A Comparison of Peugeot DW10 Dynamometer and Vehicle Engine Performance

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Summary

The CEC F-98-08 Peugeot DW10 diesel fuel injector coking test has now been formally approved for nearly three years, during which time it has become widely accepted as an important measure of base fuel and additive performance in modern direct injection common rail equipped vehicles. There has however been some discussion during this time as to the relationship of this dynamometer test to behaviour in actual vehicles. This paper describes work with a vehicle equipped with a DW10 engine that aims to address this issue. A series of DW10 bench engine tests were conducted to explore the effect of biodiesel (B10) and deposit control additive on injector fouling. A set of injectors fouled in the DW10 bench engine test using biodiesel were then installed in a Peugeot 307 vehicle and the vehicle power was measured on a chassis dynamometer. The power loss measured was comparable to that measured in the test bed engine. The vehicle was then driven under normal road driving conditions with the same fouling B10 biodiesel and the power remained largely unchanged. When the vehicle was driven on the same biodiesel treated with an advanced diesel deposit control additive (DCA), the power restored almost to the starting level. This was confirmed by cleaning the injectors in an ultra sonic bath and then retesting them. This paper presents a valuable comparison between engine tests that are conducted under precisely controlled laboratory conditions and vehicle tests that are conducted in a more variable environment, but one that is representative of that experienced by end users. It shows that fouled injectors will display a comparable level of power loss in a vehicle as in the bench test and it confirms that an effective deposit control additive that provide benefits in the bench engine, will also provide benefits under normal driving conditions.

1. Introduction

More and more consumers are being attracted to diesel powered passenger cars due to their improved performance, fuel economy and emissions. While these benefits can be attributed to a number of improved design features the most noteworthy is the fuel injection equipment (FIE). Most new diesel vehicles are now equipped with a common rail, high pressure, direct injection fuel system. These systems operate at up to 2,500 bar and are fitted with precisely engineered injectors driven by a solenoid or a piezoelectric actuator. The injectors have multiple holes of <0.1 mm that are shaped to maximise the hydraulic flow. They are electronically controlled and are capable of multiple injection strategies, with up to six discrete and precise injection events per combustion cycle. The fuel is injected directly into the combustion chamber, where it instantly forms a fine fuel spray distribution. The end result is a controlled and efficient combustion process and a diesel engine that is quieter, more fuel efficient, cleaner and more powerful.

While modern fuel systems deliver improved performance when they are in a new and clean state, their efficiency can deteriorate over time due to the formation of deposits, both in the injector holes and inside the injector on the needle guide and on the control valve. Because these injectors operate under higher pressures they have narrower clearances (1 to 2 microns), which make them less tolerant of deposits. Thin layers of deposit that would have had little impact on the operation of traditional injectors, can now lead to a significant deterioration in performance. Furthermore, the higher pressures and temperatures experienced in these injectors create a favourable environment for fuel degradation and deposit formation. FIE technology being developed to meet Euro 6 emissions legislation is expected to be even more sensitive to injector deposit related problems.

Many Original Equipment Manufacturers (OEMs) have experienced incidences of injector deposits in bench engine durability testing and in the field. In many cases these problems have been attributed to the presence of low levels of metal contaminants (e.g. zinc), or the use of unstable or contaminated biodiesel. Injector fouling can lead to a significant loss of power, rough idling and in severe cases the engine may fail to start. While OEMs are able to resolve these problems by cleaning or replacing the fouled injectors, this can be time consuming and expensive, so they have encouraged fuel marketers to produce ‘cleaner’ fuels and to employ effective fuel additives that can prevent deposits forming, or remove deposits when they have already formed.

Two OEMs, Peugeot and Continental (formerly Siemens), were also instrumental in the development of an industry standard test for injector fouling in modern diesel vehicles. In March 2008, the CEC (Coordinating European Council for the development of performance tests for transportation fuels, lubricants and other fluids) introduced the new CEC F-98-08 injector fouling bench engine test [1]. This test is based on a standard production Peugeot DW10 common rail engine, but uses developmental Euro 5 injectors, instead of the standard Euro 4 production injectors. The Euro 5 injectors (supplied by Continental) were selected because they were sensitive to deposits, as well as being representative of the most advanced technology. This engine test employs a sulphur free diesel (coded DF-79-07) dosed with 1ppm zinc (Zn) to accelerate the rate of fouling. The new DW10 injector fouling test is described and discussed in more detail in Section 2 of this paper.

