Coventry University

University of Brighton

Fuel Additive Combustion Testing Programme

Authors: Dr Steven Begg
s.m.begg@brighton.ac.uk
Dr. Nwabueze Emekwuru
nwabueze.emekwuru@coventry.ac.uk

Document Version 6
Contract Number TE-01/Nwabueze Emekwuru – Coventry University

Contents

1.0 Executive Summary

A fuel additive incorporating low dosages of metallic nanoparticles has been developed by Tuireann Energy Ltd. Hitherto, such nanofluid based fuels have incorporated relatively higher dosages of metallic nanoparticles and have been shown to improve the combustion processes when used in internal combustion engines.

To investigate the effects of the fuel additives, T1 & T2, developed by Tuireann, upon the combustion of fuels in internal combustion engines, a series of preliminary engine performance tests were carried out using a production 3-cylinder engine at the Sir Harry Ricardo Laboratories at the University of Brighton. Evaluation of the test data was undertaken by Coventry University and the University of Brighton.

The tests consisted of the measurement of fuel consumption and engine performance over a range of typical engine speeds and loads operating points, as well as combustion indicating analysis at these points.

The results indicated that T1 and T2 additives injected at a post-throttle position can reduce the fuel consumption of the engine, particularly evident at part-load, throttled operating conditions. Generally, the addition of both additives significantly affected the combustion phasing resulting in higher net mean effective pressures and improved combustion stability. However, further work needs to be carried out to ascertain whether this effect was due to the presence of the T2 additive carried over from the pre-throttle cases into the post throttle studies as a result of the testing sequence. In addition, further work is required to determine how the residence time of the additives impacts performance over a longer time period.

2.0 Scope of Work

Devise a test cycle programme and evaluate the performance of a commercial spark-ignition combustion engine when running without and with the T1 and T2 fuel additives using the AVL test stand facility at the University of Brighton.

Conduct a series of investigative experiments to initially determine the optimum operating test programme and injection location for the air/fuel additive device.

Investigate performance parameters such as fuel consumption, the engine power and torque, and pressure-based combustion characteristics at various engine loads representative of the range of cases encountered in the NEDC drive cycle.

Investigate the repeatability of the experiments in order to evaluate the experimental uncertainty in the results.

3.0 Test Team and Facility

Dr Steven Begg, University of Brighton

Dr Nwabueze Emekwuru, Coventry University

Dr Samuel Jun, Tuireann Energy Ltd

Mr. Rick Chambers, University of Brighton

Engine Test Laboratory, E14

Heavy Engineering Building, School of Computing, Engineering and Mathematics,

University of Brighton, Lewes Road, Moulsecoomb, Brighton, BN2 4GJ

4.0 Summary of Experimental Apparatus

- Volkswagen-Audi Group Skoda Fabia, naturally aspirated, spark ignition, in-line 3-cylinder, six valves, water cooled engine with a swept volume of 1198 cc (VW-AG AWY variant of engine- Polo, Fox, Lupo, Skoda Fabia, Seat Ibiza- see Appendix 1 for Engine specification))
- AVL DynaPerform chassis dynamometer and ancillary equipment. Test bed instrumented to measure temperatures, pressures (Druck) and mass flow rates of fuel (AVL gravimetric balance), air (Endress and Hauser T-Mass) and coolant. Cylinder 1 is fitted with a Kistler Piezoelectric type, spark plug mounted in-cylinder pressure transducer (10 bar/Volt).
- Automated AVL Bobcat test stand control and AVL 620 Indiset/Indicom data acquisition system.
- The engine uses a K6 Emerald ECU with standard, baseline maps for spark and fuel injection. The original baseline calibration of the AFR mapping was carried out using an ETAS Lambda module and Bosch LSU wideband lambda oxygen sensor. Map corrections are only applied during cranking and cold starting. It is important to note that in the tests conducted here, the engine was not operated with closed loop lambda feedback control; the fuel injection timing and duration and the ignition timing did not vary from the engine baseline map. In this mode of operation, spark and fuelling did not adjust for variations in oxygen concentration in the exhaust gas. In this way, effects of the additives could be compared directly against the baseline engine case without automatic changes in the operating parameters between cases.

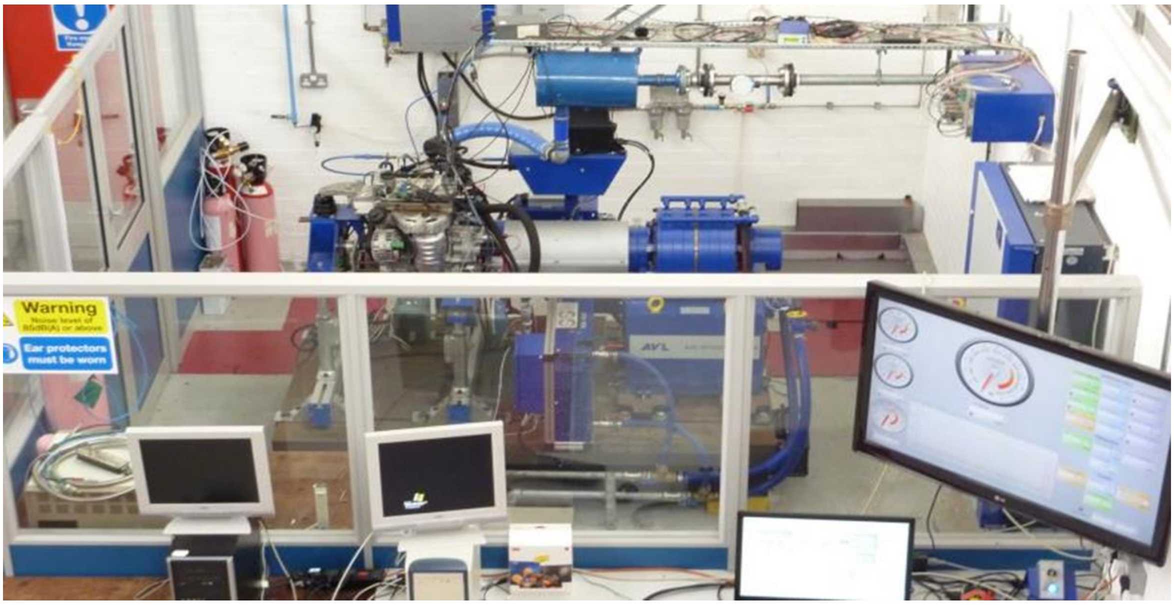


Figure 1: Engine Test-stand Laboratory, E14, Sir Harry Ricardo Laboratories, University of Brighton.

5.0 Test Programme

5.1 Test bed Preparation

The following actions were carried out prior to testing:

- Fuel tank and system flush and fill with baseline fuel, 95 RON Pump grade, unleaded gasoline (BP pump grade- single batch).
- Test bed calibration including dynamometer torque, in-cylinder pressure transducer, and each of the Bobcat data acquisition channels. The certification documents are provided in Appendix 2.
- Discussion to establish the range of operating test points based upon throttle/speed control mode of operation. The test case measurement operating points are broadly based upon typical speed and load conditions for a vehicle in an urban environment inside the envelope of the NEDC drive cycle. The selection of the engine test points is given in Appendix 3. The *'Key Points', (KP)* refer to a list of engine speed (rpm) against load (throttle position, % TPS) conditions (KP1 to KP12).
- Determination of optimum test duration was carried out by comparison of datasets from preliminary tests at 20, 150 and 210 seconds per data acquisition window per individual test point. The 210 seconds duration was adopted as the best compromise between total duration of test, fuel and exhaust high limit temperatures and fuel reservoir volume.
- Determination of the optimum injection location for the additive mist. Locations were identified upstream and downstream of the throttle body. These are identified in Appendix 4. The additive nebuliser was positioned a short distance from the injection locations.

5.2 Test Procedure

The engine test bed, engine configuration and test routine for selected operating points is loaded into the AVL Bobcat system. The test sequence is as follows:

- Warm-up routine including fast idle period during which engine coolant temperature reaches a steady-state condition >65 °C.
- Atmospheric air temperature and fuel temperature are noted at the start and end of test.
- Automatic change of the demand signal for the engine speed and throttle position (set point) from the current setting to the required one is carried out over a pre-defined ramp period.
- The engine is then maintained at this set point for a further period to ensure that a stable operating condition has been achieved.
- At the end of this stabilisation period the measurement system is started and the sensors mounted on the engine are recorded at a frequency of 1Hz. The data acquisition system computes and records the average and standard deviation for each measured value during this period.
- The high-speed data acquisition system (AVL Indiset 620) is triggered to acquire 500 consecutive cycles of engine data (in-cylinder combustion gas pressure for calculation, ignition and fuel injection signals for reference).
- This procedure is repeated until all the specified test points have been recorded.

5.3 Test Programme and Order of Events

A test programme was setup to evaluate the performance of the T1 and T2 fuel additives in a series of progressive stages, benchmarked against a baseline test performed using pump grade gasoline fuel. The programme proceeded in the following chronological order (without strip, clean and rebuild):

1. Baseline benchmarking, without water injection (210 seconds per Key Point (KP))
   File set name: Baseline 210 W_O_W_x

2. Water injection pre-throttle location (High flow rate, 0.4 ml/min, d=1-6 μm, 200 parts gasoline: 1-part H_2O), (210 seconds per KP)
   File set name: Baseline 210 W_W_x

3. T2 additive pre-throttle location (Low flow rate, 0.2 ml/min), (210 seconds per KP)
   File set name: Baseline 210 W_T2_x

4. T2 additive pre-throttle location (High flow rate, 0.4 ml/min)
   No INDISET data
   File set name: n/a

5. T2 additive post-throttle location (Low flow rate, 0.2 ml/min), (210 seconds per KP)
   File set name: PThro 210 W_T2_x

6. T1 additive post-throttle location (Low flow rate, 0.2 ml/min), (210 seconds per KP)
   File set name: PThro 210 W_T1_x

7. T1 additive post-throttle location (Low flow rate, 0.2 ml/min, **No artificial static charge applied**), (150 seconds per KP)
   File set name: PThro 150_W_T1_x

6.0 Test Results

6.1 Mean Test Results

These are data acquired from the AVL Bobcat 10 Hz data acquisition system. The data is presented as a time history or as mean values averaged over 210 seconds at each test point. These data were amalgamated with the mean data acquired from the high-speed, AVL Indiset data acquisition system. The experimental uncertainty with regards to these results is included in the data files sent to the client for each test case. (These were within acceptable limits in all test cases). In the following figures, the relative size of the symbol indicates the throttle position; the smallest size represents the 15% throttle cases, whilst the medium and largest sizes represent the 25% and 35% throttle cases respectively.

6.1.1 Directly measured variables

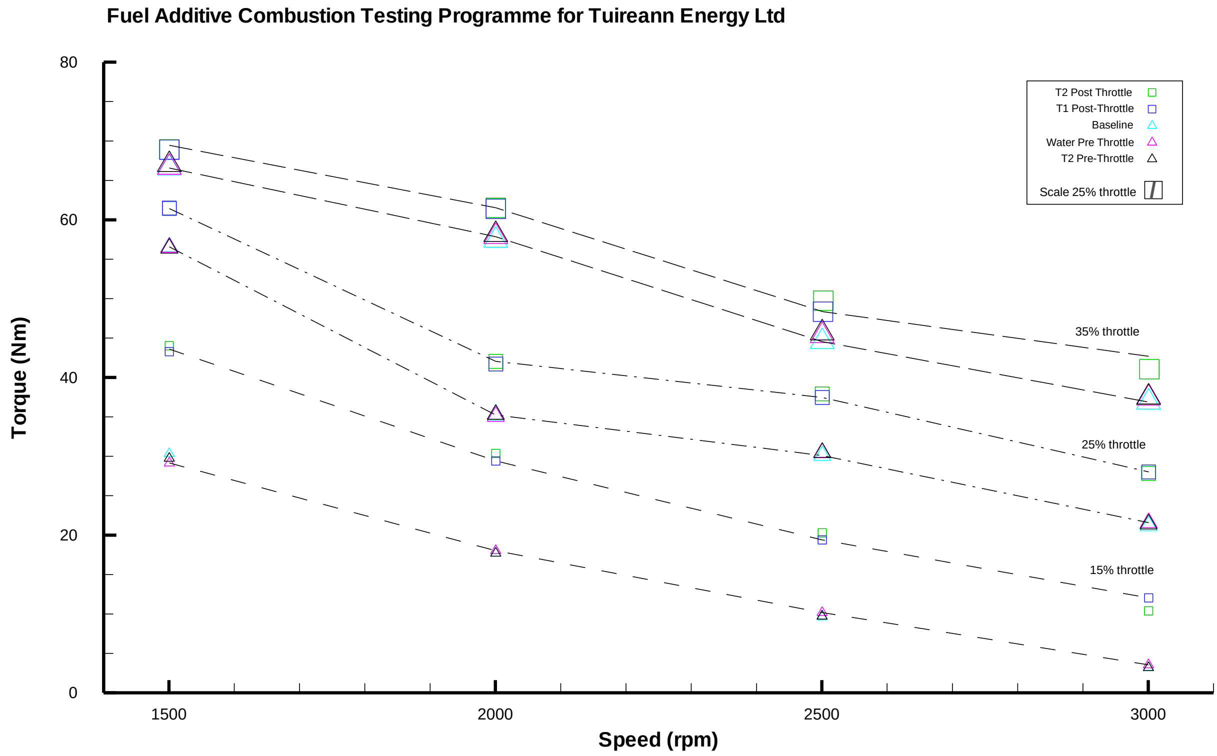


Figure 2: Engine Brake Torque versus engine speed for the test programme with and without the additives, at three different throttle positions.

The engine torque is a good indicator of an engine's ability to do work. The results, as shown in Figure 2, indicate a fall in the engine brake torque value with increases in the engine speed at all of the throttle positions tested. For the baseline case and the pre-throttle cases with water injection and the T2 additive, the variation of the engine torque with engine speed were similar for all the throttle positions tested. However, for post-throttle positions, there were significant increases (46% at 1500 rpm, 15% throttle position, T2 post-throttle versus baseline) in the measured engine torque values for all the engine speed values measured. However, this difference decreased significantly with increase in the throttle position opening (8.3% @25% throttle position; 1.5% @ 35% throttle position).

