



Report

For
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Evaluation of the effects of Militec-1® on the fuel consumption and exhaust emissions of a diesel engine

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Summary

A single-cylinder diesel engine was used to evaluate the effects of the synthetic based metal conditioner marketed as Militec-1® on the engine fuel consumption and exhaust emissions. First, baseline tests without Militec-1® were carried out and values for fuel consumption, smoke, nitrogen oxides (NO_x), unburnt hydrocarbons, carbon monoxide (CO) and carbon dioxide (CO₂) were recorded. Militec-1® was then added to the oil reservoir and tests were carried out under the same operating conditions as the baseline tests. The effects of Militec-1® are presented and discussed in the following sections.

1. Experimental Set-up and Test Conditions

The experiments were carried out using a 773 cm³, naturally aspirated, air-cooled, single-cylinder, direct injection, diesel engine. The main engine specifications are: bore 98.4 mm, stroke 101.6 mm, conrod length 165.0 mm, compression ratio 15.5, maximum power 8.6 kW at 2500 rpm and maximum torque 39.2 Nm at 1800 rpm. The engine test rig is instrumented for research purposes. An electric dynamometer with a motor and a load cell is coupled to the engine and used to load and motor the engine. Instrumentation includes thermocouples to measure oil, air, inlet manifold and exhaust temperatures, pressure gauges mounted at relevant points, air and fuel flow measuring devices as well as normal engine test bed safety features. A pressure transducer (KISTLER 6125B) mounted flush at the cylinder head and connected via a charge amplifier (KISTLER 5011) to a data acquisition card is used to record the cylinder pressure. The crankshaft position is measured using a digital shaft encoder.

An AVL Digas4000 analyser was used to measure NO_x, CO, and CO₂, by NDIR (nondispersive infrared gas analysis), and oxygen-O₂ concentrations in the exhaust (electrochemical method). Additional measurements of NO_x were carried out using a chemiluminescence analyzer. Hydrocarbons were measured with a heated FID (flame ionization detector). Smoke was measured using an EFAW 68A Bosch smoke meter. Atmospheric conditions (humidity, temperature, pressure) were monitored during the tests. Data acquisition and combustion analysis were carried out using LabVIEW based developed software. The estimated uncertainties of measurement are shown in Table 1.

Tests at ten different operating conditions were performed. Following the baseline tests, 2oz of Militec per litre of lubricating oil were added to the standard engine oil. The engine was then run-in for 25 hours prior to testing with Militec. There was no oil change between testing. Table 2 shows the engine speed and load (torque) values for each of the ten tested operating conditions. The actual values of speed and torque as well as the corresponding values of power and brake mean effective pressure¹ (BMEP) are presented in Tables 3 and 4 (first four columns) for the tests without and with Militec addition, respectively. Apart from engine speed and torque all the other engine operating parameters were fixed. The injection timing was 22 CA (crank angle) degrees BTDC (before top dead centre) in all cases. All the tests were carried out with ultra low sulphur diesel fuel.

2. Results and Discussion

The measured and calculated values obtained from the tests are shown in Tables 3 and 4. The presented values are averages of three readings. In all cases the repeatability was excellent and hence only the average values are given in this report.

¹ Measure of engine work output.

Figure 1 shows the **brake specific fuel consumption**² (BSFC) plotted against engine speed for the three different tested engine loads. It is evident that BSFC values were lower for tests with Militec compared to operation without Militec addition. The improvement ranged from approximately 1.4% to just below 7% (at 1000 rpm, 30 Nm). Only in one case higher BSFC was recorded with Militec compared to operation without addition (1500 rpm, 10 Nm). However, the difference in this case was below 1%, which is within experimental error (see Table 1). Overall, it can be stated that Militec addition resulted in fuel economy improvements.

The most important issue for diesel engines in terms of exhaust emissions is the reduction of particulate and nitrogen oxides (NOx) emissions. The well known particulate-NOx trade-off makes their simultaneous reduction very challenging. In this work, particulate emissions were not measured but the measured smoke emissions (expressed in Bosch Smoke Number units, BSN) provide a good indication. The obtained **smoke emissions** and **brake specific nitrogen oxides** (BSNOx) values are presented in Figures 2 and 3, respectively. Militec addition resulted in reduced smoke emissions (only in one case smoke was unaffected). In most cases the reduction was not more than 0.2 BSN units but, nevertheless, it is clear that a systematic smoke emission reduction was obtained with Militec addition. On inspection of the BSNOx values shown in Figures 3, it appears that in all the tested cases at 1000 and 1500 rpm there was a considerable reduction of NOx emissions when Militec was added. Reductions of over 10% were achieved in most cases. At the higher speed of 2000 rpm the NOx emissions at the mid and high load conditions were not improved with Militec. However, considering that at these conditions smoke was reduced, it is evident that overall Militec resulted in improved emissions in all the tested cases.

