The influence of water injected on the reduction of NOx emissions in Diesel engine

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Abstract. In recent years, diesel engine manufacturers have been looking for ways to reduce NOx emissions and smoke emissions to meet increasingly stringent standards. Although there are exhaust gases treatment methods to reduce NOX emissions, attempts are being made to control their production in the cylinder. Various methods are used to control the production of NOx in the cylinder: flue gas recirculation, multiple fuel injections. These methods lead to increased fuel consumption and pollutant emissions. To reduce the emission of NOx, the temperature in the combustion chamber must be reduced. By introducing water into the combustion chamber, the desired effect is obtained. In this paper we have studied the effect of lowering the temperature in the combustion chamber on the power of the engine and the emissions of NOx and particles. The study was made on a Renault 4-cylinder diesel engine, water cooled. During operation, a quantity of 5%, 10% and 20% of the amount of diesel introduced into the cylinder was injected into the intake manifold. During the tests, the engine power decreases with 3%. NOx emissions decreased by up to 22%, but particulate emissions increased by about 36%.

1. Introduction

In the context of declining oil reserves, the use of diesel engines has expanded, which has the following advantages: high efficiency, high engine torque and low fuel consumption. The disadvantages of diesel engines are NOx and particulate emissions [1]. NOx emissions are harmful to the human body and the environment [2]. Various options have been tested to reduce emissions and comply with regulations: exhaust gas recirculation, increased injection pressure, variable distribution, injection strategies, renewable fuels, mixtures of fossil fuels and renewable fuels, exhaust gas treatment [3]. The increase in the number of engines used in industry has led to an accelerated increase in fossil fuel consumption, which will lead to depletion of crude oil reserves and increased pollutant emissions. Engine manufacturers are forced to increase the thermal efficiency of engines and reduce pollutant emissions.

One method of reducing NOx emissions is to introduce a quantity of water into the cylinder. The water reduces the combustion temperature and thus decreases the quantities of NOx formed [4].

Three methods can be used to introduce water into the cylinder: water emulsion (introducing a water-diesel mixture into the cylinder), injecting water in the inlet manifold or injecting water into the cylinder [5].

The first method (water emulsion) involves modifying the injection equipment to supplement the dose of emulsion introduced into the cylinder.

The third method involves equipping the engine with a new injector for each cylinder, which involves high costs and technological complications. [6].

The method of injecting water into the intake manifold is a simple and inexpensive method.

This paper presents the influence of water injection in the inlet manifold on engine power, NOx and particulate matter emissions. To obtain the standard value of the engine, the tests starts with the engine fuelled with regular fuel. The experiments were repeated with water injections. The results are presented in comparison with the standard value of the engine.

2. Method

A Renault K9K engine was used for the tests. Figure 1 show the test scheme used. In Table 1 are presented the engine specifications.

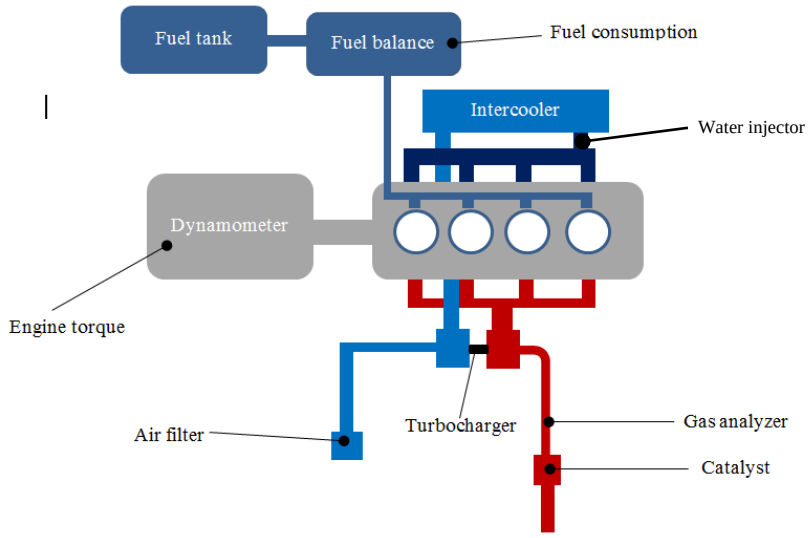

Figure 1. Test setup.

Table 1. Engine specifications.

Engine type	Renault K9K 720
Cylinder number	4
Bore & stroke	76 &80.5 mm
Total displacement	1451 cm^3
Compression ratio	15.3:1
Maximum power	72 kW @ 3700 rpm
Maximum torque	200 Nm @ 2700 rpm
Injection system	Common-rail direct injection
Cooling	Water

The Dynas3 LI250 dynamometer was used to measure the engine power. Engine power was measured at 2% accuracy.

The tests were made at 4 engine loads (25%, 50%, 75% and full load), at the speed corresponding to the maximum torque (2700 rpm).

The amount of water introduced into the cylinder was 5, 10 and 20% of the instantaneous engine consumption. Engine power, NOx and particulate matter emissions were monitored.