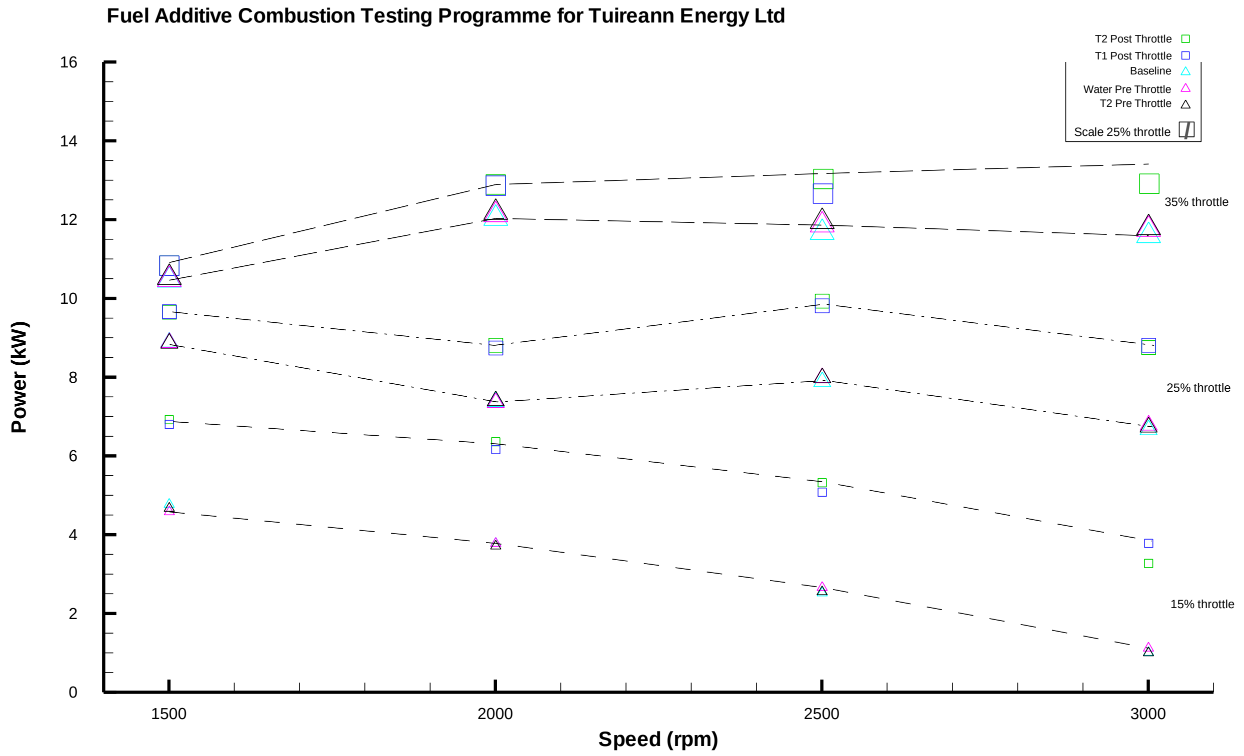


Figure 3: Engine Brake Power versus engine speed for the test programme with and without the additives, at three different throttle positions.

The engine power is an indication of the rate at which the engine can do work. The results, as shown in Figure 3, indicate a fall in the indicated engine brake power value with increases in the engine speed at the 15% throttle value, an almost flat curve at the 25% throttle value, and an initial increase followed by a flat curve at the 35% throttle position. Thus, with an increase in the throttle position, the measured engine brake power increases with engine speed. Similarly, to the measured engine brake torque values, for the baseline case, the cases with water injection and with T2 additive (pre-throttle), the variation of the engine brake power with engine speed was similar for all the throttle positions tested. However, for post-throttle T1 and T2 positions, there were significant increases (57.5% at 1500 rpm, 15% throttle position, T2 post-throttle versus baseline) in the measured engine brake power values for all the engine speed values measured. However, this difference decreased significantly with increase in the throttle position opening (9.1% @25% throttle position; 0.9% @ 35% throttle position). However, the differences do increase again at higher engine speeds.

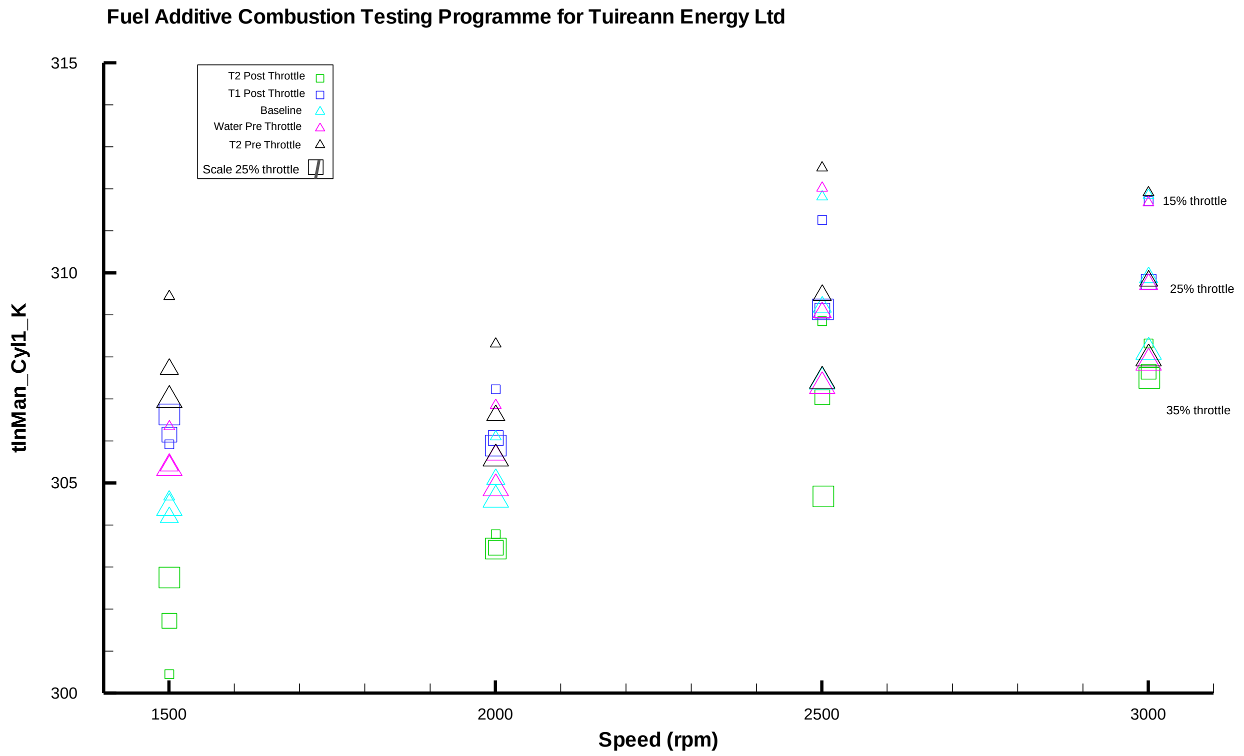


Figure 4: Engine Intake Manifold Temperature versus engine speed for the test programme with and without the additives, at three different throttle positions.

Overall the engine intake manifold temperature increased with increase in the engine speed. The post-throttle sited T2 injection system presented the least intake manifold temperature at each measured engine speed, whereas the water injection, pre-throttle case generally presented the highest engine intake manifold temperature. Whereas the engine intake manifold temperature reduced with increase in the throttle position for engine speeds from 2000 to 3000 rpm, this trend was not apparent at the 1500 rpm engine speed; there was not a consistent pattern observed.

Intake air temperature values could have consequences on the brake torque, specific fuel consumption, start of and duration of combustion, and the emissions of CO, NO, and HC.

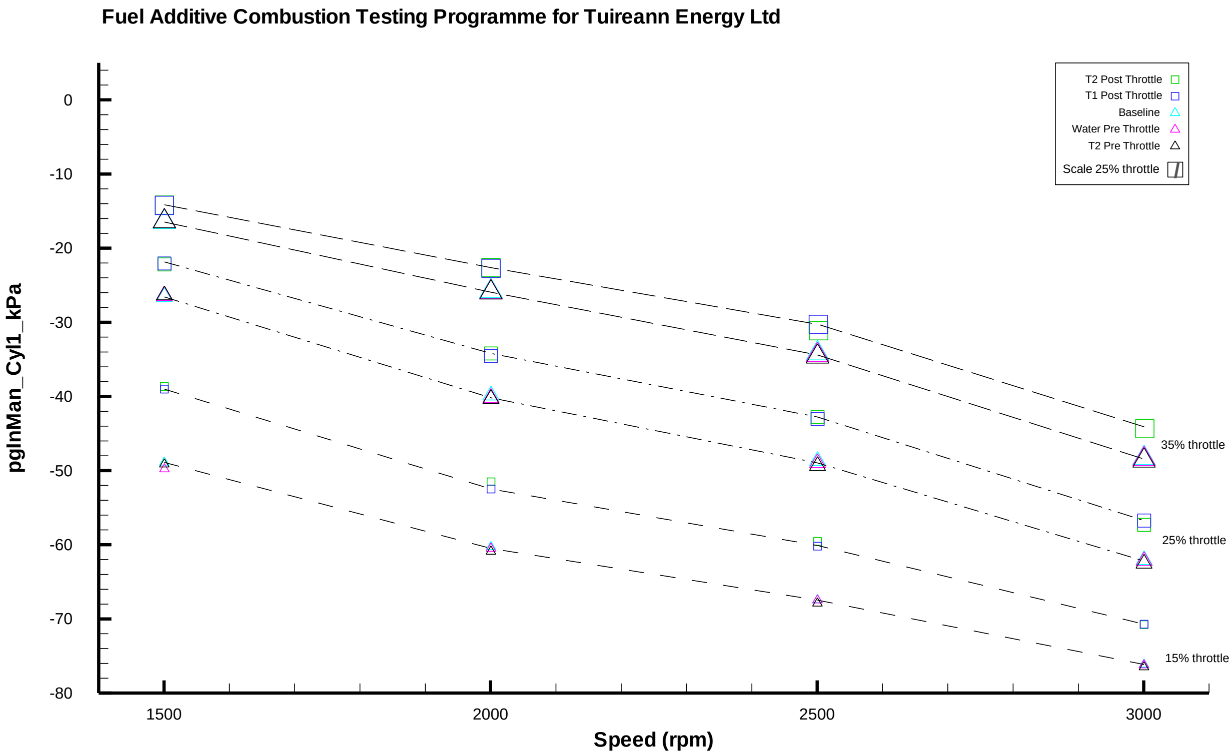


Figure 5: Engine Intake Manifold Pressure versus engine speed for the test programme with and without the additives, at three different throttle positions.

The engine intake manifold pressure increases with throttle opening as the air flow path becomes less restricted and the pressure difference between the intake manifold and the atmospheric pressure is reduced. This is evident in Figure 5, where increasing the throttle opening positions reduces the engine intake manifold pressure values. The variations in the engine intake manifold pressure with the engine speed for the various test cases follow the same trend as that of the Brake Torque in Figure 2; the differences between the base case and the T2 additive are greatest at the 15% throttle position but this diminishes to within the experimental error margins when the throttle position is increased to 35%.

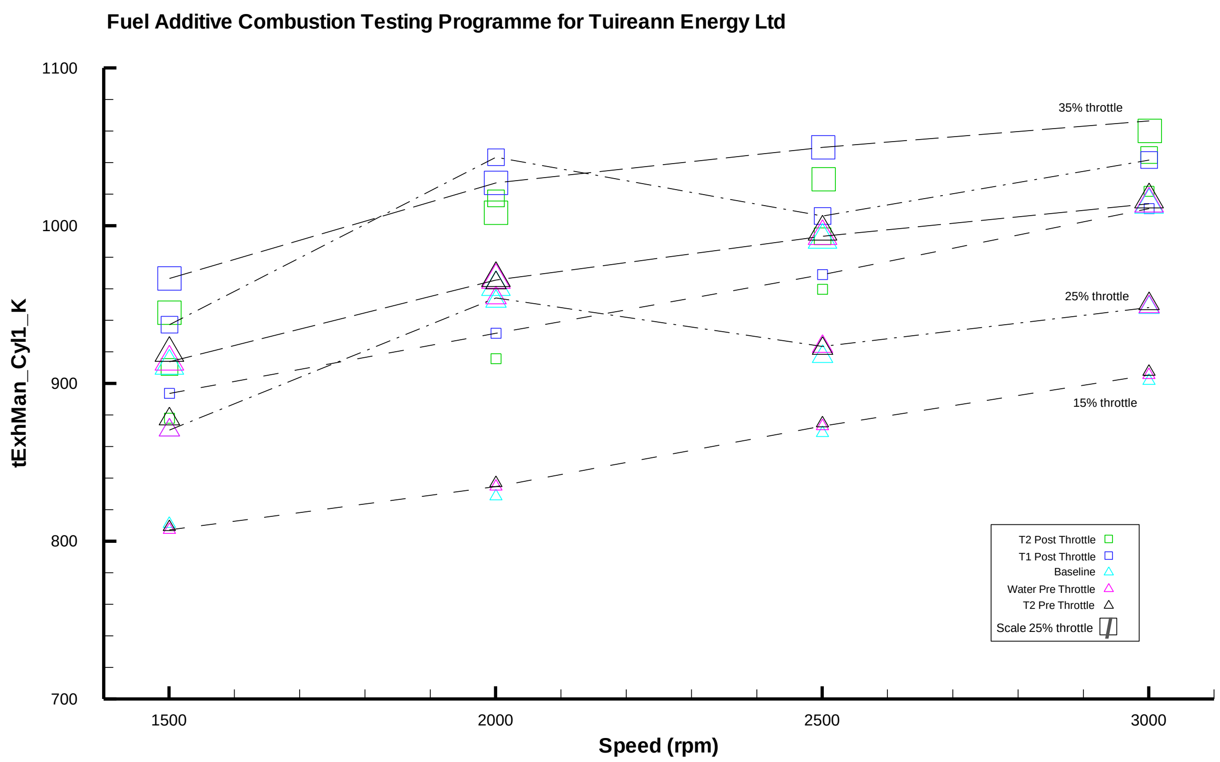


Figure 6: Engine Exhaust Manifold Temperature versus engine speed for the test programme with and without the additives, at three different throttle positions.