This argument is further supported by the obtained **brake specific hydrocarbons** (BSHC) values, shown in Figure 4. In all cases BSHC were improved when Militec was added. The improvements were very impressive ranging from approximately 15% at 2000 rpm to over 30% at 1500 rpm and over 40% at 1000 rpm. The **carbon monoxide** emissions presented in Tables 3 and 4 (expressed in vol. % of exhaust gas), were either reduced or not affected by the addition of Militec. As expected, the CO emissions of the diesel engine were low and there was not much room for improvement.

Carbon dioxide is a product of complete combustion that does not impair human health directly. Traditionally it has not been included in engine emission regulations but it is now seen as an important pollution concern because it is a greenhouse gas associated with global warming. Thus, CO₂ measurements (vol. % of exhaust gas) are given in Tables 3 and 4 for completeness of the test results with and without addition of Militec.

For selected test cases, the obtained cylinder pressure measurements were used for combustion analysis. Two indicative graphs are presented in Figures 5 and 6 where the **cylinder pressure** and **net heat release rate** (HRR) vs. crank angle have been plotted for the tests carried out with and without Militec at 1500 rpm (Figure 5) and 2000 rpm (Figure 6) and 30 Nm engine load. The graphs indicate that the peak cylinder pressure was not affected by the addition of Militec. Although a slight delay of the combustion process is indicated by Figure 6, the differences seen at other engine speeds and loads were small and within experimental error, therefore no definite conclusions can be drawn.

3. Conclusions

Addition of Militec to the engine oil affected both fuel consumption and exhaust emissions. Although not all fuel consumption differences (%) were large, Militec resulted in overall improvements in engine fuel economy. This obviously can be very beneficial in terms of fuel

² Rate of fuel consumption per unit power output.

savings over engine duty cycles. Militec addition was also beneficial in terms of smoke emissions accompanied in most cases by a considerable reduction of NO_x emissions. A rather impressive reduction of unburnt hydrocarbon emissions was achieved when the engine was operated with Militec. Carbon monoxide emissions were also measured and it was found that, overall, the CO emissions were either improved or unaffected when Militec was used (the CO emissions were low in all cases).

Obtained cylinder pressure data was used to perform standard combustion analysis, i.e. cylinder pressure trace as well as heat release analysis but the observed differences were mostly small and within the experimental error range.

No adverse effects on the engine and its operation were observed during the engine testing with Militec.

Investigation of the chemical make-up of Militec was not undertaken; therefore it is not possible to comment on the molecular behaviour of Militec and its interaction with the engine surface.

TABLES

Table 1. Accuracy of measurements.

Measurements	Accuracy
NO _x	1ppm (Digas 4000) and 5 ppm (Chemiluminescence)
CO	0.01%
CO ₂	0.01%
HC	1ppm
Smoke (BSN)	0.1
Time (fuel flow rate measurement)	0.5%
Speed	5 rpm
Torque	0.2 Nm
Computed Results	Uncertainty
Fuel volumetric rate	1%
Brake specific fuel consumption	1.5%
Break mean effective pressure	1%
Power	1%

Table 2. Engine test conditions.

	Idle	Low Load			Mid Load			High Load		
Load [Nm]	0	10	10	10	20	20	20	30	30	30
Speed [rpm]	900	1000	1500	2000	1000	1500	2000	1000	1500	2000

Table 3. Engine conditions, emissions and fuel consumption **without** Militec-1®.

Engine Speed [rpm]	Torque [Nm]	BMEP [bar]	Power [kW]	Air Flow [cc/s]	Fuel Mass [g/h]	NOx [ppm]	NOx [g/kWh]	HC [ppm]	HC [g/kWh]	Smoke [Bosch Number]	CO [%]	CO ₂ [%]	Exhaust Temp. [°C]	BSFC [g/kWh]
900	0.0	0.0	0.0	4798	174.2	226	-	209	-	0.05	0.03	1.8	120	-
1000	9.5	1.5	1.0	5230	350.8	526.7	14.69	231	30.07	0.2	0.02	3.6	185	352.6
1000	19.5	3.2	2.0	5227	570.8	762.6	9.06	267	17.05	1.6	0.05	5.6	270	279.5
1000	29.5	4.8	3.1	5155	863.3	1168.8	7.27	420	17.58	2.8	0.542	8.8	376	279.5
1500	10.3	1.7	1.6	8698	552.7	409.9	10.85	249	32.81	0.2	0.02	3.3	213	341.6
1500	20.3	3.3	3.2	8528	799.7	768.4	9.69	243	16.08	0.3	0.01	5.07	279	250.8
1500	30.3	4.9	4.8	8329	1081.0	1240.1	9.18	270	11.79	0.6	0.01	7.01	370	227.1
2000	12.2	2.0	2.6	11472	799.7	525.6	11.11	253	27.73	0.2	0.02	3.6	241	313.0
2000	22.2	3.6	4.6	11305	1228.3	795.8	8.50	260	15.63	0.4	0.018	5.8	332	264.2
2000	32.2	5.2	6.7	11045	1604	1191.8	7.80	331	13.51	0.6	0.02	8	431	238.0