From the outset, this new engine test was widely accepted in the industry and at present there are 18 laboratories that have one or more engines installed. This includes a cross section of fuel marketers, additive suppliers and independent test laboratories. Soon after its introduction, many fuel marketers introduced it into their fuel quality standards and their fuel additive tender specifications. In many cases the fuel marketers have retained the traditional Peugeot XUD-9 injector fouling test (CEC F-23-01) [2], which is based on a much older indirect injection (IDI) engine, to ensure that their fuel meets the needs of past and current engine technologies.

Whilst this new engine test has been used extensively to assess the fouling propensity of base fuels and the efficacy of fuel additives, there has been much less work focussed on the correlation between this test and the performance of on-road vehicles.

Hawthorne *et al* [4] explored the relevance of the DW10 test cycle to real world consumer operation and came to the conclusion that 'during the DW10 test the injectors are subject to a cumulative period of high speed or high load conditions equivalent to what a vehicle would experience over a full life time'. However, no actual field trial work was conducted to compare and contrast effects in the bench engine with those in a vehicle. Williams *et al* [5] conducted a fleet test with vehicles equipped with high pressure, direct injection engines to investigate the extent and severity of diesel fuel degradation and contamination in vehicle systems. They concluded that some contamination was evident in the fuel system of most vehicles. Furthermore, they concluded that fuel contaminants present in the fuel at the point of combustion had accumulated in the vehicle fuel system and did not come from the market fuel. The authors did not conduct any power loss or injector fouling tests.

This paper presents initial results from a study that is in progress at Lubrizol to compare and contrast this new bench engine test with on-road vehicles, to better understand its relevance to on-road operations. DW10 bench engine tests were conducted to assess the fouling propensity of biodiesels and the efficacy of deposit control additive (DCA). A suitable fouling biodiesel was identified and used to prepare a set of fouled injectors, in the bench engine test. The fouled injectors were transferred to a Peugeot 307 vehicle, which was subjected to an on road mileage accumulation test using the same fouling B10. The first stage was conducted with the unadditised B10 and then two consecutive stages were run on the B10 treated with DCA. Power measurements were made in a chassis dynamometer at the end of each stage. The objectives of this programme were:

- Determine if power loss in the bench engine test would correlate to vehicle performance.

- Establish whether the deposits generated in a fouling fuel under bench engine test conditions would change markedly when exposed to real world conditions

- Determine if the efficacy of a DCA as established using the bench engine test, would correlate to on road driving conditions

2. The CEC F-98-08 DW10 Test

The new CEC injector coking test employs a Peugeot DW10 2.0 litre common rail unit with a maximum injection pressure of 1600 bar, fitted with Euro 5 level fuel injection equipment supplied by Continental (formerly Siemens). Each injector has six holes of 110 microns (0.11mm) and is representative of the most advanced technology. The test cycle used in the DW10 test [1] represents a step change in severity compared to the well understood CEC F-23-01 XUD-9 method [2]. While the XUD-9 test cycle was designed to be representative of city driving conditions the DW10 better represents the higher temperature conditions experience in motorway driving.

The new method uses changes in engine power as a measure of injector fouling, which is a challenge with respect to developing a discriminating test. Unlike an intake valve deposit test for gasoline engines, which is a primary measure of deposit formation, or flow loss as in the existing XUD-9 test, which is a secondary measure of deposit formation, power is a tertiary measurement in which many other factors must be held in control in order to achieve a repeatable, discriminating measurement. This is in addition to the usual challenge of maintaining repeatability and discrimination during the accumulation phases of the test protocol.

A high speed, high load, one hour cycle forms the basis of the DW10 test cycle (see Figure 1). At the beginning of the test, the cycle is run 16 times with DF-79-07 reference base fuel to break in the fuel injectors.

Following this break-in period, the test fuel is flushed in and the cycle is then repeated 8 times (one 8 hour block) and an engine power measurement is logged in the final stage of each one hour cycle. At the end of these 8 cycles the engine is shutdown for a 4 hour 'soak' period. The soak period was originally for 8 hours, but the CEC group have now reduced this to 4 hours as the shorter soak had no effect on the final result and it helped to reduce the time and cost for each test. Following this, the 8 hour cyclic running and 4 hour soak period is then repeated another two times, followed by a final 8 hour cyclic running period. This gives a total of four 8 hour periods of running and three 4 hour soak periods, which results in 32 hours running time (with 32 corresponding engine power results being logged) and 12 hours total soak time. The total test cell time for the method is therefore 60 hours (16 + 32 + 12).