This is indicative of the in-cylinder pressure and temperature values, which in turn are a consequence of the timing and heat released during the combustion process. More efficient combustion leads to the production of more energy, including heat, higher in-cylinder pressures and temperatures and hence engine exhaust manifold temperatures. From Figure 6, the engine exhaust manifold temperature values increase with increasing engine speed, and with increasing throttle position opening. The baseline and T2 pre-throttle position cases presented similar values whilst the T1 and T2 post-throttle position cases presented engine exhaust manifold temperature values that were higher at the 15% throttle position for the baseline cases but similar with increased throttle opening positions.

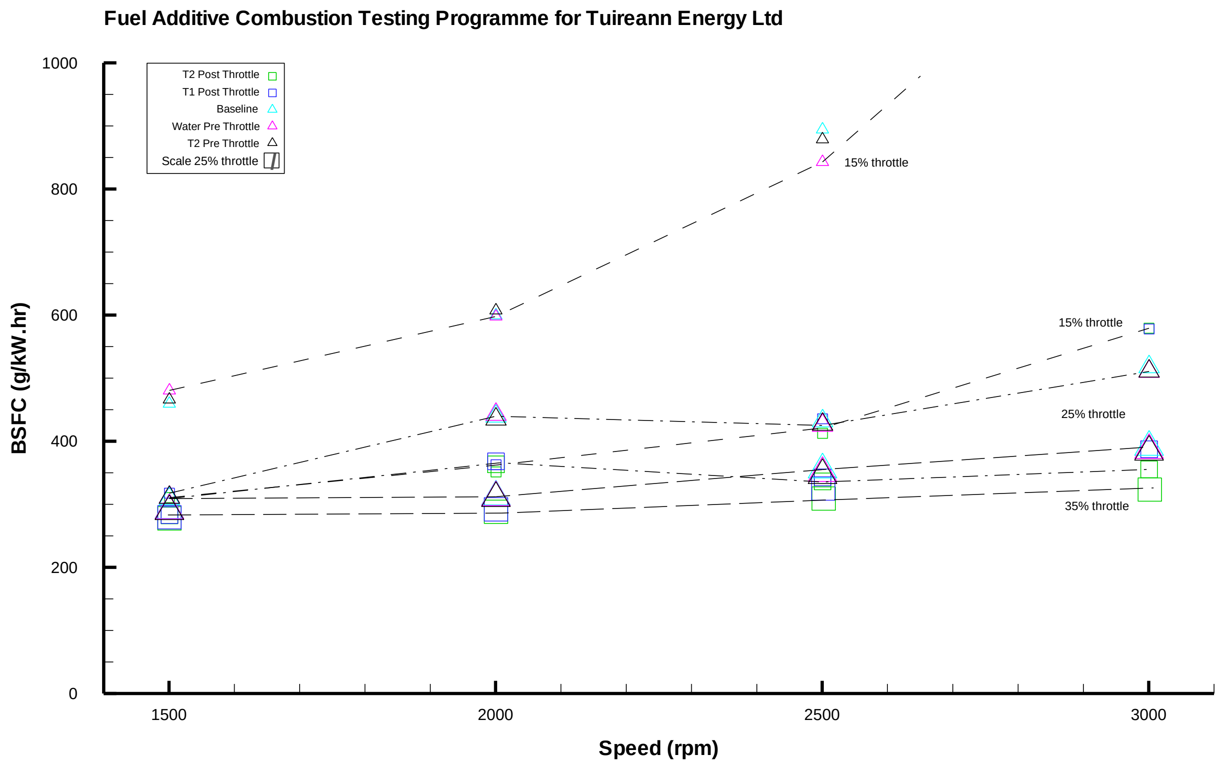


Figure 7: Brake Specific Fuel Consumption versus engine speed for the test programme with and without the additives, at three different throttle positions.

The specific fuel consumption is a measure of how efficiently an engine uses the fuel supplied to it to produce work at given operating conditions. The brake specific fuel consumption decreases as engine speed increases, reaches a minimum, and starts to increase at high engine speeds. Figure 7 appears to capture the later upward rising curve of the brake specific fuel consumption for the engine. Fuel consumption increases at higher engine speeds due to an increase in friction losses. At idle, the brake specific fuel consumption is 'infinite' since the engine is not producing any useful work but is consuming fuel. As the load increases (increased throttle opening), the brake specific fuel consumption falls, and eventually reaches a minimum level from which it might start rising again depending on other engine conditions. From Figure 7, the greatest difference is observed between the post-injection and baseline cases at the 15% throttle position results.

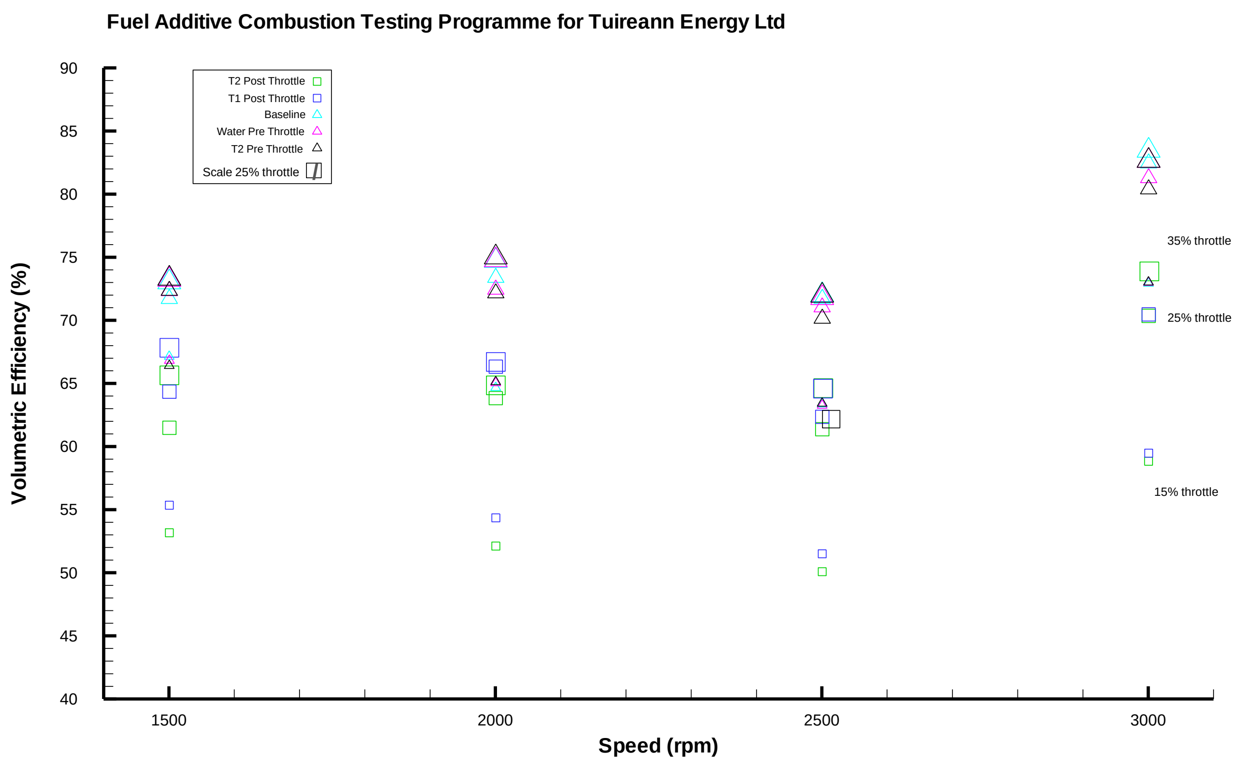


Figure 8: Volumetric efficiency versus engine speed for the test programme with and without the additives, at three different throttle positions.

The volumetric efficiency is the ratio of the actual air mass flow rate consumed to a theoretical air mass flow rate without losses. It is a measure of the ability of an engine to consume air. A Thermal mass flow meter (Endress and Hauser T-Mass), located upstream of the damping plenum, was used in this study rather than the engine MAF sensor. However, it was noted during the testing that the meter developed an intermittent fault resulting in experimental errors in the determination of the flow rate. This resulted in inconsistent results for air flow rate (that have in turn affected the calculation of the AFR from the mean air and fuel flow rates). The data is provided for completeness but the Volumetric Efficiency must be considered indicative of trends only. Note that the intake manifold pressure (IMAP) measurements are not affected by these errors (see Figure 5 above).

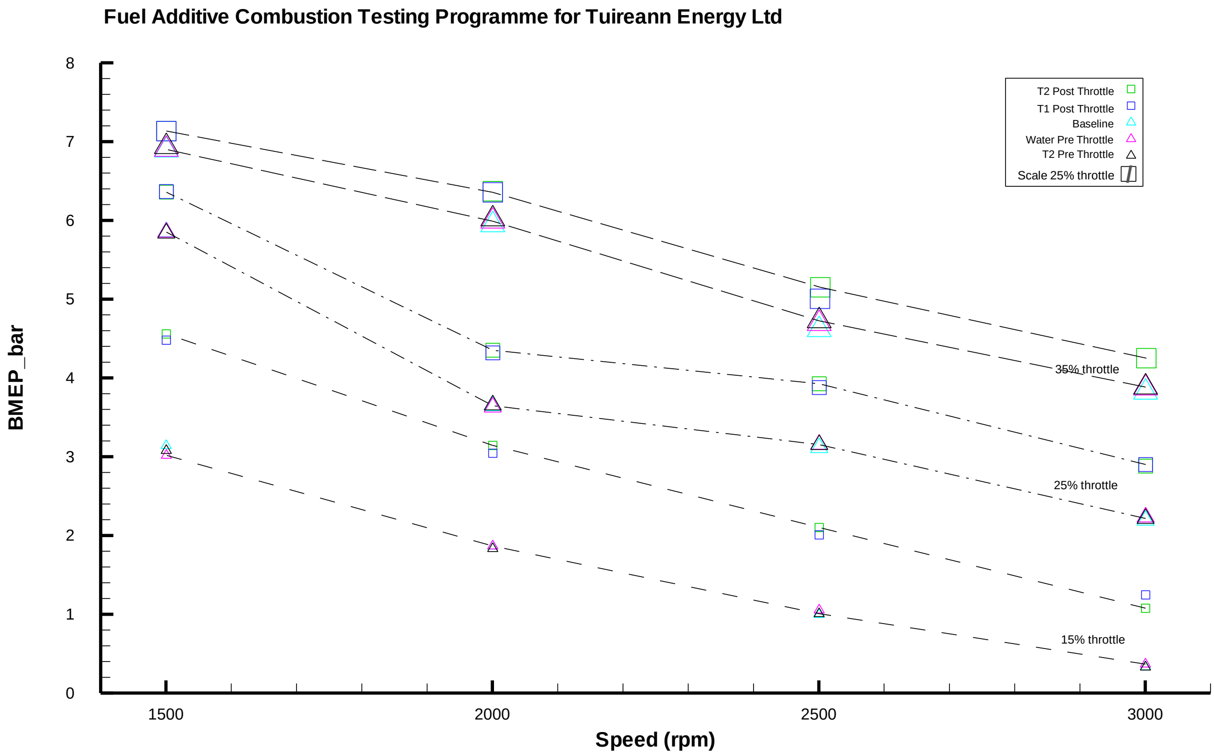


Figure 9: Brake Mean Effective Pressure versus engine speed for the test programme with and without the additives, at three different throttle positions.

This is a useful relative engine performance measure that is independent of engine size. It is the work per cycle divided by the cylinder volume displaced per cycle. Best practice Brake MEP values of good engine designs are well established and therefore the actual BMEP values in Figure 9 can be compared with those of existing designs. The greatest difference is observed in the brake mean effective pressure values between the post-throttle and baseline cases at the 15% throttle position.

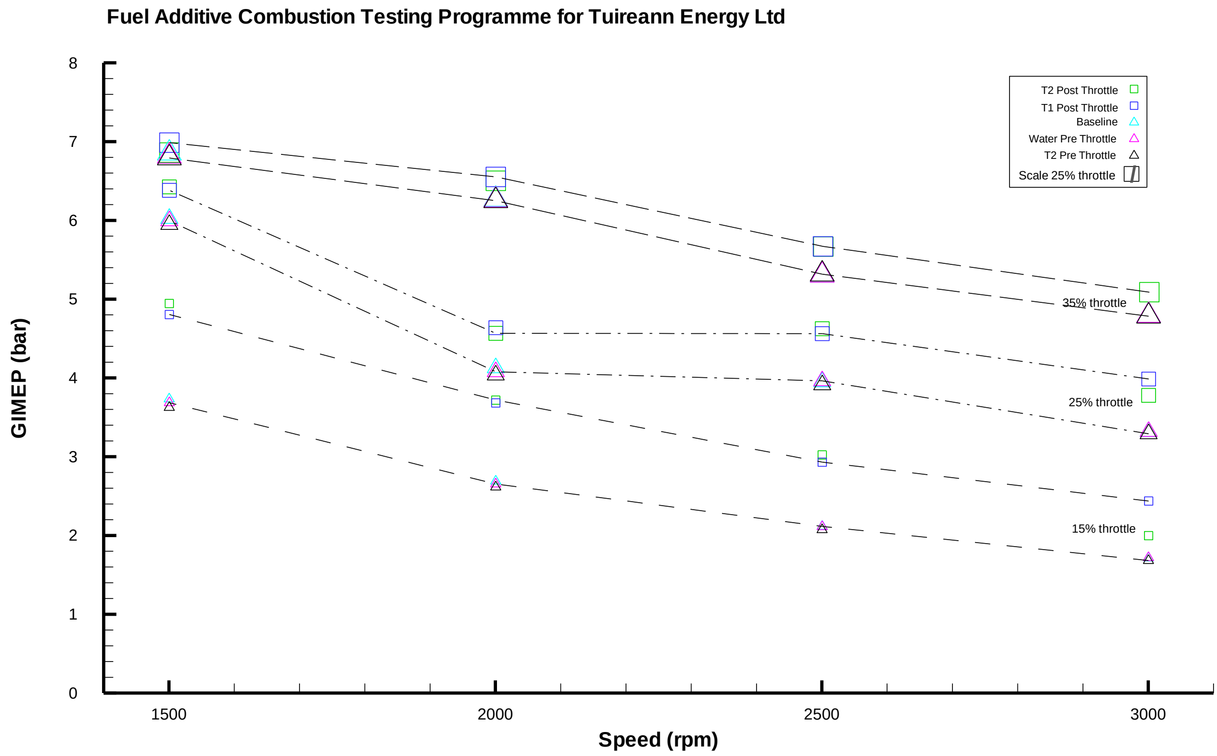


Figure 10: Gross Mean Effective Pressure versus engine speed for the test programme with and without the additives, at three different throttle positions.