Table 4. Engine conditions, emissions and fuel consumption **with** Militec-1®.

Engine Speed [rpm]	Torque [Nm]	BMEP [bar]	Power [kW]	Air Flow [cc/s]	Fuel Mass [g/h]	NOx [ppm]	NOx [g/kWh]	HC [ppm]	HC [g/kWh]	Smoke [Bosch Number]	CO [%]	CO ₂ [%]	Exhaust Temp. [°C]	BSFC [g/kWh]
900	0.0	0.0	0.0	4725	170.4	187.7	-	123	-	0.05	0.03	1.67	119	-
1000	9.8	1.6	1.0	5236	357.0	438	11.8	131	16.57	0.1	0.02	3.3	181	347.8
1000	19.8	3.2	2.1	5254	568.7	680.7	8.0	152	9.59	1.0	0.048	5.3	269	274.2
1000	29.8	4.8	3.1	5028	812.9	1048	6.4	232	9.37	2.6	0.385	8	375	260.5
1500	11.3	1.8	1.8	8718	611.6	379	9.1	178	21.49	0.1	0.02	3.44	218	344.5
1500	21.3	3.5	3.3	8526	813.1	771	9.2	175	11.03	0.3	0.01	5.38	291	243.0
1500	31.3	5.1	4.9	8338	1068.4	1117	8.0	176	7.42	0.4	0.01	6.71	386	217.3
2000	12.8	2.1	2.7	11469	799.6	495.3	10.0	225	23.48	0.1	0.01	3.7	255	298.2
2000	22.8	3.7	4.8	11269	1228.3	830.9	8.6	217.6	12.68	0.2	0.01	5.94	344	257.2
2000	32.8	5.3	6.9	11580	1604.5	1178.7	8.0	278	11.64	0.4	0.02	7.8	441	233.5

FIGURES

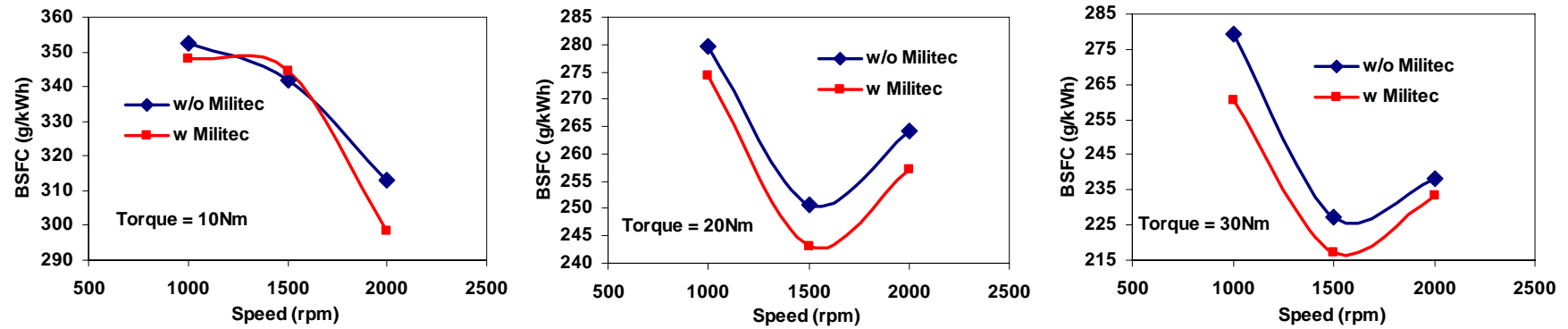


Figure 1. Brake Specific Fuel Consumption (BSFC) at 10 Nm, 20 Nm and 30 Nm Torque.