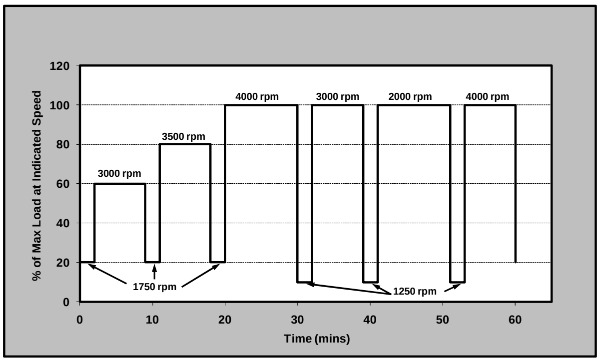

Figure 1 Chart of one hour speed-load cycle used in CEC DW10 test.

A key part of the DW10 test protocol is the use of a trace amount of a soluble zinc salt (zinc neodecanoate). One part per million (ppm) of zinc (Zn) is added to the reference fuel (DF-79-07) to provide a repeatable high fouling reference fuel. Energy dispersive X-ray spectroscopic (EDS) examination of injector channels indicates that this trace zinc appears to contribute to fouling through deposition on injector holes, as well as through accelerating the formation of fuel degradation products and thus deposit forming precursors [3].

Fuel surveys have reported trace amounts of zinc and other pro-fouling metals like copper and iron in market fuels and vehicle studies have shown that metals contamination can occur in the vehicle fuel system itself [5] [6]. Therefore, the DW10 test in its current form is broadly representative of the problems that can occur in vehicles that run for a period of time on fuels that contain trace levels of metals.

It has been shown that an effective deposit control additive (DCA) can prevent deposits forming in the DW10 engine test [3], [7], [8] and can remove deposits, and restore power, when they have already formed [9], [10]. It has also been shown that metal deactivator can control deposit formation in the Ford Puma injector fouling test [8], a developmental engine test that preceded the DW10. This test, like the DW10, is a high pressure, direct injection, light duty diesel injector fouling test that utilises zinc (1ppm) to accelerate the rate of fouling. It is therefore reasonable to assume that metal deactivator would also provide performance benefits in the DW10 engine test. The metal deactivator probably acts to chelate the zinc (Zn) metal, preventing it from depositing on the injector surface and acting as a catalyst for fuel degradation. Therefore, one needs to be careful when selecting fuel additives based on the DW10 test alone, as this could result in the application of additives which are limited in their scope to control deposits and leave vehicles exposed to deposits that form from fuel degradation products.

Whilst the XUD-9 test cannot be used as a predictor of good DW10 performance [7], it does not respond to trace metals (such as Zn) [7], so it can be used to confirm the true detergency performance of a fuel. By using the XUD-9 test (CEC F-23-01) in tandem with the DW10 test, one can develop deposit control additives that are capable of protecting against different precursors and mechanisms of deposit formation, and provide a broader level of protection in the market by protecting both modern DI as well as traditional IDI engine technologies.

The CEC working group was able to demonstrate power loss for a B10 biodiesel blend (90% mineral diesel and 10% biodiesel) in the DW10; up to 20% power loss was observed for one sample of biodiesel [11]. However, the results were not repeatable and it was suspected that this was due to changes in the quality (composition) of the biodiesel in storage. Whilst the CEC working group are not in a position to recommend a suitable poor reference biodiesel blend to reference and calibrate the engine, the DW10 test itself is able to demonstrate the type of problems that can occur with problem biodiesel and it can be used to seek an appropriate solution to the problem.

This paper shows DW10 results for different samples of biodiesel and investigates the effect of Zn doping into a B10 and the efficacy of deposit control additive in B10 and B10 + zinc.

3. Biodiesel Compositional Analysis and Blending

Automotive grade biodiesel (B100) was purchased according to the EN14214 specification from a UK supplier. As it was to be used for an investigation into injector fouling issues, the supplier was asked not to treat this batch of biodiesel with anti-oxidant additive. As a consequence the biodiesel had a Rancimat induction time of <3hrs and not >6hrs as specified in EN14214. While it is a reasonable hypothesis to suggest that the exclusion of the anti-oxidant may enhance the deposit forming tendency of the biodiesel, it should be noted that the Rancimat test does not provide a good correlation to fouling in the DW10 [11].

