide (NO_x), RPM and oil temperature.

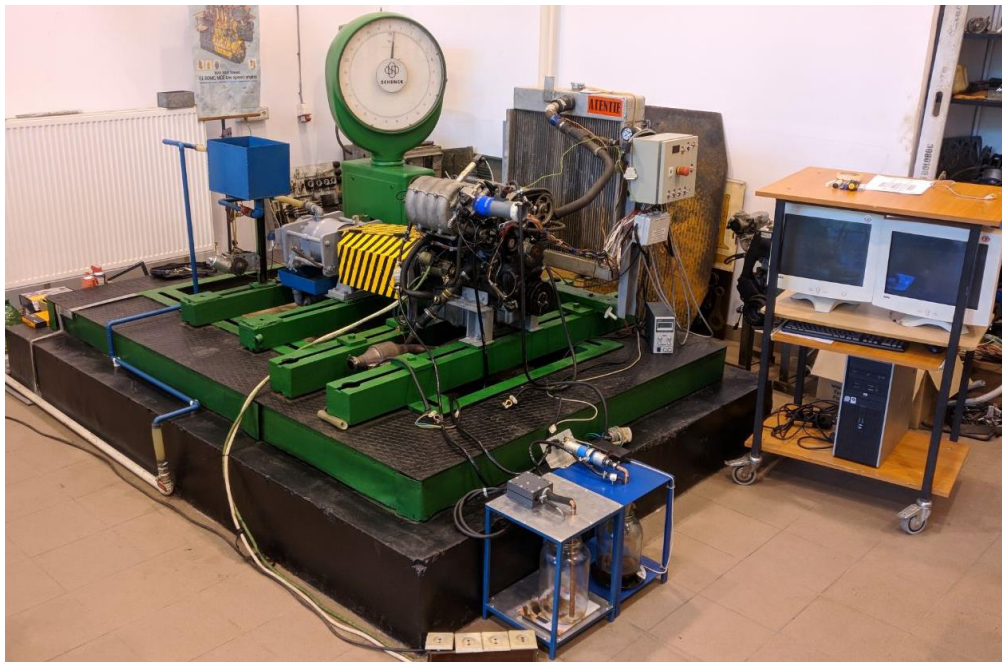


Figure 2. Experimental test bench

3. Experimental results

The main purpose of the experimental part was to observe the obtained power and the obtained emissions through the modification of the advance to spark ignition and fuel injection time. By modifying the injection time, we modify the fuel quantity introduced inside the cylinder, thus modifying the air-fuel ratio.

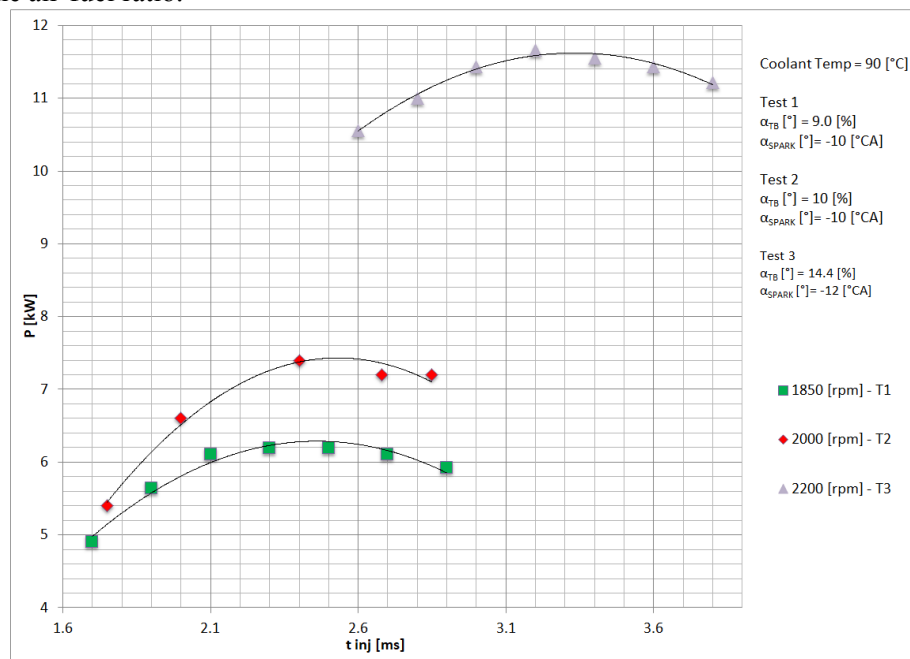


Figure 3. Power as a function of injection time

From Figure 3 we can observe that the engine power increases directly proportional with the increase of injection time, resulting in increased fuel consumption. In the literature [11] the maximum power of an internal combustion engine is achieved with an air-fuel ratio with lambda values of 0.95, this can be observed in Figure 4 that is achieved on the test bench at lambda values of ~ 0.95 [-].