The gross indicated mean effective pressure is the positive work delivered during the compression and expansion strokes, per cycle, per unit volume displaced. It is derived from the in-cylinder Pressure measurements. This contrasts with the BMEP which is determined from dynamometer brake data. Figure 10 follows the same pattern as Figure 9.

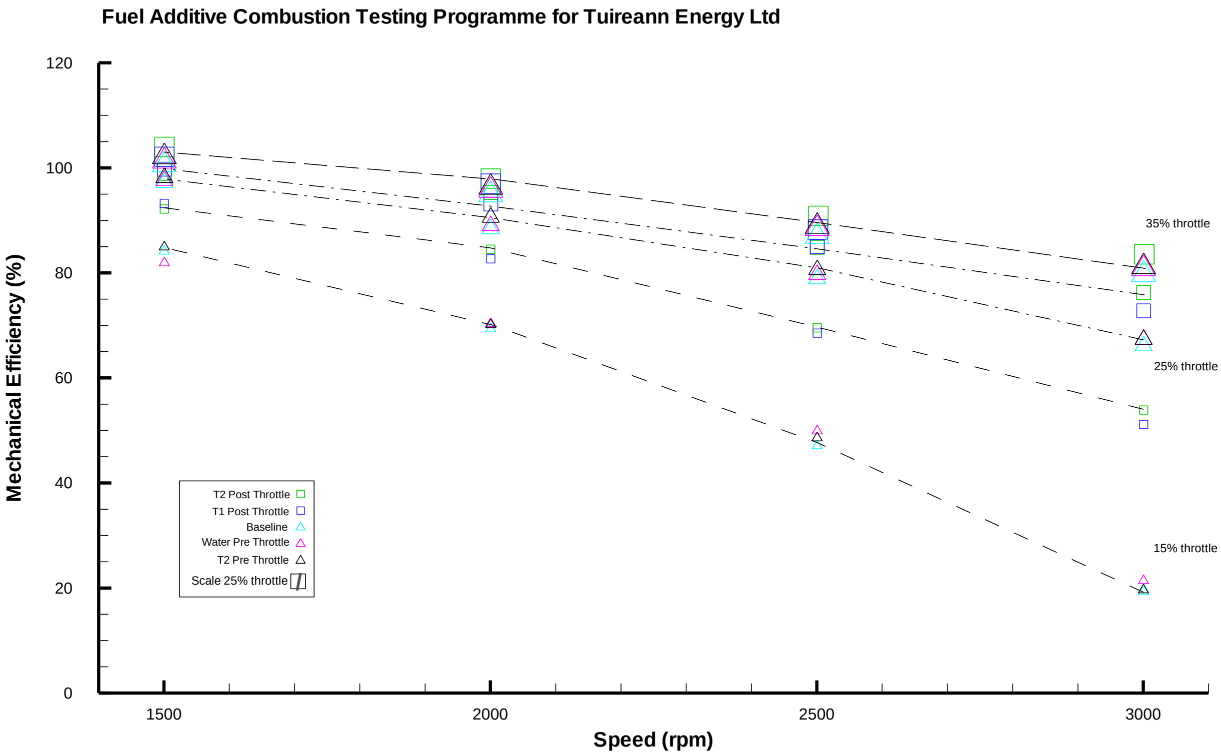


Figure 11: Mechanical Efficiency versus engine speed for the test programme with and without the additives, at three different throttle positions.

The mechanical efficiency indicates the proportion of useful power delivered by the engine at the brake from the total indicated power of the engine. It is also a measure of how the friction affects the engine. At full or wide open throttle positions at low engine speeds the engine efficiency tends towards 90% but this decreases as the engine speed increases. At lower throttle opening positions, the engine efficiency reduces until it reaches zero at idle. These trends are evident from Figure 11. The baseline, baseline with water, and the T2 pre-throttle cases all show similar mechanical efficiency values at all the test points. The T1 and T2 post-throttle cases indicate marked increases in the mechanical efficiency values at the 15% throttle opening position but similar values at the 25% and 35% throttle opening test points.

6.2 Combustion Analysis

The combustion data presented are averaged values over 500 consecutive engine cycles per test case.

6.2.1 Combustion pressure indicating- peak amplitude, angle of peak amplitude, rate of peak pressure rise.

Examples of Standard Pressure-Volume, Instantaneous Heat Release and Cumulative Heat Release curves for the baseline configuration for KP1 are presented below for illustration purposes. This data can be processed in the future for the T1 and T2 testing a long with Log P-V plots etc.

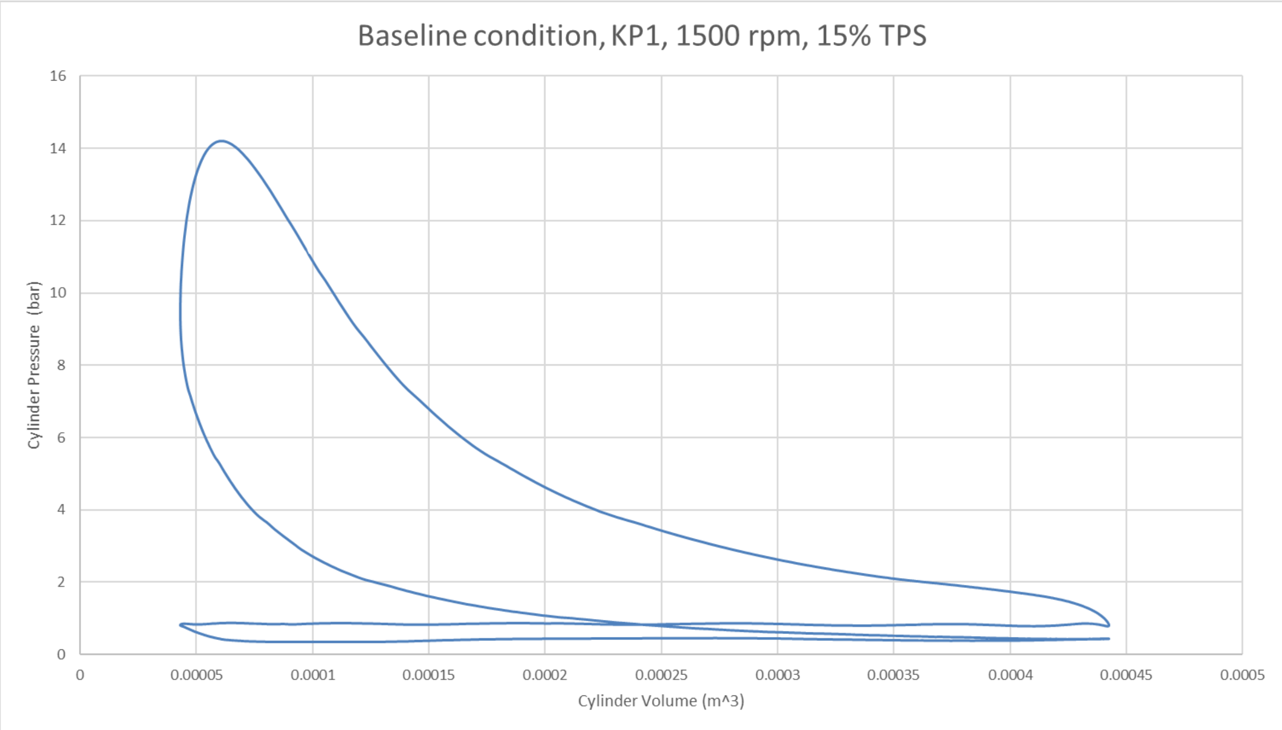


Figure 12: Example of a pressure versus volume diagram for the baseline test case, engine speed at 1500 rpm, at 15% throttle position.

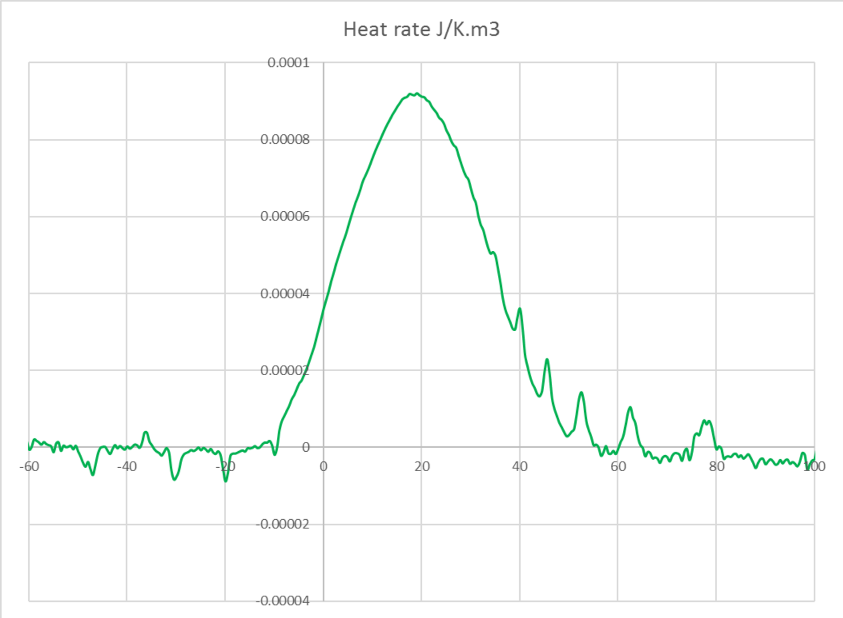


Figure 13: Example of the instantaneous heat release rate versus the crank angle, deg., for the baseline test case, engine speed at 1500 rpm, at 15% throttle position.

The rate of heat release is an indication of the rate of fuel burning which is related to the progress of fuel combustion in the combustion chamber.

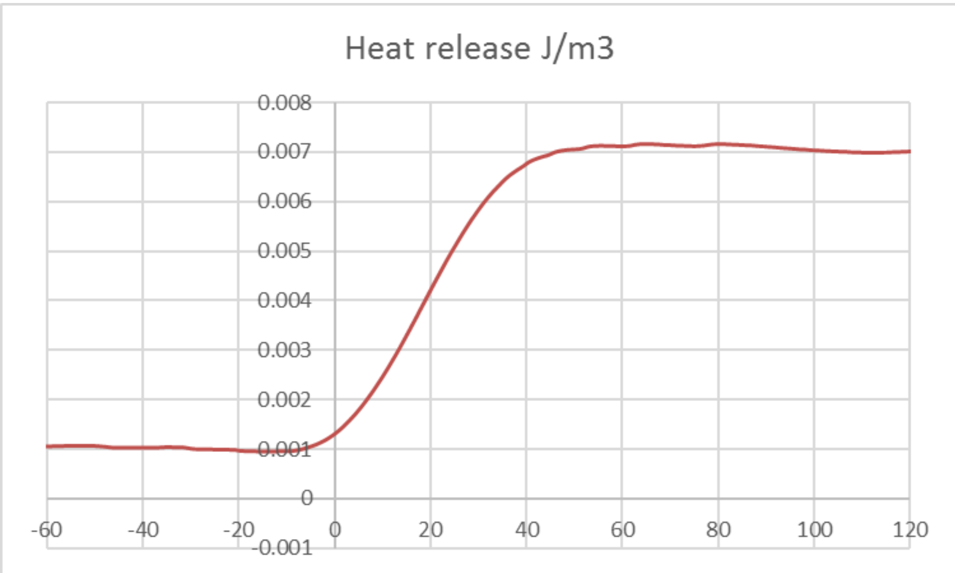


Figure 14: Example of the cumulative heat release versus crank angle, deg., for the baseline test case, engine speed at 1500 rpm, at 15% throttle position.

Pressure-crank angle data

An example of the effect of the addition of T1 and T2 (post-throttle injection) can be seen in Figure 15 for the in-cylinder pressure against engine crank angle, for test point, KP1, averaged over 500 consecutive engine cycles. The ignition and injection signals for each test are overlaid as a reference and as an aid to ensure consistency. Their scales are arbitrary. The last number appended relates to the key points in Table A3.1. In each plot, six in-cylinder gas pressures are shown as follows

Pre-throttle cases- 210WOW (Baseline), 210WW (Water injection), 210 WT2 (T2 injection)

Post Throttle cases- PThrotWT1 (T1 injection), PThrot 210 WT2 (T2 injection), PThrot 150 WT1 (T1 injection shortened duration)

Each case has a corresponding pair of ignition (IGN) and injection (INJ) traces. The filenames are those described in Section 5.3.

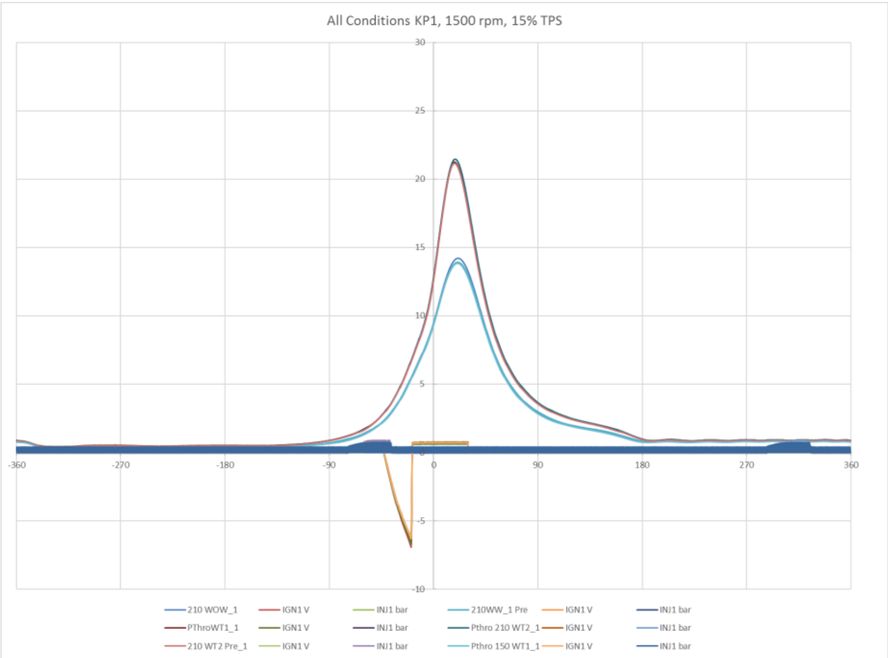


Figure 15: The in-cylinder pressure, bars, versus the engine crank angle, deg., for all the test cases, engine speed at 1500 rpm, at 15% throttle position.