Analysis of the purchased biodiesel (B100) by gas chromatography (GC) showed it contained a high proportion of oleate ester (C18:1) which suggested it was predominantly rapeseed methyl ester (RME); see Figure 2. However, the relatively high proportion of palmitate ester (C16:0) suggested that it also contained a reasonable portion of palm oil derived methyl ester (PME). From the level of C16:0 observed it was estimated that the biodiesel B100 contained around one third PME. PME is known to contribute to filter blocking problems in winter due to its high level of saturated fatty acid methyl ester (FAME). However, since this batch of biodiesel was purchased and consumed during the summer period, it was much less of a concern.

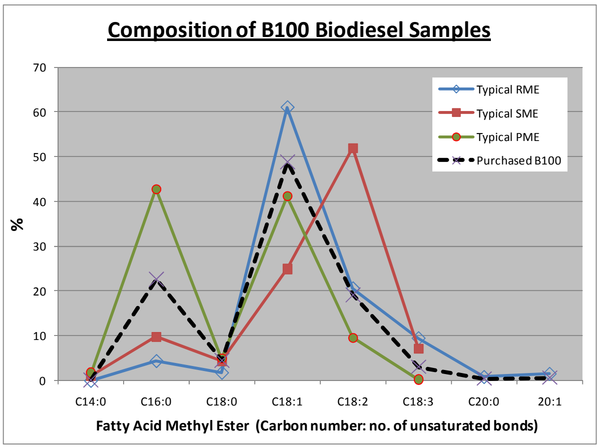

Figure 2: GC analysis: Fatty Acid Methyl Esters present in purchased B100 versus typical biodiesels

For this programme the B100 biodiesel was stored in new drums, which were filled to maximum capacity to minimise exposure to air. As a further precaution, when a drum was opened, it was completely blended into B10 to avoid storing part filled drums, which may be more exposed to air and thus prone to oxidation. The drums were stored in a dry environment, away from direct sunlight and elevated temperatures, to further avoid issues associated with contamination and degradation. Each drum of B100 was homogenised, before it was blended with mineral diesel to ensure a uniformity of quality throughout the batch and test programme. B10 blends were tested soon after they were prepared.

4. DW10 Test Results

The DW10 engine used for this programme was successfully referenced using DF-79-07 + 1ppm Zn in the normal manner. After 32 cycles around 7% power loss was observed which falls within the accepted range of 6% +/- 2%. B10 blended from DF-79-07 and the purchased B100, gave approximately the same level of power loss as the B0 + 1ppm Zn (see Figure 3).

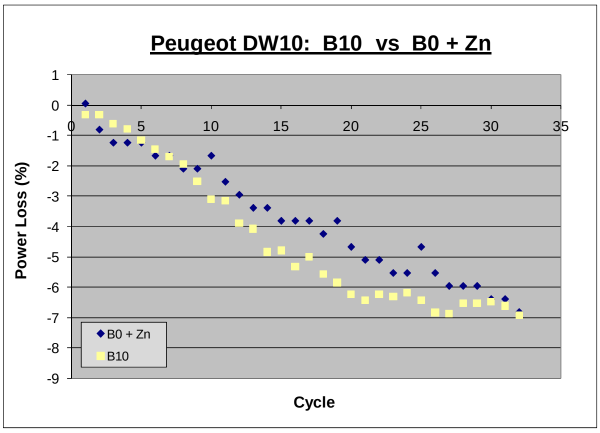

Figure 3: DW10 Results for DF-79-07 + Zn vs B10 biodiesel

This was an excellent result for this programme as earlier batches of biodiesel, purchased by Lubrizol and tested as a B10 in DF-79-07, had proven to be highly variable in their propensity to cause injector fouling (see Figure 4).