An electronic system was used to control the amount of water, which varied the opening time of the injector.

NOx emission was measured with an HGA 400 apparatus.

The particulate emission was measured with the AVL 415 S Smokemeter.

The temperature at which the tests were performed was 20^{o}C and the air humidity was 48%.

The temperature of the water introduced into the cylinder was 20^{o}C, and the pressure was 4 bar.

3. Results

3.1 Engine Power

As seen in Figure 2, when the water is injected, decreases of power were obtained for all loads. The power produced by the engine when it was fuelled with mineral diesel was 63.8 kW. When the water was injected, the maximum power decreased with 3 % for 20% water at 100% load. At low loads, the power variation is small.

The presence of water in the air introduced into the cylinder leads to a change in the amount of oxygen available for burning fuel. This reduces the AFR, which leads to a worsening of the burning speed. In addition, some of the energy developed by burning fuel is used to evaporate water.

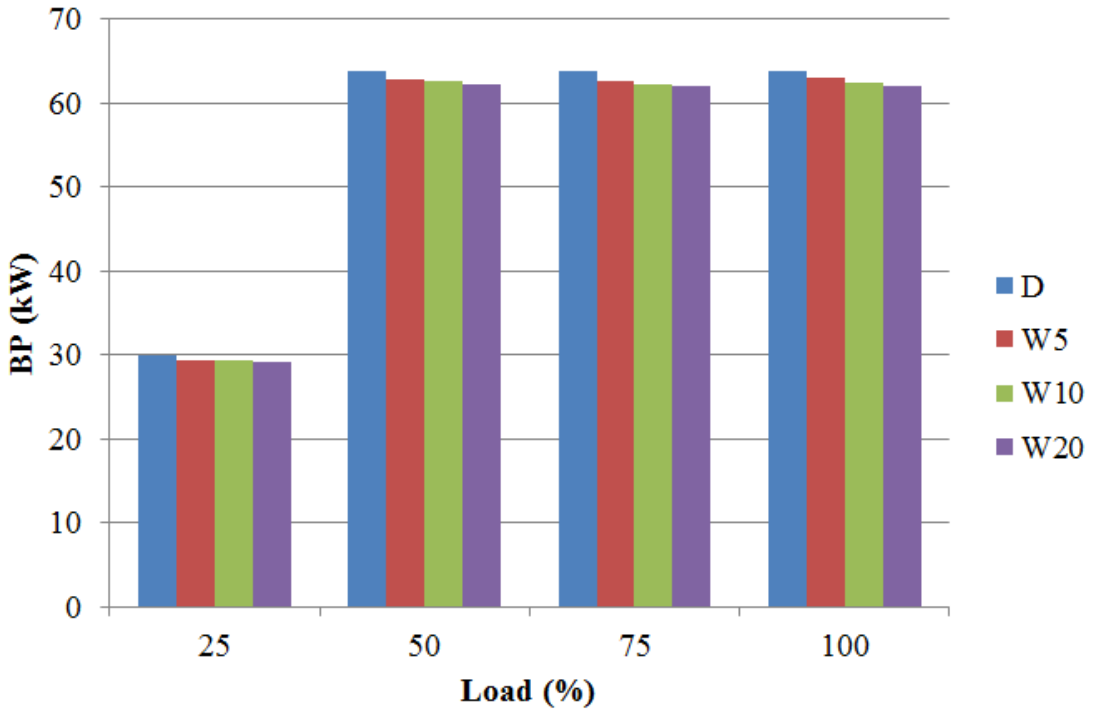

Figure 2. Engine power.

3.2 NOx emissions

In Figure 3 is presented the NOx emission of the engine. NOX emissions decrease as the percentage of water increases. The main factor for the formation of NOx emission is the maximum temperature in the cylinder. The emission of NOx is favoured by the high temperature in the cylinder. The water in

the combustion chamber reduces the combustion temperature. The emission of NOx decreases with the increase of the percentage of water.