From Figure 15, there are increased in-cylinder peak pressure, the angle of peak pressure, rate of pressure rise and angle of maximum rate of pressure rise values for the T1 and T2 post-throttle cases. The addition of T1 and T2 affects both phasing and rate of combustion. The combustion phasing is advanced resulting in a greater peak pressure and rise in rate of combustion. The effects are most evident at the smaller throttle angles.

The tabulated data and indicating figures for Key Points, KP1 to KP12 are provided in the Appendices.

Table 1 below shows the corresponding combustion indicating data (including ignition (Spark) and Injection (ITU) for Figure 15. All units are in bars or degrees ATDC/BTDC. The AVL abbreviations related to the real-time processed data over 500 cycles are as follows:

CDMCOUNT - crank division marker pulse.
CYCTIME - cumulative cycle time in ms.
CYCDUR - individual cycle time in ms.
IGTI1 – ignore.
SPARK1 - angle of spark trigger signal before TDC (deg).
PMAX1, APMAX1, RMAX1, ARMAX1 - values of maximum in-cylinder pressure (bar), angle where it occurred (deg), maximum rate of pressure rise (bar/deg) and angle (deg) where it occurred.
IMEP1, IMEPH, IMEPL - indicated mean effective pressure - net, gross, pumping (bar).
AI05%, 10%, 50% and 90% - burn angles for 5, 10, 50 and 90% mass fraction burned calculated from the heat release inferred from the in-cylinder pressure.

Table 1: Combustion tests details for all the test cases, engine speed at 1500 rpm, at 15% throttle position.

	210 WOW_1	210WW_1 Pre	PThroWT1_1	Pthro 210 WT2_1	210 WT2 Pre_1	Pthro 150 WT1_1
SPEED, rpm	1500.5	1500.7	1500.6	1500.3	1500.6	1500.6
CDMCOUNT	2880.0	2880.0	2880.0	2880.0	2880.0	2880.0
CYCTIME	20080.3	20100.2	20101.1	2075.8	20079.0	20104.4
CYCDUR, ms	80.0	80.0	80.0	80.0	80.0	80.0
IGTI1	-8252.0	-8252.0	-8252.0	-7925.1	-8252.0	-8252.0
SPARK1	-18.9	-19.0	-18.9	-18.9	-18.9	-18.9
ITI1	-7664.9	-7984.6	-6966.0	-8552.0	-7362.2	-7702.1
ITU1	1.0	0.6	1.0	0.0	1.3	0.5
ITIPRE1	-8007.3	-8210.2	-7748.8	-8552.0	-7826.6	-8108.1
ITUPRE1	0.0	0.0	-32.7	0.0	0.0	0.0
ITIPOS1	-8007.3	-8210.2	-7748.8	-8552.0	-7826.6	-8108.1
ITUPOS1	0.0	0.0	-32.7	0.0	0.0	0.0
PMAX1	14.3	14.0	21.4	21.6	14.0	21.3
APMAX1	21.4	21.1	18.3	19.0	20.8	18.4
RMAX1	0.4	0.4	0.7	0.7	0.4	0.7
ARMAX1	1.1	0.7	3.8	3.4	0.9	3.8
IMEP1	3.3	3.2	4.4	4.5	3.2	4.4
IMEPH1	3.7	3.7	4.8	4.9	3.6	4.8
IMEPL1	-0.4	-0.5	-0.4	-0.4	-0.4	-0.4
AI05%_1	0.8	0.7	-1.5	-1.6	0.7	-1.6
AI10%_1	4.2	4.2	1.3	1.3	4.0	1.2
AI50%_1	19.9	20.4	14.3	14.7	19.9	14.3
AI90%_1	36.9	37.9	31.7	31.4	36.9	31.3

6.2.2 Combustion phasing-

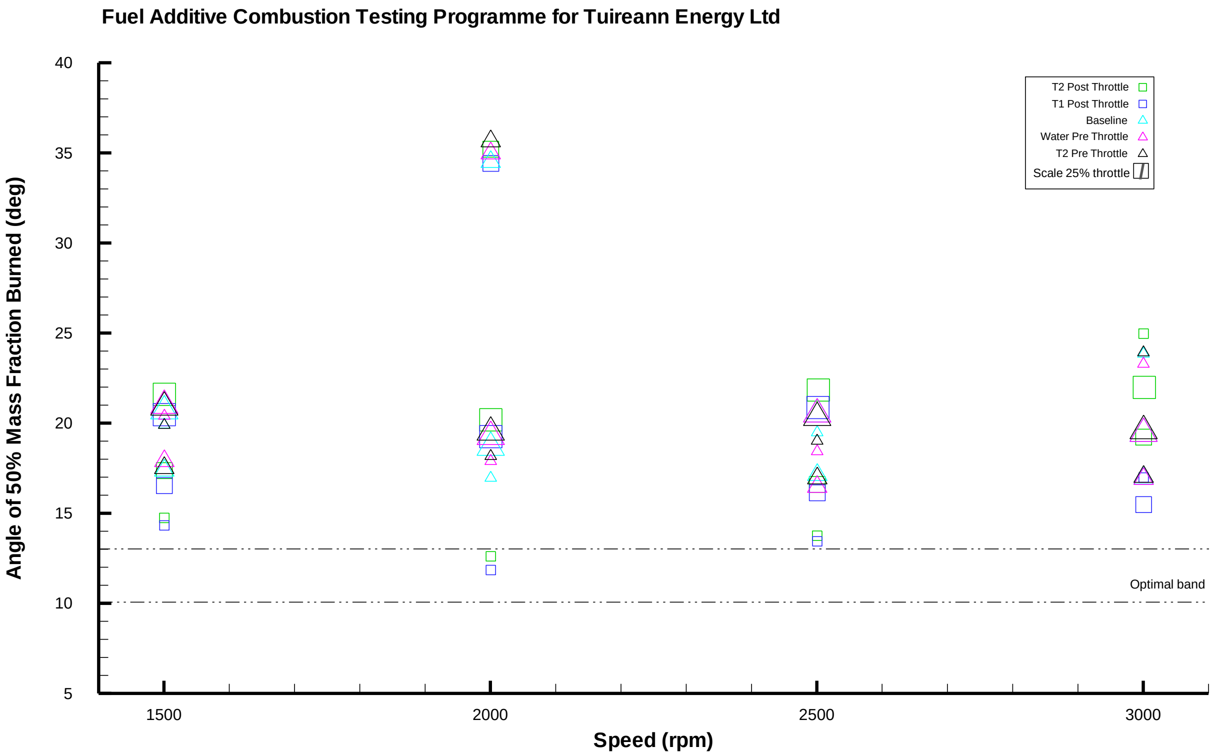


Figure 16: Angle of 50% Mass Fraction Burned (CA50) versus engine speed for the test programme with and without the additives, at three different throttle positions.

The addition of T1 and T2 affects both the phasing and rate of combustion. This is reflected in the 50% Mass Fraction Burned position, commonly used to evaluate optimum combustion phasing. The effect due to the additives is most significant again at the smaller throttle angles. The spark ignition timing (Ignition map) was far from optimal at the 2000 rpm condition at 25% throttle in all cases.

6.2.3 Combustion stability

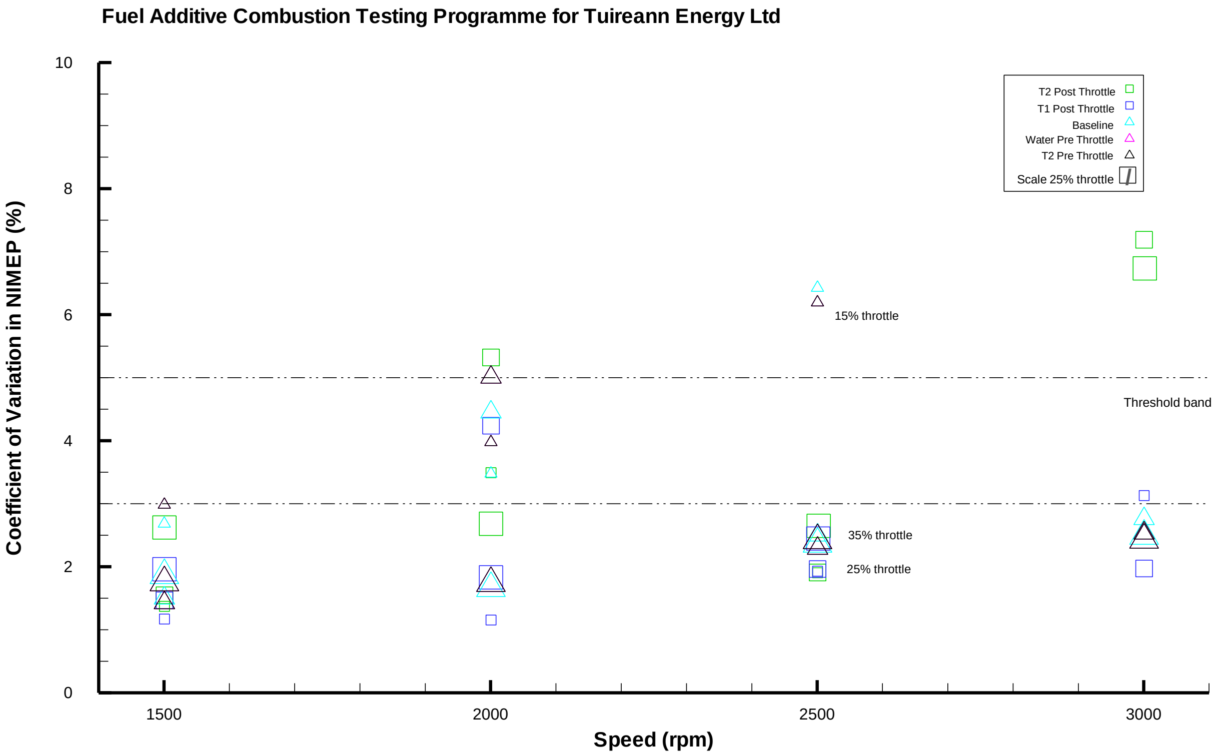


Figure 17: Coefficient of Variation in the Indicated mean effective pressure versus engine speed for the test programme with and without the additives, at three different throttle positions.

The CoV in IMEP is used as a measure of combustion stability. It is defined as the ratio of standard deviation in the Net IMEP to the mean value of the Net IMEP. In these tests it was calculated over 500 engine cycles. Generally, engine combustion engineers consider values up to 5% as acceptable for gasoline engines. The results of these tests show that generally this threshold is met, with most cases below 3%, except in the case of T2 at wider throttle and 3000 rpm.

7.0 Conclusions

A comprehensive set of engine performance tests, including fuel consumption, engine power and combustion characteristics, were carried out using a 1.2 litre, naturally aspirated, spark ignition, 3 cylinder production engine. The repeatability of the tests and the uncertainty in the results were ascertained.

For the tests, the engine was operated with 95 RON pump grade, unleaded gasoline as the baseline test case. Other subsequent tests included pre-throttle water injection, pre-throttle injection of the T2 additive, post-throttle injection of T1 and T2 additives as well as a case without static charge applied.

All the results had a common trend; the baseline, baseline with water injection, and T2 injection at the pre-throttle position all present similar results for all the test cases examined. All the T1 and T2 post-throttle injection cases present significant improvements in all the test cases examined for the 15% throttle opening position. The addition of the T1 and T2 additives at the post-throttle position appears to advance the combustion phasing, thus increasing the peak in-cylinder pressure, and therefore, the rate of combustion. However, at the 25% and 35% throttle opening positions, the results for all the test cases are less significant or within the experimental error margins.

The T1 and T2 additives appear to have the potential to improve the combustion of fuel in the engine at low throttle opening positions but further work needs to be conducted in order to ascertain if the observed data differences are due to the additives (and which one), or the positioning of the injection process (increased suction effect through the nebuliser) or a combination of both. This could then inform the application of the improvements to cases of higher throttle openings.

8.0 Recommendation for Future Work

A test cycle involving water injection at the post-throttle position. To eliminate the effect of the throttle position for injection.

Study of the effects of the influence of ignition timing swing and AFR upon torque and combustion phasing for each test case.

A test cycle involving a re-run with the baseline fuel, until initial baseline performance conditions are re-established, before every additive test. To isolate the influence of the additives.

A test cycle involving long term use analysis of the additives. To investigate the residency effect of the additives.

Single-cylinder engine programme with simplified operation to investigate fundamental key parameters.

Single droplet (evaporation, heat transfer, combustion) and spray (droplet size distribution, heated sprays, impingement) analyses to better understand the thermophysical processes underpinning the additives.

Detailed emissions tests at NEDC and representative cycles.