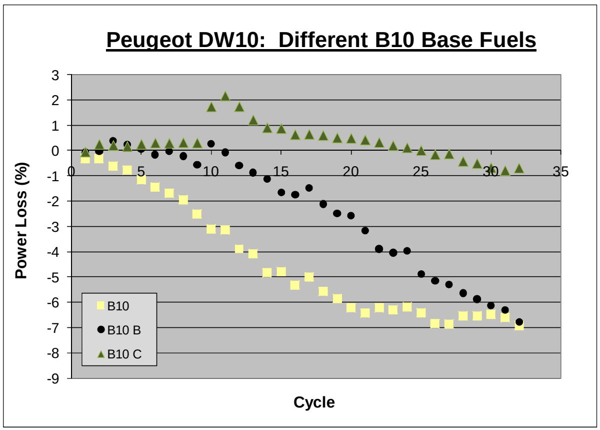

Figure 4: DW10 results for different B10 biodiesels

One batch of B10 in particular (B10 B), had shown no sign of fouling for the first twelve cycles, but thereafter the amount of power loss steadily increased, reaching around 7% power loss after 32 cycles. Another batch of B10 (B10 C) gave <1% power loss after 32 cycles, however, close inspection of the data showed a small improvement in power after 12 cycles and then a very gradual loss of power over the next 20 cycles, albeit at a much slower rate than other samples. Unfortunately, this test was not extended beyond 32 cycles, so it is not possible to say if this was a true sign of injector fouling, or whether this gradual drift in power is within the repeatability of the test. While engine tests conducted with biodiesels that have a delayed response to fouling or a very slow rate of fouling, could be extended to try and reach a reasonable level of power loss, this would increase the cost of each test and as a consequence, that of the overall test programme.

The B10 purchased for this programme was dosed with 1ppm zinc and tested in the DW10 bench engine test.

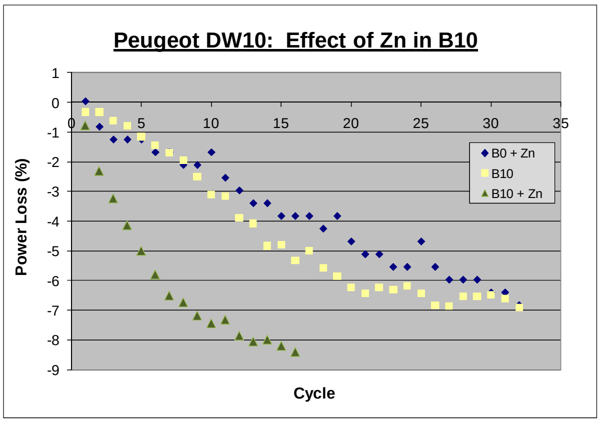

Figure 5: DW10 results for B10 + Zinc

The results, plotted in Figure 5, show an increased rate of power loss, showing that the biodiesel fouling agents and the zinc have combined to increase the severity of the test conditions.

Having demonstrated the fouling propensity of this biodiesel, both in the presence and absence of zinc, and having generated fouled injectors in both cases, we now had the opportunity to assess the efficacy of Lubrizol's deposit control additive (DCA) in removing these deposits and restoring the engine power. The results from both clean-up tests are plotted in Figure 6 below, with the corresponding dirty up phases.

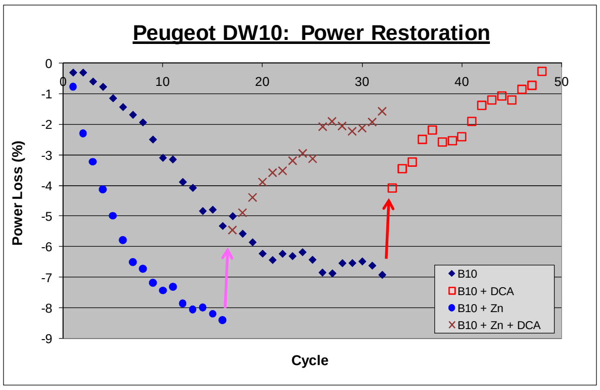

Figure 6: DW10 clean up tests with deposit control additive (DCA)

In both cases the additive gave an initial sharp gain in power, followed by a more gradual restoration of power. In the case of the B10 test, the power recovered almost to the starting level after 16 cycles. Because the B10 + zinc test was starting from a worse position (greater degree of power loss), it did not quite reach the start of test power level after 16 cycles, however by extrapolation, only another 7 or 8 cycles would have been required to achieve complete clean-up.

The purchased biodiesel was tested again in DW10 as a B10 (10% B100 in DF-79-07). In this repeat test an increased rate of power loss was observed (see Figure 7). Just over 6% power loss was observed after 16 cycles, versus 7% in the original test after 32 cycles.