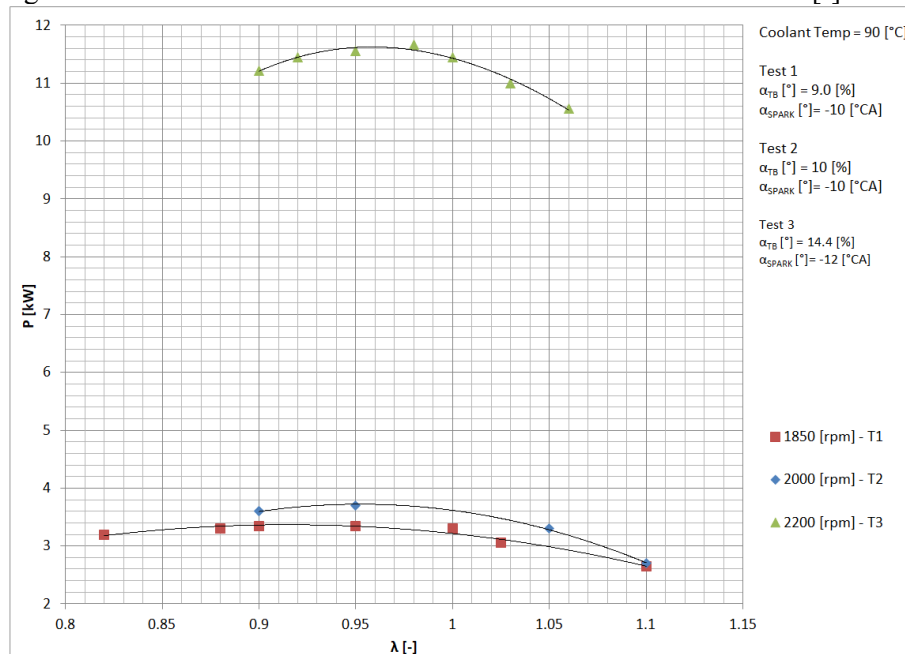


Figure 4. Power as a function of air fuel ratio

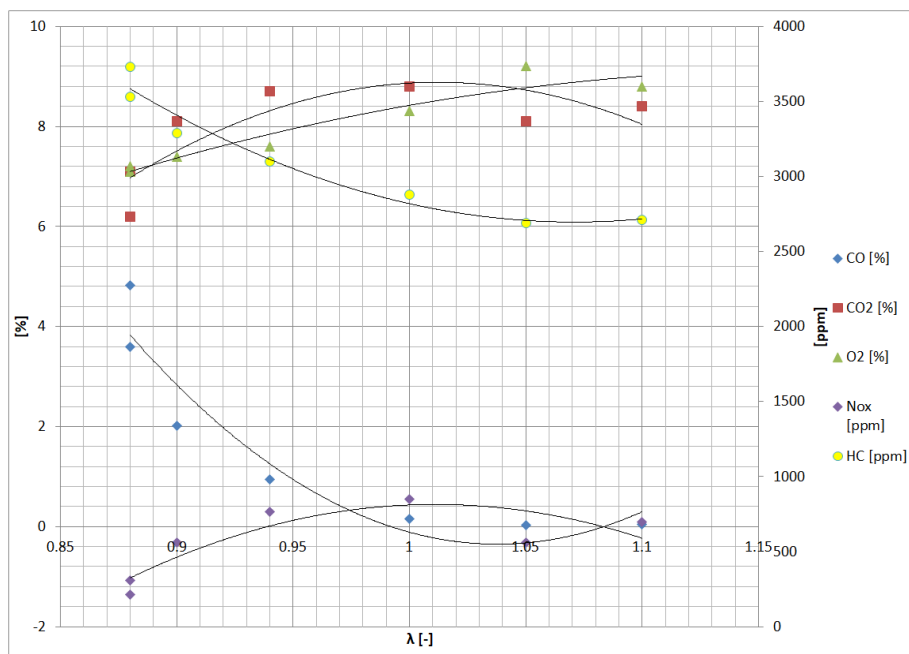


Figure 5. CO, CO₂, O₂, NO_x and HC emissions function of the air-fuel ratio

From Figure 5 the overall conclusion is that the CO emissions have a general decreasing tendency in relation with the increasing of the air-fuel ratio, while the CO₂ emissions have a general increasing

tendency, while O_2 increases from a point where all the oxygen in the air-fuel mixture burns out to a point where is an excess of O_2 .