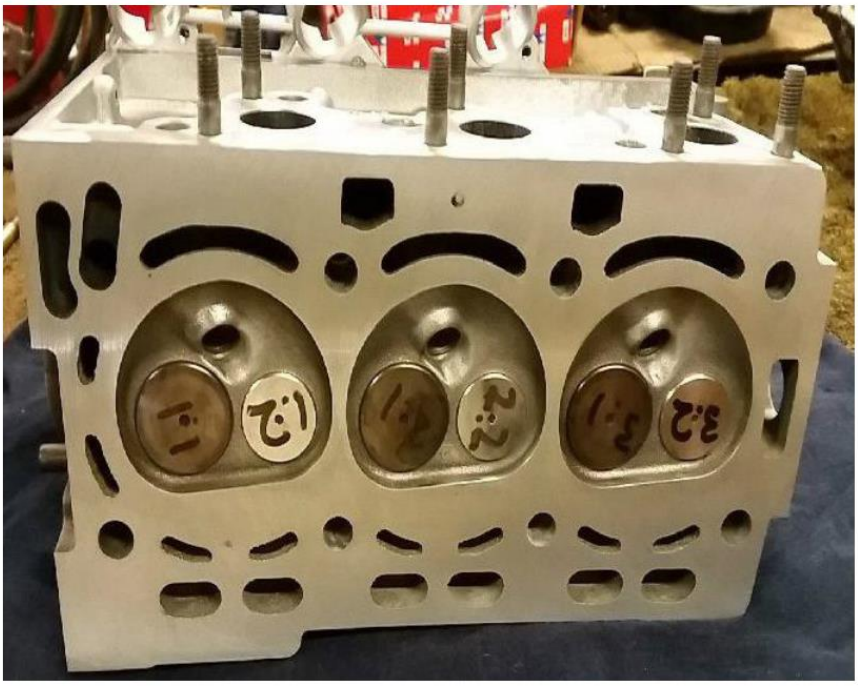
Appendices

Appendix 1 Engine specification

http://www.scribd.com/doc/27643869/1-2-3cyl-Engine#scribd
http://www.scribd.com/doc/40477415/3-cylinders-engines-for-Skoda-cars-Engine-code-AWY-AZQ

VW Polo Fox Lupo Fabia (6Y) Ibiza

1.2 l, 6V I3 AWY BMD AZQ BME series



http://www.gumtree.com/p/car-replacement-parts/vw-polo-fox-lupo-fabia-ibiza-1.2-6v-12v-awy-bmd-bbm-azq-bme-cylinder-head-repair/1089705270

Engine code	AWY	AZQ
Type	3-cylinder inline engine with 2 valves per cylinder	3-cylinder inline engine with 4 valves per cylinder
Displacement	1198 cm^3	1198 cm^3
Alésage	76.5 mm	76.5 mm
Course	86.9 mm	86.9 mm
Compression ratio	10.3 : 1	10.5 : 1
Max. power output	40 kW at 4750 rpm^{-1}	47 kW at 5400 rpm^{-1}
Max. torque	106 Nm at 3000 rpm^{-1}	112 Nm at 3000 rpm^{-1}
Engine management system	Simos 3PD (Multipoint)	Simos 3PE (Multipoint)
Fuel	Unleaded petrol RON 95 (91 possible with reduction in output)	Unleaded petrol RON 95 (91 possible with reduction in output)
Emission standard	EU4	EU4

http://www.scribd.com/doc/40477415/3-cylinders-engines-for-Skoda-cars-Engine-code-AWY-AZQ#scribd

stroke ratio: 0.88:1 - undersquare/long-stroke, 399.4 cc per cylinder
Connecting rod length 130 mm

Figure A1.1: VW AWY/BMD 1.2 litre engine, with the specifications in the table.

Appendix 2 Test bed calibration certification

young calibration

CERTIFICATE OF CALIBRATION

ISSUED BY YOUNG CALIBRATION LIMITED
DATE OF ISSUE: 08/08/19
CERTIFICATE NUMBER: C99485A

Young Calibration Ltd
5 Cecil Pashley Way
Shoreham Airport
Shoreham-by-Sea
West Sussex, BN43 5FF

+44 (0)1273 455572
enquiries@youngcalibration.co.uk
www.youngcalibration.co.uk

Document : YCF/016
Issue Number : 2.8
Page 1 of 1 Page
Approved Signatory

NBull

☐ A. Young ☐ M. Hindle
■ N. Marden ☐ C. Millard

Customer: University of Brighton
Customer Address: Centre for Automotive Engineering
C214 Cockcroft Building
Brighton
East Sussex, BN2 4GJ

Customer's Reference No.: CI04686

YCL Project Number: 52049

Calibration Date: 08 August 2019
Requested Due Date: 08 August 2020
Calibration Performed By: L. Harris & A. Young
Calibration Procedure: Procedure 53R

Manufacturer & Model: AVL Bobcat
UUT Description: AVL 733S Fuel Meter
Customer ID Number: Bobcat
Serial Number: 4067
Equipment Condition: Used / As Found / Final
Nominal Calibration Range: Refer to Results

Calibration Location: Bobcat Training Bed

Laboratory Temperature: 20.5 to 21.5 °C
Laboratory Barometric Pressure: 1005.1 to 1006.1 mbarA
Laboratory Humidity: 55.0 to 57.0 %RH
Reference Equipment: Traceable to UK National Standards

Calibration Method & Notes

The fuel meter was calibrated by filling the internal bucket of the AVL 733S, draining off measured amounts of fuel, and comparing the indicated readings from the AVL 733 with the actual fuel mass collected whilst also completing an internal Accuracy Check using the AVL 733S Dynamic Software.

Calibration Results

Indicated Start Mass (g)	Indicated Final Mass (g)	Derived Batch Mass (g)	Actual Batch Mass (g)	Observed Error (%)	Internal Check Weight (g)
1807	1599	208.4	208.6	-0.09	90.0
1599	1400	198.7	198.9	-0.10	
1400	1188	212.5	212.8	-0.14	
1188	967	221.1	221.4	-0.15	90.0
967	723	244.0	244.3	-0.14	
723	478	244.7	245.0	-0.11	
478	222	255.5	255.7	-0.07	90.0

The uncertainty of the fuel measurement is ± 0.5%

The uncertainties reported refer to the measured values only and not to the ability of the instrument to maintain its calibration.

Calibration Method & Notes

The pressure transducer channels were calibrated using a series transfer method of calibration with a reference pressure calibrator whose calibration is traceability to national standards via UKAS Lab 0604

The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor k=2, providing a level of confidence of approximately 95%.
The uncertainty evaluation has been carried out in accordance with ISO 17025 requirements.
This certificate is issued in accordance with the laboratory requirements of ISO 17025. It provides traceability of measurement to the SI system of units and / or to units of measurement realised at the National Physical Laboratory or other recognised national metrology institutes.
The certificate may not be reproduced other than in full, except with the prior written approval of the issuing laboratory.

Figure A2.1: Test bed calibration certification.

young calibration

CERTIFICATE OF CALIBRATION

ISSUED BY YOUNG CALIBRATION LIMITED
DATE OF ISSUE: 08/08/19
CERTIFICATE NUMBER: C99485B

Young Calibration Ltd
5 Cecil Pashley Way
Shoreham Airport
Shoreham-by-Sea

Approved Signatory

West Sussex, BN43 5FF

+44 (0)1273 455572
enquiries@youngcalibration.co.uk
www.youngcalibration.co.uk

□ A. Young □ M. Hindle
■ N. Marden □ C. Millard

Customer: University of Brighton
Customer Address: Centre for Automotive Engineering
C214 Cockcroft Building
Brighton
East Sussex, BN2 4GJ

Customer's Reference No.: CI04686

YCL Project Number: 52049

Calibration Date: 08 August 2019
Requested Due Date: 08 August 2020
Calibration Performed By: L. Harris & A. Young
Calibration Procedure: Procedure 53R

Manufacturer & Model: AVL Bobcat
UUT Description: Test Bed Data System
Customer ID Number: Bobcat
Serial Number: Pressure Module
Equipment Condition: Used / As Found / Final
Nominal Calibration Range: Refer to Results

Calibration Location: Bobcat Training Bed

Laboratory Temperature: 20.5 to 21.5 °C
Laboratory Barometric Pressure: 1005.5 to 1006.5 mbarA
Laboratory Humidity: 56.0 to 58.0 %RH
Reference Equipment: Traceable to UK National Standards

Calibration Results

Oil Pressure
Exhaust Pressure
Post Cat Pressure

Inlet Cyl Pressure 1

Applied Pressure (kPa)	Indicated Pressure (kPa)	Applied Pressure (kPa)	Indicated Pressure (kPa)	Applied Pressure (kPa)	Indicated Pressure (kPa)
0.0	-0.2	0.0	0.0	0.0	0.0
200.0	199.2	50.0	49.9	100.0	99.8
400.0	399.1	100.0	99.9	200.0	199.9
600.0	599.3	150.0	149.9	300.0	300.0
800.0	800.0	200.0	199.9	400.0	399.9
		250.0	250.0		

Barometric Pressure		Air Intake Flow	
Applied Pressure (mbarA)	Indicated Pressure (mbarA)	Applied Current (mA)	Indicated Flow (kg/hr)
800.0	800.1	4.000	0.00
900.0	900.0	8.000	50.01
1005.6	1005.8	12.000	100.02
1100.0	1099.9	16.000	150.03
1200.0	1199.9	20.000	200.04

The uncertainty of the absolute pressure m
mbar
The uncertainty of the gauge pressure mea
mbar
The uncertainty of the current measureme
mA

The uncertainties reported refer to the measured values only and not to the ability of the instrument to maintain its calibration.

West Sussex, BN43 5FF

The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor k=2, providing a level of confidence of approximately 95%.
The uncertainty evaluation has been carried out in accordance with ISO 17025 requirements.

This certificate is issued in accordance with the laboratory requirements of ISO 17025. It provides traceability of measurement to the SI system of units and / or to units of measurement realised at the National Physical Laboratory or other recognised national metrology institutes.

Figure A2.2: Test bed calibration certification.

young calibration

CERTIFICATE OF CALIBRATION

ISSUED BY YOUNG CALIBRATION LIMITED
DATE OF ISSUE: 08/08/19
CERTIFICATE NUMBER: C99485C

Young Calibration Ltd
5 Cecil Pashley Way
Shoreham Airport
Shoreham-by-Sea

Document : YCF/016
Issue Number : 2.8
Page 1 of 1 Page
Approved Signatory

+44 (0)1273 455572
enquiries@youngcalibration.co.uk
www.youngcalibration.co.uk

□ A. Young □ M. Hindle
■ N. Marden □ C. Millard

Customer: University of Brighton
Customer Address: Centre for Automotive Engineering
C214 Cockcroft Building
Brighton
East Sussex, BN2 4GJ
Customer's Reference No.: CI04686
YCL Project Number: 52049
Calibration Date: 08 August 2019
Requested Due Date: 08 August 2020
Calibration Performed By: L. Harris & A. Young
Calibration Procedure: Procedure 53R

Manufacturer & Model: AVL Bobcat
UUT Description: Test Bed Data System
Customer ID Number: Bobcat
Serial Number: Temperature Module
Equipment Condition: Used / As Found / Final
Nominal Calibration Range: Refer to Results
Calibration Location: Bobcat Training Bed
Laboratory Temperature: 20.5 to 21.5 °C
Laboratory Barometric Pressure: 1006.0 to 1007.0 mbarA
Laboratory Humidity: 55.0 to 57.0 %RH
Reference Equipment: Traceable to UK National Standards

The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor k=2, providing a level of confidence of approximately 95%.
The uncertainty evaluation has been carried out in accordance with ISO 17025 requirements.

This certificate is issued in accordance with the laboratory requirements of ISO 17025. It provides traceability of measurement to the SI system of units and / or to units of measurement realised at the National Physical Laboratory or other recognised national metrology institutes.

The certificate may not be reproduced other than in full, except with the prior written approval of the issuing laboratory.

Figure A2.3: Test bed calibration certification.

young calibration

CERTIFICATE OF CALIBRATION

ISSUED BY YOUNG CALIBRATION LIMITED
DATE OF ISSUE: 08/08/19
CERTIFICATE NUMBER: C99485D

Young Calibration Ltd
5 Cecil Pashley Way
Shoreham Airport
Shoreham-by-Sea

Document : YCF/016
Issue Number : 2.8
Page 1 of 1 Page
Approved Signatory

Calibration Method & Notes

libration wi
sability to

national standards via UKAS Lab 0604

Calibration Results

Applied Temperature (°C)	Ch 1 (°C)	Ch 2 (°C)	Ch 3 (°C)	Ch 4 (°C)	Ch 5 (°C)	Ch 6 (°C)	Ch 7 (°C)	Ch 8 (°C)	Ch 9 (°C)	Ch 10 (°C)
0	0.8	0.6	0.7	0.6	0.7	1.2	0.6	0.7	0.9	1.0
300	300.8	300.6	300.7	300.5	300.7	301.1	300.6	300.6	300.9	301.0
600	600.9	600.7	600.8	600.6	600.9	601.3	600.8	600.7	600.9	601.0
900	901.0	900.8	900.8	900.6	900.9	901.4	900.9	900.8	901.0	901.1
1200	1201.2	1200.9	1201.0	1200.7	1201.1	1201.5	1201.1	1200.9	1201.1	1201.2

Applied Temperature (°C)	Ch 11 (°C)	Ch 12 (°C)	Ch 13 (°C)	Ch 14 (°C)	Ch 15 (°C)	Ch 16 (°C)	Ch 17 (°C)	Ch 18 (°C)	Ch 19 (°C)	Ch 20 (°C)
0	0.7	0.0	0.7	0.8	0.3	0.3	0.5	0.6	0.6	0.6
300	300.7	300.0	300.7	300.8	300.3	300.3	300.6	300.6	300.7	300.6
600	600.8	600.0	600.8	600.9	600.4	600.5	600.7	600.7	600.8	600.7
900	900.8	900.0	900.8	901.1	900.5	900.7	900.8	900.8	900.9	900.6
1200	1201.0	1200.1	1201.0	1201.6	1200.6	1200.5	1201.0	1201.0	1201.0	1200.6

The uncertainty of the temperature me: 0.6°C

The uncertainties reported refer to the measured values only and not to the ability of the instrument to maintain its calibration.

The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor k=2, providing a level of confidence of approximately 95%.
The uncertainty evaluation has been carried out in accordance with ISO 17025 requirements.

This certificate is issued in accordance with the laboratory requirements of ISO 17025. It provides traceability of measurement to the SI system of units and / or to units of measurement realised at the National Physical Laboratory or other recognised national metrology institutes.