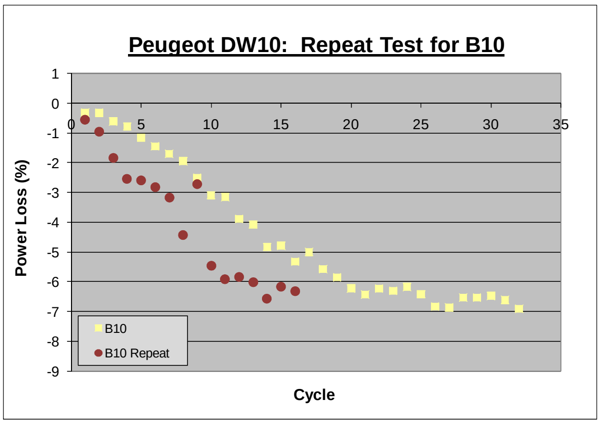

Figure 7: Repeat DW10 test for B10

It is not clear if this difference in severity is a sign of the B100 degrading in storage, or just variation in DW10 testing with biodiesel blends.

This second set of B10 fouled injectors was used for the planned vehicle test programme. The objective of this programme was to assess fouled injectors in an on-road vehicle and to assess the efficacy of the deposit control additive in real world driving conditions.

5. Peugeot 307 Programme: Test Vehicle and Protocol

A Peugeot 307 vehicle equipped with a DW10 engine was purchased for this test programme. To ensure that the vehicle was suitable for the intended tests, the standard production Euro 4 injectors were removed and a clean set of DW10 CEC Euro 5 injectors was installed. The installation of the Euro 5 injectors was completed successfully and the vehicle was run with no discernable difference in driving performance.

When the vehicle was tested in the chassis dynamometer with the Euro 5 injectors installed it gave 3 to 4 kW less power than when fitted with the Euro 4 injectors. As a similar offset is observed in bench engine testing, this was not expected to affect the programme operation or results.

The test programme was designed as follows. The vehicle engine power was measured at each of the following stages.

1. At start of test with the fouled injectors installed.
2. After a period of driving on the base B10.
3. After an initial period of driving on the B10 treated with deposit control additive (DCA).
4. After a further period on the B10 + DCA.

5. A final set of measurements was made with the injectors after they had been cleaned by sonication (i.e. cleaning of injectors in an ultrasonic bath, to remove all traces of deposit).

Miles accumulated on each fuel type are summarised in Table 1 below.

Power measure	Stage/Fuel	Mileage Accumulation (Km)	Tank Fills
1	Dirty Injectors	SOT	n/a
2	B10 base	1839	2.3
3	Additised B10	2634	3.3
4	Additised B10	2786	3.5
5	Sonicated Injectors	EOT	n/a

Table 1: Peugeot 307 programme details

The vehicle was run on B10 base fuel for just over 2 tank fills to establish whether the deposits and power measurement were stable. The vehicle was then run on additised B10 for almost 7 tank fills with a measurement made around half way through the clean up phase, to monitor the effect of the additive. The total distance on additised B10 was 5,420 Km.

This test programme produced power measurements for the injector set in a fouled and cleaned state, as well as interim results with B10 base fuel and B10 additised fuel.

All power measurements were made at MIRA (Nuneaton, UK) utilising their NVH (Noise, Vibration, & Harshness) facility. An engine speed sensor was fitted to the vehicle. For each test the vehicle was secured to the dynamometer and the engine warmed to normal operating temperatures. Time and vehicle dashboard gauges were used to ensure that the engine was up to temperature. At this stage the driver selected 3rd gear and took the vehicle up to 100% throttle (wide open throttle). The dynamometer computer control system then took control and brought the vehicle road speed back down to 30 kph. Once stabilised at this condition, the driver retained the wide open throttle position and the test commenced. The dynamometer increased the vehicle speed by 3 kph every second and the power was measured at a rate of 100 Hz. The vehicle engine speed data and dynamometer data were also recorded at this same rate. The test completed when the vehicle's engine speed had reached approximately 5,000 rpm. Each power sweep lasted was approximately 40 seconds. This protocol was repeated at least 3 times until a consistent set of data was obtained.

Although the engine power was measured up to 5,000 rpm the data analysis focussed on measurements made under more typical driving conditions; i.e. 2,500 to 3,500 rpm or between 40 and 60 mph (see Table 2).

rpm	2500	3000	3500
km/hr	66	79	92
miles/hr	41	49	57

Table 2: Road speeds measured driving in 3rd gear for test conditions analysed

At the start of test, the fuel tank was drained and the fuel system flushed with the test B10. The vehicle was driven to the MIRA test site using the standard production injectors. At the test site the injectors were replaced with the dirty injectors from the CEC bench engine test and the vehicle was ready to be tested.