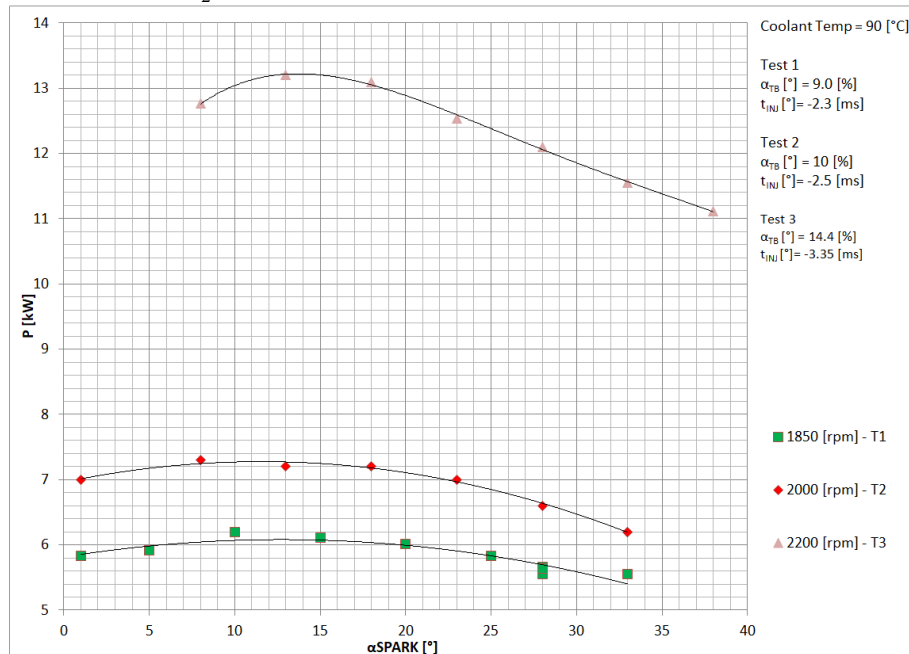


Figure 6. Power function of advance to spark ignition

From Figure 6 one can observe that the power has an increasing tendency proportional with the increase of the advance to spark ignition until a value of -14°CA . After this value the power starts to decrease, resulting the maximum power for which the advance to spark ignition is optimum.

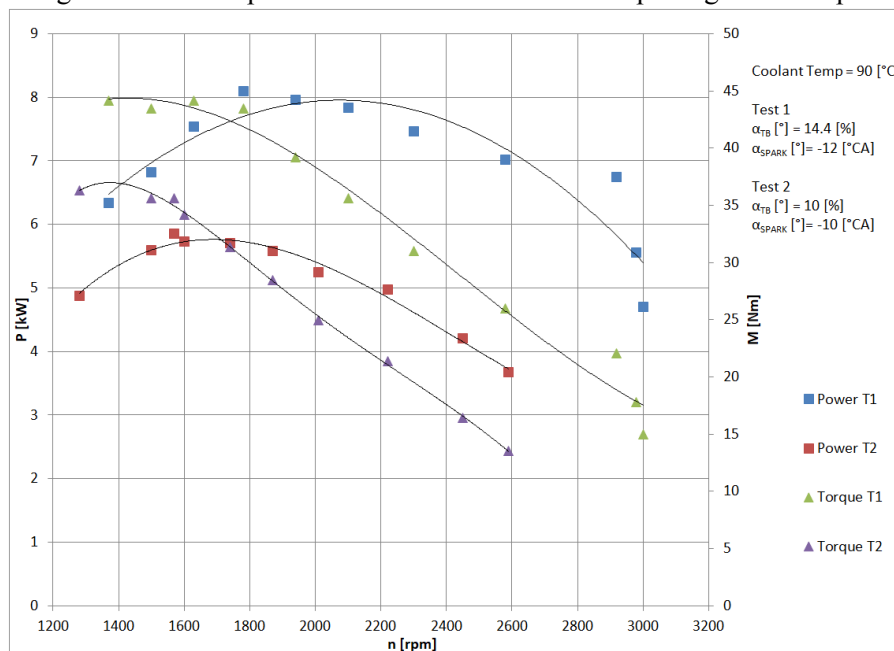


Figure 7. Partial load characteristics

From Figure 7 we can observe that both power and engine torque have a normal tendency as described in the literature.