Figure A2.4: Test bed calibration certification.

young calibration

CERTIFICATE OF CALIBRATION

ISSUED BY YOUNG CALIBRATION LIMITED
DATE OF ISSUE: 20/08/19
CERTIFICATE NUMBER: C99485-D

Young Calibration Ltd
5 Cecil Pashley Way
Shoreham Airport
Shoreham-by-Sea
West Sussex, BN43 5FF

+44 (0)1273 455572
enquiries@youngcalibration.co.uk
www.youngcalibration.co.uk

Document : YCF/033

□ A. Young □ M. Hindle
■ N. Mardon □ C. Millard

Customer: University of Brighton

Manufacturer & Model: Kistler 6118BFD16 & 5001

Issue Number : 3.8
Page 1 of 1 Page
Approved Signatory

Customer Address: Centre for Automotive Engineering
C214 Cockcroft Building
Brighton
East Sussex, BN2 4GJ

Purchase Order Number: CI04687
Date of Receipt: 08 August 2019
YCL Project Number: YC/52049
Calibration Date: 20 August 2019
Requested Due Date: N/A
Calibration Performed By: N. Mardon
Calibration Procedure: Procedure 53K

UUT Description: Piezo-electric pressure transducer & amplifier
Serial Number: 4328278 & 26187
Customer ID Number: N/A
Equipment Condition: Used / As Received / Final
Instrument Range: 0 to 200 bar
Nominal Calibration Range: 0 to 120 bar
Calibration Fluid: Sebacate Oil
Calibration Location: YCL Laboratory
Laboratory Temperature: 19.5 to 20.5 °C
Laboratory Barometric Pressure: 999.5 to 1000.5 mbar A
Laboratory Relative Humidity: 39.0 to 41.0 %RH
Reference Equipment: YC/010/082 & 417

Calibration Method & Notes
The UUT (Unit Under Test) was allowed a minimum of 1 hour to acclimatise to the laboratory conditions prior to calibration.
The calibration was conducted using quasi-static comparison method of calibration against a deadweight tester.
The UUT was exercised over its range and where applicable the manufacturers procedure for zeroing was performed prior to calibration.
The UUT was powered from the customer supplied Kistler Type 5001DC charge amplifier and output voltage read from a YCL precision multimeter.
The calibration was performed with the UUT in the vertical plane with the pressure port orientated downward.
The datum for the pressure measurements was taken to be the sealing face of the UUT.
Non-SI units: The conversion value used in relation to the Pascal was 1.0E-5 bar.
*The derived pressure is calculated by multiplying the output voltage, amplifier gain and sensitivity settings, divided by the average calculated transducer sensitivity.
The Combined MU (measurement uncertainty) combines the UUT and reference values. The measurement uncertainty component for the reference pressure is ± 0.050 %.

Calibration Results

Actual Pressure (bar)	UUT Amp (Sensitivity)	UUT Calculated (pc/bar)	Derivered Pressure (bar)	Derived Error (bar)	Derived Error (% FS)	Combined MU (± bar)
0.0000	17.1	-	-	-	-	-
10.0000	17.1	14.00	9.835	-0.165	-0.14	0.0050
20.0000	17.1	14.16	19.881	-0.119	-0.10	0.0100
30.0000	17.1	14.22	29.958	-0.042	-0.04	0.0150
40.0000	17.1	14.24	39.994	-0.006	0.00	0.0200
50.0000	17.1	14.26	50.068	0.068	0.06	0.0250
60.0000	17.1	14.26	60.101	0.101	0.08	0.0300
70.0000	17.1	14.28	70.184	0.184	0.15	0.0350
80.0000	17.1	14.29	80.255	0.255	0.21	0.0400
90.0000	17.1	14.29	90.318	0.318	0.27	0.0450
100.0000	17.1	14.29	100.377	0.377	0.31	0.0500
110.0000	17.1	14.30	110.442	0.442	0.37	0.0550
120.0000	17.1	14.29	120.455	0.455	0.38	0.0600

Amplifier Sensitivity: 10 Mechanical Units / Volt

Average Transducer at 120 bar: 14.24 pc/bar

The results and uncertainties reported refer to the measured values of the UUT stated and are not indicative of its reproducibility or ability to maintain its calibration.

The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor k =2, providing a level of confidence of approximately 95%. The uncertainty evaluation has been carried out in accordance with ISO 17025 requirements.

Figure A2.5: Test bed calibration certification

young calibration

CERTIFICATE OF CALIBRATION

ISSUED BY YOUNG CALIBRATION LIMITED
DATE OF ISSUE: 11/09/19
CERTIFICATE NUMBER: C99485-E

This certificate is issued in accordance with the laboratory requirements of ISO 17025. It provides traceability of measurement to the SI system of units and / or to units of measurement realised at the National Physical Laboratory or other recognised national metrology institutes.

Young Calibration Ltd
5 Cecil Pashley Way
Shoreham Airport
Shoreham-by-Sea
West Sussex, BN43 5FF

+44 (0)1273 455572
enquiries@youngcalibration.co.uk
www.youngcalibration.co.uk

Document : YCF/016

□ A. Young □ M. Hindle
■ N. Marden □ C. Millard

Customer: University of Brighton

Manufacturer & Model: AVL Bobcat

The certificate may not be reproduced other than in full, except with the prior written approval of the issuing laboratory.

Issue Number : 2.8
Page 1 of 1 Page
Approved Signatory

Customer Address: Centre for Automotive Engineering
C214 Cockcroft Building
Brighton
East Sussex, BN2 4GJ

Customer's Reference No.: CI04687

YCL Project Number: 52049

Calibration Date: 11 September 2019
Requested Due Date: 11 September 2020
Calibration Performed By: L. Harris & A. Young
Calibration Procedure: Procedure 53R

UUT Description: Dyno Torque
Customer ID Number: Bobcat
Serial Number: Unknown
Equipment Condition: Used / As Found / Final
Nominal Calibration Range: Refer to Results

Calibration Location: Bobcat Training Bed

Laboratory Temperature: 20.5 to 21.5 °C
Laboratory Barometric Pressure: 1019.5 to 1020.5 mbarA
Laboratory Humidity: 55.0 to 57.0 %RH
Reference Equipment: Traceable to UK National Standards

Calibration Method & Notes

The AVL dynamometer was fitted with calibration arms on both sides of the dyno and with a weight hanger on the positive side. The dyno was balanced back to zero using a slide weight on the opossing calibration arm.

Calibrated weights were applied on the hanger and the derived torque calculated.

Calibration Arm Length = 1019 mm

Calibration Results : As Found

Dyno Calibration Table		Applied Mass	Derived Torque	Indicated Torque
(mV)	(Nm)	(kg)	(Nm)	(Nm)
-38.001	0.0	0.000	0.0	0.0
-500.00	400.0	10.078	100.7	117.0

Calibration Results : After Adjustment

Dyno Calibration Table		Applied Mass	Derived Torque	Indicated Torque
(mV)	(Nm)	(kg)	(Nm)	(Nm)
-38.188	0.0	0.000	0.0	0.0
-172.03	100.8	1.000	10.0	10.0
		1.500	15.0	15.0
		3.540	35.4	35.4
		4.539	45.4	45.5
		9.078	90.7	90.8
		10.078	100.7	100.8

The uncertainty of the above measurements is ± 0.25%

The uncertainties reported refer to the measured values only and not to the ability of the instrument to maintain its calibration.

The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor k =2, providing a level of confidence of approximately 95%.
The uncertainty evaluation has been carried out in accordance with ISO 17025 requirements.

This certificate is issued in accordance with the laboratory requirements of ISO 17025. It provides traceability of measurement to the SI system of units and / or to units of measurement realised at the National Physical Laboratory or other recognised national metrology institutes.

The certificate may not be reproduced other than in full, except with the prior written approval of the issuing laboratory.

Figure A2.6: Test bed calibration certification

Appendix 3 Engine test points schedule (for 210s example)

Table A3.1 Engine test points schedule; 201 seconds.

Engine Speed	Throttle Position	Ramp to Setpoint	Steady Measure	Key Test Points
(rpm)	(%)*	(s)	(s)	(-)
1500	15	10	0	
1500	15	0	210	KP1
1500	25	10	0	
1500	25	0	210	KP2
1500	35	10	0	
1500	35	0	210	KP3
2000	15	10	0	
2000	15	0	210	KP4
2000	25	10	0	
2000	25	0	210	KP5
2000	35	10	0	
2000	35	0	210	KP6
2500	15	10	0	
2500	15	0	210	KP7
2500	25	10	0	
2500	25	0	210	KP8
2500	35	10	0	
2500	35	0	210	KP9
3000	15	10	0	
3000	15	0	210	KP10
3000	25	10	0	
3000	25	0	210	KP11
3000	35	10	0	
3000	35	0	210	KP12

*note- the testbed linear actuator throttle span from 0 - WOT is ranged as 0 - 40 %.

Appendix 4 Determining injection positions: pre- and post- throttle feed locations

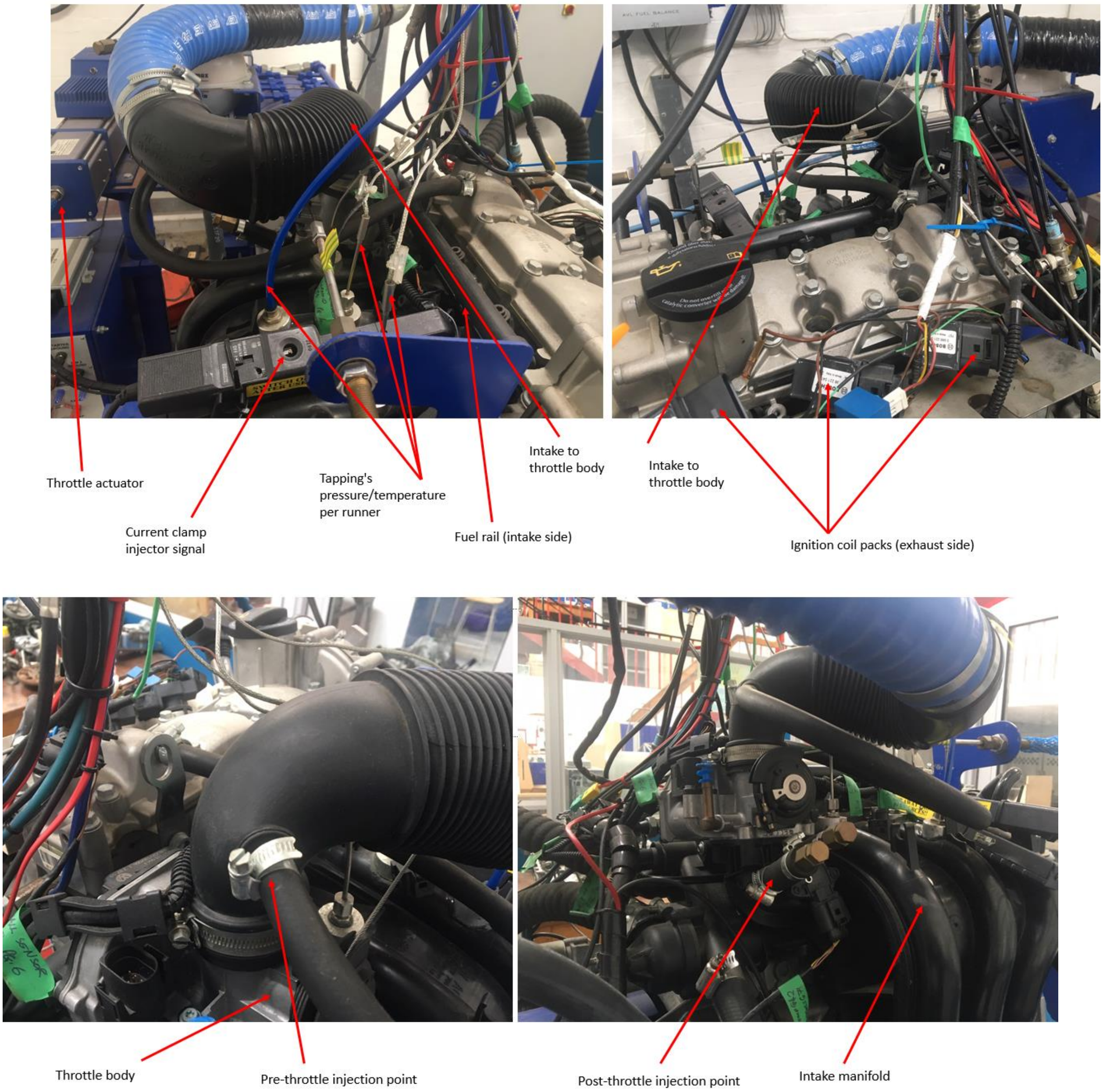
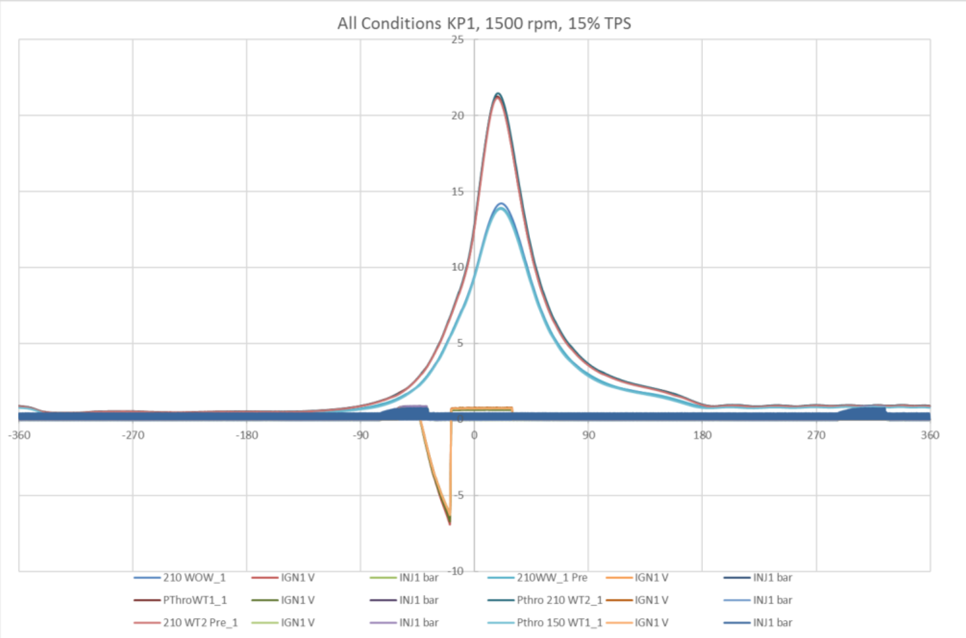


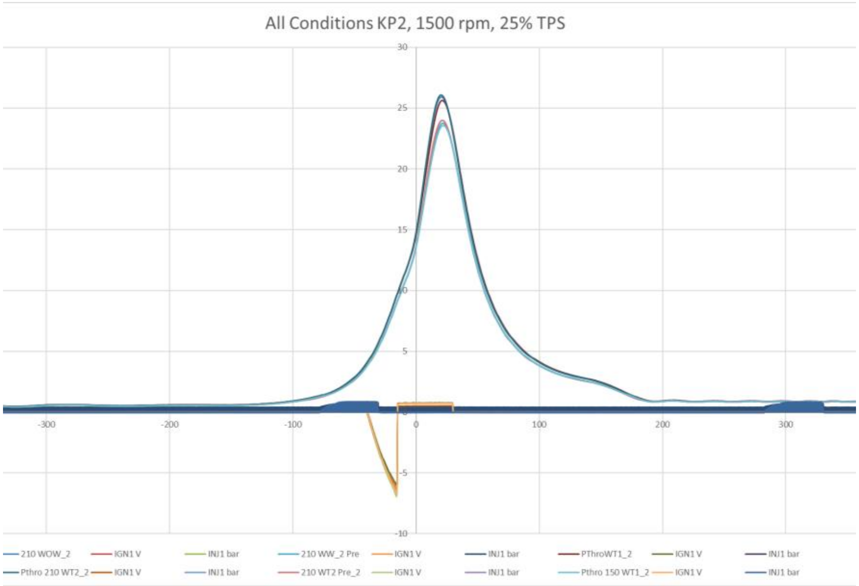
Figure A4.1: Locations of the pre-throttle and post-throttle injection points.

