Effect of ozone addition on working parameters of diesel engine

K Prajwowski¹ T Osipowicz¹ and Ł Mozga¹

¹West Pomeranian University of Technology Szczecin, al. Piastów 19, 70-310 Szczecin, PL
E-mail: tosipowicz@zut.edu.pl

Abstract. One of the methods of improving the operating parameters of internal combustion engines is increasing the oxygen content in the air supplied to the combustion chamber by supplying ozone to the intake system or to the working space of the engine. It is advantageous to make the surface of the engine intake system in a rough or ribbed form. This causes turbulence in the supplied air with ozone, which may increase the efficiency of ozone in contact with the fuel in the combustion chamber. The article presents the results of tests carried out on dynamometric stands with compression-ignition engines. The test object was the FIAT 1.3 JTD MULTIJET engine. The main aim of this work is to determine the effect of ozone on engine operating parameters and the toxicity of exhaust gases. In particular test cycles the ozone was fed into the suction manifold and, along with the sucked air, fed to the combustion chamber. The test results include power and torque measurements for 100%, 50% and 10% of the maximum engine load.

1. Introduction
The impact of ozone on the work of internal combustion engines has interested researchers for a long time, due to its strong oxidizing properties. The results of experiments carried out so far for drive units with different combustion systems show the benefits resulting from such an addition, especially in terms of fuel consumption (including gas fuel) and the improvement of exhaust gas toxicity. The introduction of ozone with inlet air results in lower CO, HC (or THC), soot emission and a small increase in NOx [2, 4, 5, 10]. Despite the use of different generation techniques, positive results were observed even at low concentrations. It is worth emphasizing that the improvement of economic and ecological properties was obtained for SI and CI engines [4]. Nevertheless, in this matter the results of operational tests, showing for example the impact of the addition of ozone on dynamic parameters of the drive unit, are still missing. This is due to the fact that the majority of the experiments were conducted in reactors specially prepared for this purpose and the examples can also be found in the national literature [11, 13].

2. Measurement methodology
During the tests, the FIAT 1.3 JTD MultiJet engine was fed with diesel oil complying with PN-EN 590+A1:2017-06 [7,9]. Measurements of parameters were carried out in the range of rotational speeds of the crankshaft: 1000-4400 rpm at the maximum fuel dose. In selected cycles, ozone was supplied through the nozzles to the air filter before the air flow meter (fig. 1). Obtained results for the engine with the ozone supplied and, for the comparison, without ozone were divided into two groups, which were used to determine a number of external characteristics of the tested engine.
3. Research stand

Research centres in order to determine the actual parameters of the engine which are named the engine operating parameters, such as power, fuel consumption, etc., perform specific tests in a special laboratory on a test bench called an engine test bench. Depending on the needs, the scope of research can be very diverse: from primitive power measurements and fuel consumption, to complex scientific research depending on the engine test bench equipment. The research shown in Figure 2 was carried out on the test stand at the Department of Automotive Engineering at ZUT (West Pomeranian University of Technology) in Szczecin, Poland.

**Figure 2.** Scheme of the test bench with FIAT 1.3JTD MultiJet engine
1 – AMX212F measuring instrument, 2 – 1.3JTD engine, 3 – AMX 100 brake, 4 – coolant thermometer, 5 coolant thermometer, 6 – coolant tank, 7 – exhaust gas temperature meter, 8 – MDO 2 opacimeter with a control panel,

One of the most important elements on the test bench is the brake imposing a load to the FIAT 1.3JTD MultiJet combustion engine with smooth regulation of the set load value. During the tests, the
AUTOMEX AMX 100 electromotive brake was used, along with the AUTOMEX AMX 212F mass measuring device as well as control and measurement instrumentation (power panel, Fiat Panda 2 dashboard, PC with PARM software). To measure smoke opacity, the MAHA MDO 2 opacimeter and IMR 1500 exhaust gas analyser were used which indicated $O_2$, $CO$, $CO_2$, $NO$, $NO_x$, $\lambda$. Ozone was produced outside the engine using an OZ-1G/OZ-B1000 generator with an output of 1000 mg/h.

The FIAT 1.3JTD MultiJet engine has been equipped with systems that ensure carrying out the experiment in accordance with PN-ISO 15550: 2009 [8]. The basic technical data of the tested engine is summarized in Table 1. It is a turbocharged, four-cylinder diesel unit with a direct injection system of the MultiJet Common Rail type.