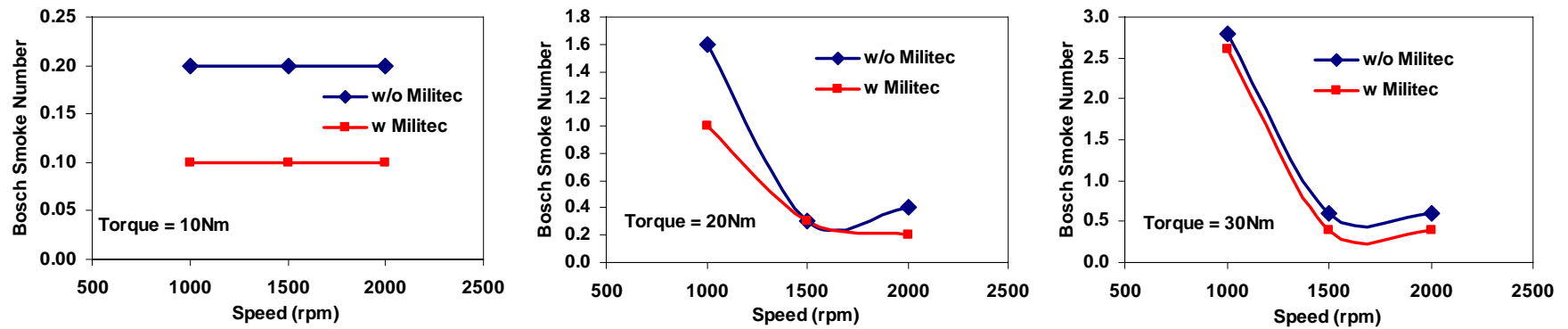


Figure 2. Smoke emissions (Bosch Smoke Number) at 10 Nm, 20 Nm and 30 Nm Torque.

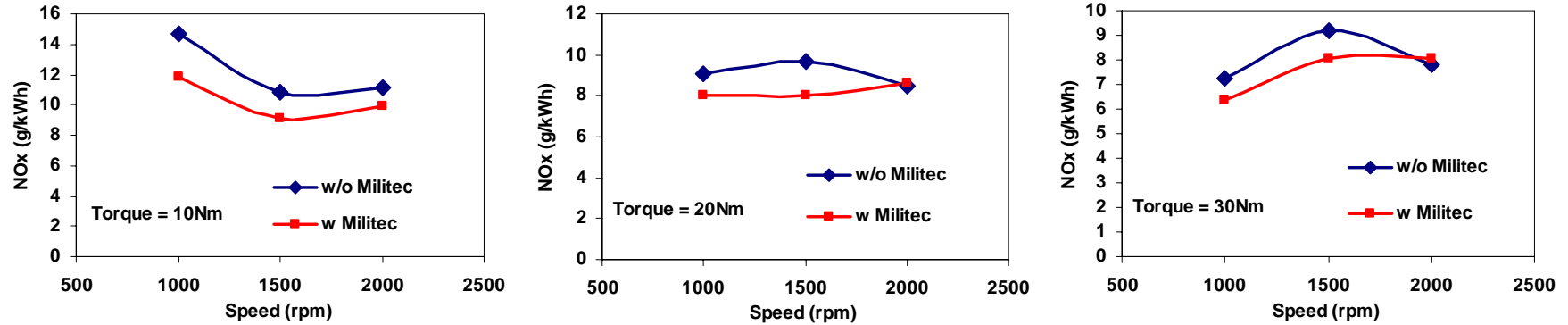


Figure 3. NOx emissions (BSNOx, g/kWh) at 10 Nm, 20 Nm and 30 Nm Torque.