6. Peugeot 307 Programme: Results and Discussion

Results obtained for the dirty injectors (at the start of test) versus the clean (sonicated) injectors at the end of test are compared in Figure 8. The three individual test runs are shown for the dirty injectors, as well as the average. For comparison purposes and clarity only the average data for the clean injectors is shown.

This plot shows a clear discrimination between the dirty and the sonicated injectors. It also shows that the maximum power achieved with the Euro 5 injectors was just over 82 kW which is significantly less than the maximum power measured in the bench engine test (around 100 kW). If allowances are made for driveline losses, vehicle age and injector set differences, the expected power at the vehicle wheels would still be in the range of 90 – 95 kW. To explore this further Lubrizol contacted the local Peugeot dealer and they confirm that the vehicle was equipped with the correct engine (DW10 BTED4) and that it was rated for 100 kW. Furthermore, the dealership's diagnostic equipment confirmed that the vehicle did not have any ECU error codes.

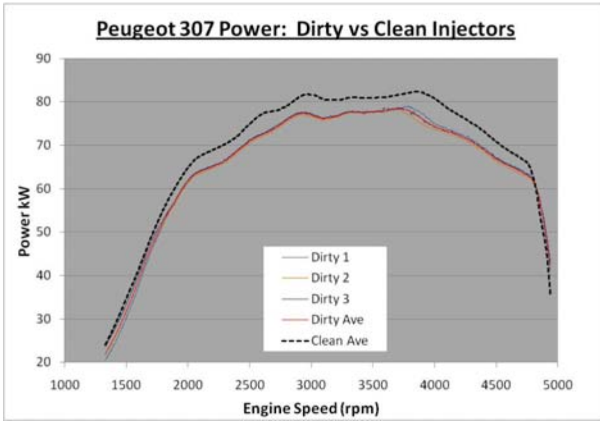

Figure 8: Power Measurements for Dirty and Clean (Sonicated) injectors

As explained earlier all subsequent data analysis focuses on the typical driving conditions between 2,500 rpm and 3,500 rpm. Power measurements for the full sweep between 2,500 and 3,500rpm are shown in Figure 9.

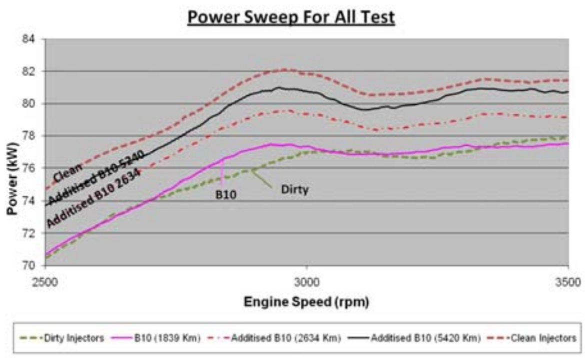

Figure 9: Power sweep between 2500 to 3500 rpm for all stages

A comparison of the power sweep for the dirty injectors (green dashed line) versus that for the vehicle after driving on B10 (full pink line) shows that the power remained largely unchanged. When the vehicle was driven on additised diesel for 2,634 Km, there was a restoration of power (dotted / dashed red line) which continued to improve while driving on the additised fuel (full black line). After a total of 5,420 Km (approximately 7 tank fills) on the additised fuel the power was nearly equivalent to the clean state (dark brown dashed line). Although these effects are clearly observed in Figure 9, a more detailed analysis was conducted to quantify the effects.

A more detailed analysis of the results obtained in the middle of this engine speed range (3,000 rpm) is shown in Table 3. This shows the power measured at this engine speed at all stages of this test. Using the clean, sonicated data set as a baseline, the power loss (in kW) was calculated at each stage of the test (see column 3). The fourth column shows the % power loss relative to the SOT power (81.8 kW). The effect of deposit control additive (DCA) on clean up is then summarised in the final two columns. The first shows the gain in power by subtracting the SOT power loss (6%) from the % loss at each stage. The final column shows the % clean up for each stage relative to the clean (sonicated) injectors.

It should first be noted that the 6% power loss observed at 3,000rpm was extremely close to the power loss measured on the test bed engine (6.3%).