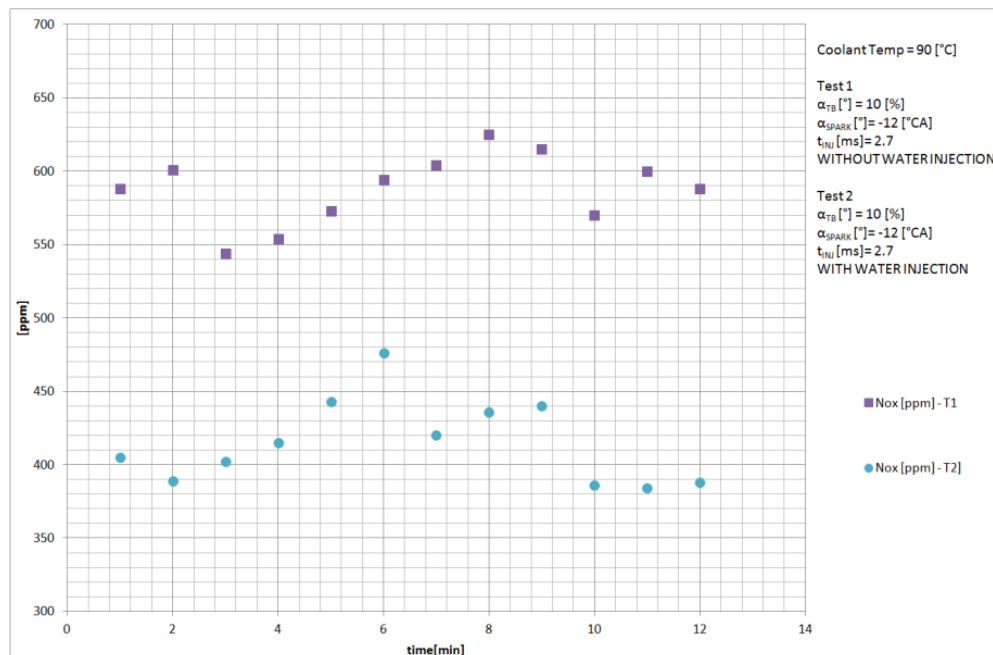


Figure 8. NO_x emissions with and without water injection

A simple test run was made under the same conditions with and without the water injection and in Figure 8 we can observe a decrease in NO_x emission values with an average of 30%. We also see that we have some high and some low peaks, they are due to the change of the water injection timing inside the combustion chamber, this means that we also have to find the correct timing of the water injection, not only the quantity.

4. Conclusions

After the tests it was determined that the spark ignition advance and injection time have a normal tendency as described in the literature [11], so we can observe that the test bench can provide us with constant valid data with little error deviations. The test bench will be improved by adding some extra sensors to record more parameters electronically.

According to Mingrui [8] he achieved a reduction of NO emissions up to 34.6% on average, for injecting 15% of water for a given mass of fuel. This thing can be observed that we reduced the NO emissions with an average of 30%.

A general conclusion is that water injection is a good field of study and without many published results.

Acknowledgment

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References

- [1] Alkidas A C 2007 Combustion advancements in gasoline engines, *Energy Convers. Manag.* **48**(11) 2751-2761
- [2] Fennell D, Herreros J and Tsolakis A 2014 Improving gasoline direct injection (GDI) engine efficiency and emissions with hydrogen from exhaust gas fuel reforming, *Int. J. Hydrogen Energy* **39**(10) 5153-5162
- [3] Nande A M, Wallner T and Naber J 2008 Influence of Water Injection on Performance and Emissions of a Direct-injection Hydrogen Research Engine, *SAE International* 2008-01-

2377

- [4] Subramanian V, Mallikarjuna J M, and Ramesh A 2007 Effect of water injection and spark timing on the nitric oxide emission and combustion parameters of a hydrogen fuelled spark ignition engine, *Int. J. Hydrogen Energy* **32**(9) 1159-1173
- [5] Wu Z J, Yu X, Fu L Z, Deng J, Hu Z J and Li L G 2014 A high efficiency oxyfuel internal combustion engine cycle with water direct injection for wasted heat recovery, *Energy* **70** 110-120
- [6] Boretti A 2013 Water injection in directly injected turbocharged spark ignition engines, *Appl. Therm. Eng.* **52**(1) 62-68
- [7] Cesur I, Parlak A, Ayhan V, Boru B and Gonca G 2013 The effects of electronic controlled steam injection on spark ignition engine, *Appl. Therm. Eng.* **55**(1) 61-68
- [8] Mingrui W, Sa N T, Turkson R F, Liu J P and Guo G L 2017 Water injection for higher engine performance and lower emissions, *Journal of the Energy Institute* **90** 285-299
- [9] Kohketsu S, Mori K, Sakai K and Nakagawa H 1996 Reduction of Exhaust Emission with New Water Injection System in a Diesel Engine, *SAE Transactions* **105** 74-81
- [10] Stoica V, Borborean A, Ciocan A and Manciu C 2017 Minimal algorithm for running an internal combustion engine, *IOP Conf. Ser.: Mater. Sci. Eng.* **294** 012036
- [11] Reif K 2015 *Gasoline Engine Management*, Springer Vieweg, Friedrichshafen, Germany