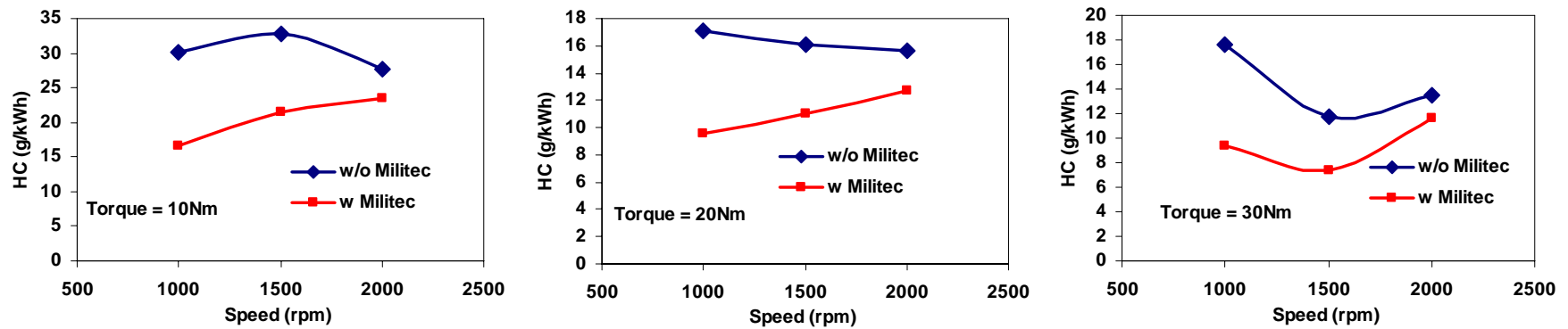


Figure 4. HC emissions (BSHC, g/kWh) at 10 Nm, 20 Nm and 30 Nm Torque.

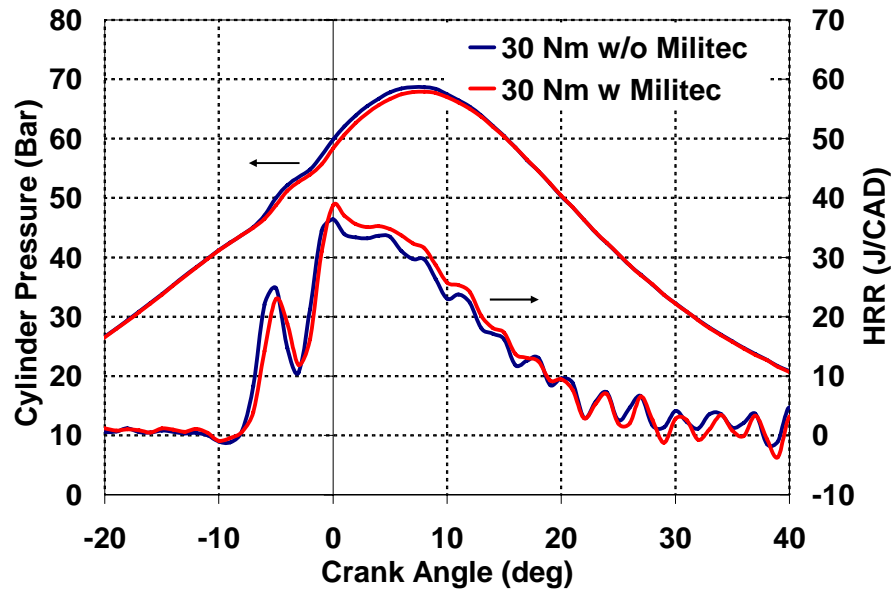


Figure 5. Cylinder Pressure (left y-axis) and Heat Release Rate (right y-axis) at 1500 rpm speed, 30 Nm torque.

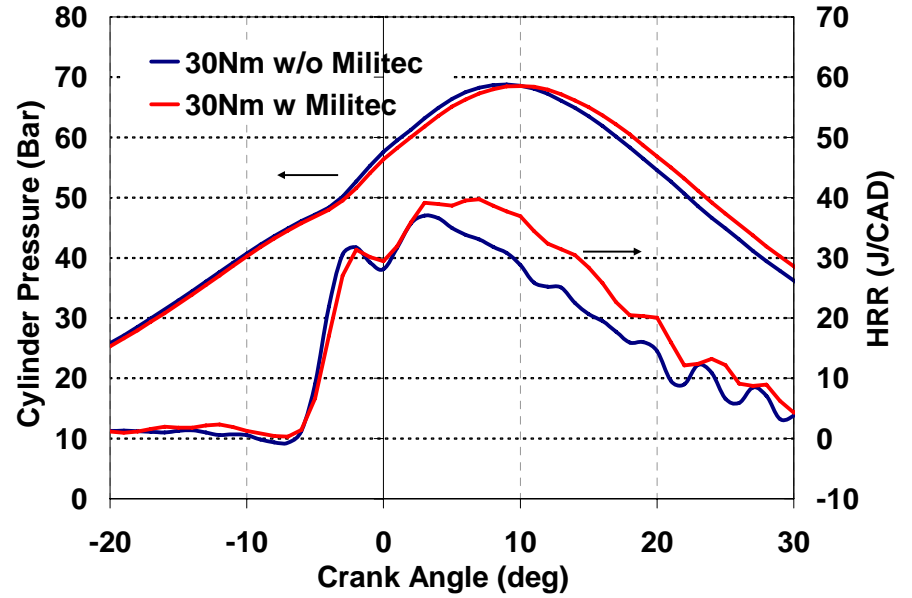


Figure 6. Cylinder Pressure (left y-axis) and Heat Release Rate (right y-axis) 2000 rpm speed, 30 Nm torque.