1	2	3	4	5	6
Stage	Power (kW)	Power Loss (kW)	% Loss	Clean Up (%)	% Clean Up
Dirty	76.9	4.9	6.0		
B10 base (1839)	77.3	4.5	5.5	0.5	8
Additised B10 (2634)	79.3	2.5	3.1	2.9	49
Additised B10 (5420)	80.7	1.1	1.3	4.6	77
Clean (Sonicated)	81.8	0.0	0.0		

Table 3: Results obtained at 3,000rpm

The effect on power of driving on B10 base fuel (0.4kW gain) is within the variation of the measurements made. The deposit control additive reduced the power loss by almost 50% in the first phase and then by a further 28% in the second phase, giving a total of 77% power restoration over the 5,420 Km or approximately 7 tank fills.

A similar story was observed at lower (2,500rpm) and higher (3,500rpm) engine speeds as shown in Tables 4 and 5.

Stage	Power (kW)	Power Loss (kW)	% Loss	Clean Up (%)	% Clean Up
Dirty	70.5	4.3	5.7		
B10 base (1839)	70.7	4.1	5.4	0.3	5
Additised B10 (2634)	72.4	2.3	3.1	2.6	46
Additised B10 (5420)	73.7	1.0	1.4	4.4	76
Clean (Sonicated)	74.7	0.0	0.0		

Table 4: Results obtained at 2,500rpm

Stage	Power (kW)	Power Loss (kW)	% Loss	Clean Up (%)	% Clean Up
Dirty	77.8	3.7	4.5		
B10 base (1839)	77.5	4.0	4.9	-0.4	-9
Additised B10 (2634)	79.1	2.3	2.9	1.6	36
Additised B10 (5420)	80.7	0.7	0.9	3.6	80
Clean (Sonicated)	81.5	0.0	0.0		

Table 5: Results obtained at 3,500rpm

The data shown on the last column of Tables 3 to 5 are plotted in Figure 10. This shows the amount of power restoration at each stage of the trial at all three engine speeds.

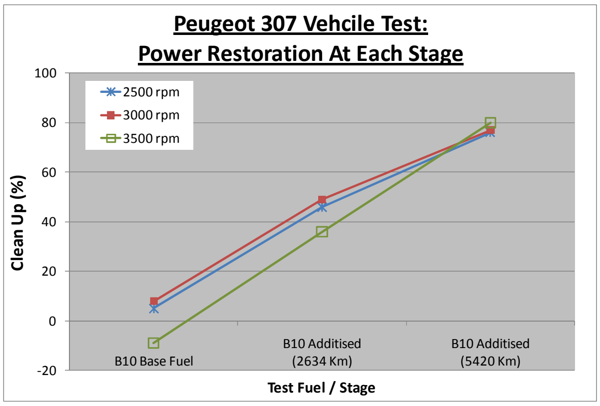

Figure 10: Power restoration achieved at each stage of the trial (at 2500, 3000 and 3500 rpm).

Again, the base B10 clearly had little effect on the deposit levels and the deposit control additive steadily restored the power over the duration of the trial.

7. Conclusions

- The DW10 bench engine test can be used to investigate the fouling propensity of biodiesels and the efficacy of deposit control additive in biodiesel.
- The fouling propensity varies from sample to sample of biodiesel. Some do not form deposits while others can match or even exceed the fouling propensity of zinc doped diesels.
- An effective deposit control additive can restore power in the bench engine, even when challenged with the combination of a fouling biodiesel and Zn contamination.
- Injectors fouled in the DW10 bench engine also demonstrated power loss in a Peugeot vehicle. The level of power loss was comparable to that observed in the bench engine, when the vehicle was driven at between 2,500 and 3,500rpm in 3rd gear.
- Deposits generated on the test stand did not change appreciably when the injectors were run in the vehicle on the same base B10.
- Deposit control additives that had effectively removed deposit and restored power in the DW10 bench engine, also removed deposit in typical on-road driving conditions.

This initial data clearly demonstrates the relevance of the bench engine test to on-road vehicle testing. Further tests are planned to strengthen this conclusion and develop a more robust correlation.

8. Further Work

Further work is planned in the following areas

1. Extend this study to injectors that have been fouled to increasing levels of power loss (10 to 20% power loss) to see if a correlation can be developed between the engine test and vehicle testing.
2. Attempt to dirty up injectors on the road with a known fouling biodiesel.
3. Demonstrate the efficacy of deposit control additives with different fuels types and test scenarios on the road.

9. References

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