### Table 1. Basic technical data of Fiat 1.3 JTD 16V MULTIJET engine[14]

| Parameter                           | Description               |
|-------------------------------------|---------------------------|
| Number of cylinders                 | 4                         |
| Cylinder layout and arrangement     | in-line, transversely in front |
| Engine cubic capacity [cm³]         | 1248                      |
| Cylinder diameter [mm]              | 69.6                      |
| Piston stroke [mm]                  | 82                        |
| Compression ratio                   | 18.1                      |
| Maximum power [KM/kW]               | 70/51                     |
| Rotational speed at max. power [rpm]| 4000                      |
| Maximum torque [kNm]                | 0.145                     |
| Rotational speed at max. torque [rpm]| 1500                     |

### 4. Results and discussion

The addition of ozone has contributed to the improvement of the dynamic parameters of the tested engine, wherein the tangible benefits can be observed only in the range of higher rotational speed of the crankshaft. After crossing $n = 2800$ rpm the differences in effective (useful) power were reaching 4.1% and 4.0% for torque, at maximum load. For 50% of the maximum load there is a decrease in power and torque. This effect was obtained without the software modification controlling the
operation of the drive unit, whereby there is a possibility of correcting for the improvement of the quality of the exhaust gases. Some analogy in increasing the performance by adding ozone can be found in the publication [5]. However, it should be emphasized that in HCCI (homogeneous charge compression ignition) engines, not the air but the prepared mixture is compressed which, at a short duration of this process and low temperatures, results in a very low level of smoke and NOx emission.

![Figure 4. External and partial characteristics (50% of total power)](image)

The analysis of the curves shown in Figure 5 shows that the addition of ozone has improved the economy of the engine. In this aspect, the characteristics of specific fuel combustion are clearly visible, which for such completion is lower in almost the entire range of the considered rotational speeds. This is confirmed by the results of the research presented in the publication [4].

![Figure 5. Specific fuel combustion with ozone and without ozone supplied](image)
The authors also obtained a reduction in fuel consumption at low ozone concentrations, whereby it was generated in a different manner, i.e. by corona discharge in the air flow of the pre-combustion chamber of the drive unit. In the environmental aspect, the most important problems of CI engines are smoke opacity and emissions of nitrogen oxides. Unfortunately, the simultaneous reduction of these threats is very difficult, and the applied solutions are sometimes opposing. This is evidenced by the course of external characteristics from Figure 6. The ozone addition has resulted in a significant reduction of soot in the exhaust gas, which is visible in the area of high rotational speeds of the crankshaft.

However, this was at the cost of NOx, the emission of which was greater from 4,2% (n=3000 rpm) to 2,0% (n=4000 rpm), at the biggest difference in emission of 9,98% (n=3400 rpm). This effect can be explained by the increase of combustion temperatures which, with a significant excess of air in turbocharged engines, creates favourable conditions for these compounds formation [3]. In CI engines
the release of carbon monoxide usually takes place parallel to the formation of soot [12]. This is confirmed by the curves shown in Figure 8. However, it should be emphasized that in the range of all rotational speeds, the addition of ozone had a clear negative effect on the amount of this compound in the exhaust gas. For example, at n =1400 rpm CO emission increased by nearly 78.8% for the maximum load, where for 50% of the maximum load CO has decreased. The research presented in the publication [10] shows that for fuels with a high cetane number, and thus provided for modern diesel engines, reduction of carbon monoxide is possible at high concentrations of ozone in the supplied air.

![Figure 8. Carbon monoxide with ozone and without ozone supplied](image)

5. Conclusions
The influence of ozone on the work of internal combustion engines is a subject of high interest to researchers. From the point of view of the environmental protection, the reduction of toxicity of exhaust gases emitted by internal combustion engines is currently one of the most important problems. The subject matter presented in the work is current and is characterized by a large practical aspect. The obtained results showed that the introduction of ozone along with the inlet air results in a reduction of NOx emissions and reduces smoke opacity. It should be noted that one ozone concentration was used in the work, which was introduced before the air filter. A more accurate assessment of the drive unit operation requires further testing for various ozone concentrations as well as for different dosage points.

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