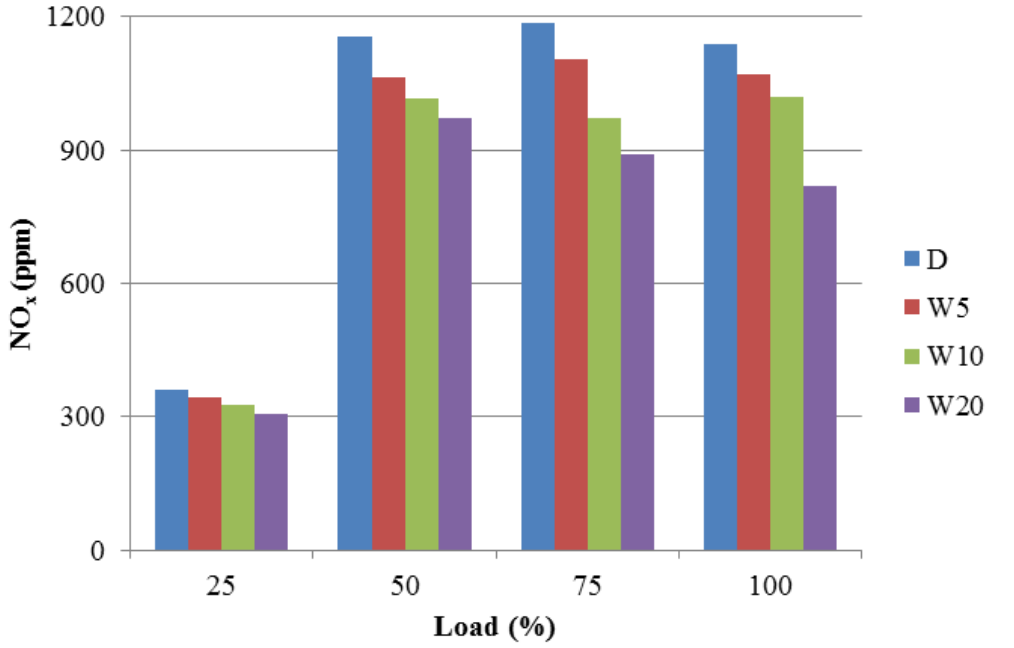

Figure 3. NOx emissions.

3.3 Smoke emissions

The particulate emission is shown in Figure 4. It is observed that the emission of particles increases with the increase of the percentage of water. Increased particulate emissions are a consequence of reduced AFR and cylinder temperature, which reduces soot oxidation.

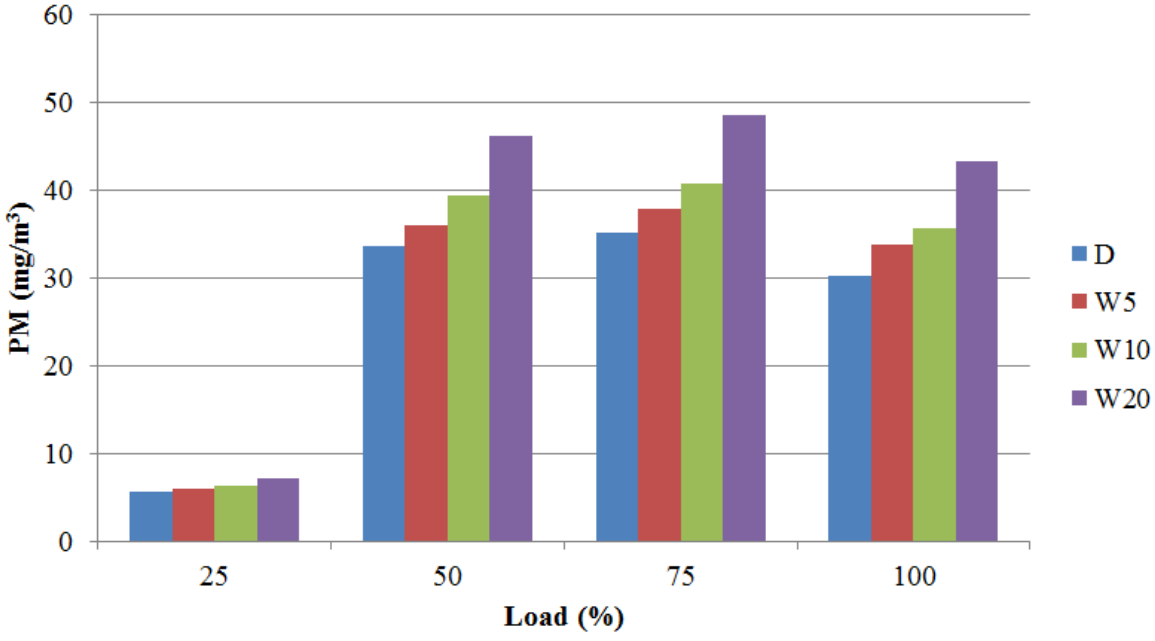

Figure 4. Smoke emissions.

4. Conclusions

snThis study shows the variation of power, noxious emissions and particles obtained by injecting water into the cylinder. The tests were performed using a quantity of water of 5, 10 and 20% of the engine consumption (dose / cycle). The engine used in the tests is a Renault K9K engine, and the tests were performed at a speed of 2700 rpm, and for 25%, 50% 75% and 100% load.

The effective power of the engine decreased due to the presence of water in the combustion chamber. In the case of fuelling the engine with diesel, the power obtained was 63.8 kW, and for the 20% water injected in the intake manifold the power decrease with 3%

NOx emission decreases with increasing percentage of water introduced into the engine. By introducing water into the cylinder, the combustion temperature decreases, and NOx formation is lower. The variation of the NOx emission is inversely proportional to the amount of water used.

Particle emissions increase with increasing amount of water. Due to the decrease in the amount of oxygen and the temperature in the cylinder, the oxidation of soot particles is reduced, which are discharged into the atmosphere.

5. References

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