Appendix 5 Pressure Indicating Analysis



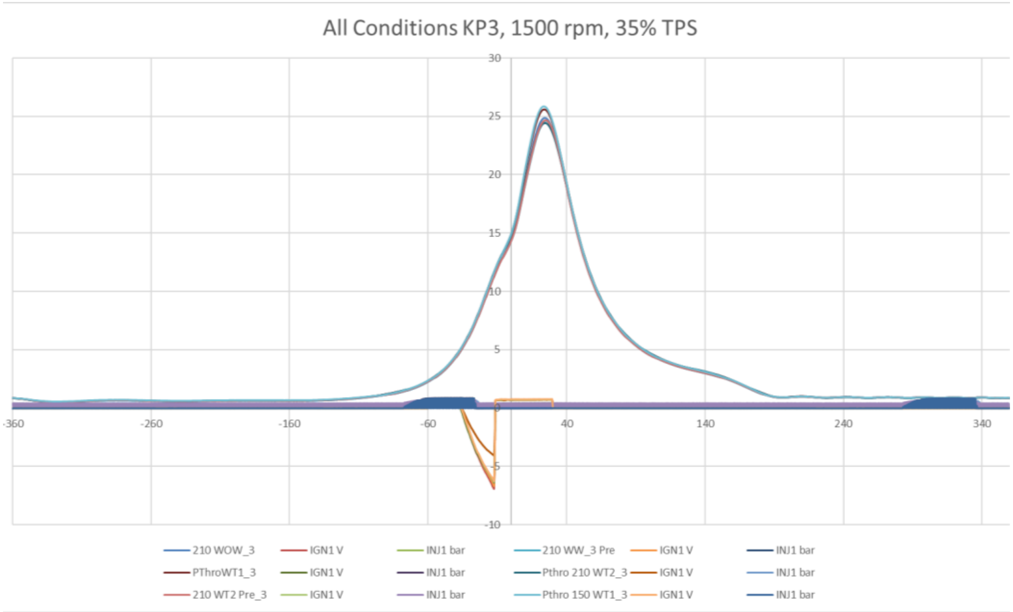
KP1	210 WOW_1	210WW_1 Pre	PThroWT1_1	Pthro 210 WT2_1	210 WT2 Pre_1	Pthro 150 WT1_1
SPEED	1500.5	1500.7	1500.6	1500.3	1500.6	1500.6
CDMCOUNT	2880.0	2880.0	2880.0	2880.0	2880.0	2880.0
CYCTIME	20080.3	20100.2	20101.1	2075.8	20079.0	20104.4
CYCDUR	80.0	80.0	80.0	80.0	80.0	80.0
IGTI1	-8252.0	-8252.0	-8252.0	-7925.1	-8252.0	-8252.0
SPARK1	-18.9	-19.0	-18.9	-18.9	-18.9	-18.9
ITI1	-7664.9	-7984.6	-6966.0	-8552.0	-7362.2	-7702.1
ITU1	1.0	0.6	1.0	0.0	1.3	0.5
ITIPRE1	-8007.3	-8210.2	-7748.8	-8552.0	-7826.6	-8108.1
ITUPRE1	0.0	0.0	-32.7	0.0	0.0	0.0
ITIPOS1	-8007.3	-8210.2	-7748.8	-8552.0	-7826.6	-8108.1
ITUPOS1	0.0	0.0	-32.7	0.0	0.0	0.0
PMAX1	14.3	14.0	21.4	21.6	14.0	21.3
APMAX1	21.4	21.1	18.3	19.0	20.8	18.4
RMAX1	0.4	0.4	0.7	0.7	0.4	0.7
ARMAX1	1.1	0.7	3.8	3.4	0.9	3.8
IMEP1	3.3	3.2	4.4	4.5	3.2	4.4
IMEPH1	3.7	3.7	4.8	4.9	3.6	4.8
IMEPL1	-0.4	-0.5	-0.4	-0.4	-0.4	-0.4
AI05%_1	0.8	0.7	-1.5	-1.6	0.7	-1.6
AI10%_1	4.2	4.2	1.3	1.3	4.0	1.2
AI50%_1	19.9	20.4	14.3	14.7	19.9	14.3
AI90%_1	36.9	37.9	31.7	31.4	36.9	31.3

Figure A5.1: Data sets for 1500 rpm, 15% throttle position.



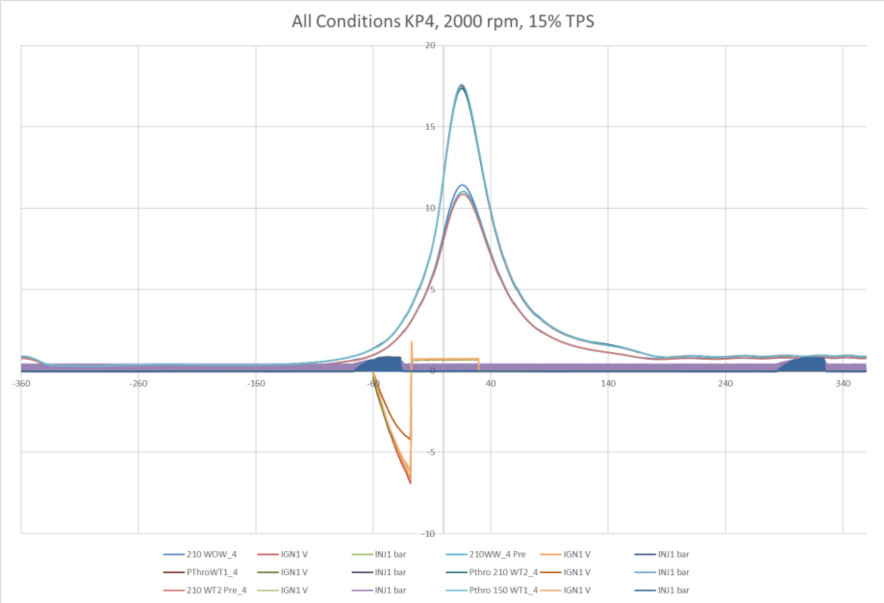
KP2	210 WOW_2	210 WW_2 Pre	PThroWT1_2	Pthro 210 WT2_2	210 WT2 Pre_2	Pthro 150 WT1_2
SPEED	1500.57	1500.49	1500.60	1500.91	1500.51	1500.66
CDMCOUNT	2880.00	2880.00	2880.00	2880.00	2880.00	2880.00
CYCTIME	20093.55	20105.96	20078.97	2080.64	20066.78	20033.95
CYCDUR	79.97	79.97	79.97	79.95	79.97	79.96
IGTI1	-8252.00	-8224.48	-8252.00	-8252.00	-8252.00	-8219.31
SPARK1	-15.29	-15.36	-15.28	-15.43	-15.27	-15.29
ITI1	-8139.22	-8359.37	-7898.23	-8552.00	-7795.87	-8159.74
ITU1	0.48	0.22	0.42	0.00	0.78	0.25
ITIPRE1	-8295.93	-8432.80	-8211.54	-8552.00	-8104.60	-8346.26
ITUPRE1	0.01	0.00	0.01	0.00	0.01	0.01
ITIPOS1	-8295.93	-8432.80	-8211.54	-8552.00	-8104.60	-8346.26
ITUPOS1	0.01	0.00	0.01	0.00	0.01	0.01
PMAX1	24.18	23.74	26.29	25.82	23.95	26.13
APMAX1	21.80	22.45	20.87	21.70	22.16	20.95
RMAX1	0.72	0.67	0.82	0.77	0.69	0.81
ARMAX1	5.99	5.93	5.92	6.68	5.97	5.64
IMEP1	5.68	5.65	6.07	6.09	5.62	6.07
IMEPH1	6.02	5.99	6.38	6.43	5.95	6.37
IMEPL1	-0.35	-0.34	-0.31	-0.33	-0.33	-0.30
AI05%_1	0.99	1.12	0.63	1.07	1.07	0.71
AI10%_1	3.87	4.09	3.41	3.96	3.99	3.51
AI50%_1	17.37	17.90	16.53	17.37	17.51	16.74
AI90%_1	32.60	32.74	32.67	33.12	32.27	32.91

Figure A5.2: Data sets for 1500 rpm, 25% throttle position.



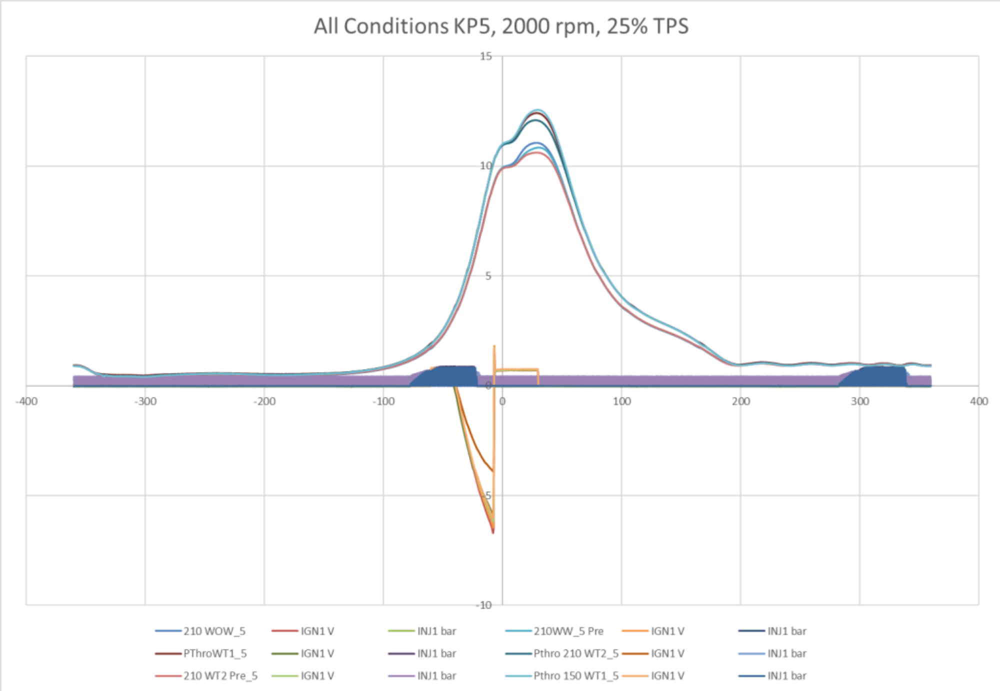
KP3	210 WOW_3	210 WW_3 Pre	PThroWT1_3	Pthro 210 WT2_3	210 WT2 Pre_3	Pthro 150 WT1_3
SPEED	1500.53	1500.45	1500.63	1500.54	1500.57	1500.61
CDMCOUNT	2880.00	2880.00	2880.00	2880.00	2880.00	2880.00
CYCTIME	20083.26	20050.23	20098.67	20097.31	20064.62	20069.59
CYCDUR	79.97	79.98	79.97	79.97	79.97	79.97
IGTI1	-8224.48	-8252.00	-8252.00	-8252.00	-8224.48	-8088.56
SPARK1	-11.91	-11.99	-11.98	-12.10	-11.96	-11.94
ITI1	-8149.71	-8414.41	-7913.89	-8552.00	-8111.70	-8167.28
ITU1	0.45	0.16	0.40	0.00	0.51	0.22
ITIPRE1	-8313.54	-8466.09	-8227.65	-8552.00	-8279.54	-8347.60
ITUPRE1	0.01	0.00	0.01	0.00	0.01	0.01
ITIPOS1	-8313.54	-8466.09	-8227.65	-8552.00	-8279.54	-8347.60
ITUPOS1	0.01	0.00	0.01	0.00	0.01	0.01
PMAX1	25.07	24.81	25.79	24.63	24.83	26.07
APMAX1	24.75	25.50	24.32	25.04	25.28	24.22
RMAX1	0.67	0.64	0.70	0.64	0.65	0.71
ARMAX1	8.32	8.53	7.86	7.07	8.45	7.99
IMEP1	6.54	6.53	6.70	6.59	6.51	6.73
IMEPH1	6.85	6.81	6.99	6.86	6.79	6.99
IMEPL1	-0.32	-0.28	-0.29	-0.27	-0.28	-0.26
AI05%_1	3.85	4.08	3.73	4.44	4.01	3.62
AI10%_1	6.79	7.04	6.63	7.39	6.96	6.48
AI50%_1	20.67	20.98	20.47	21.60	20.88	20.20
AI90%_1	36.12	35.88	36.67	38.31	35.91	36.41

Figure A5.3: Data sets for 1500 rpm, 35% throttle position.



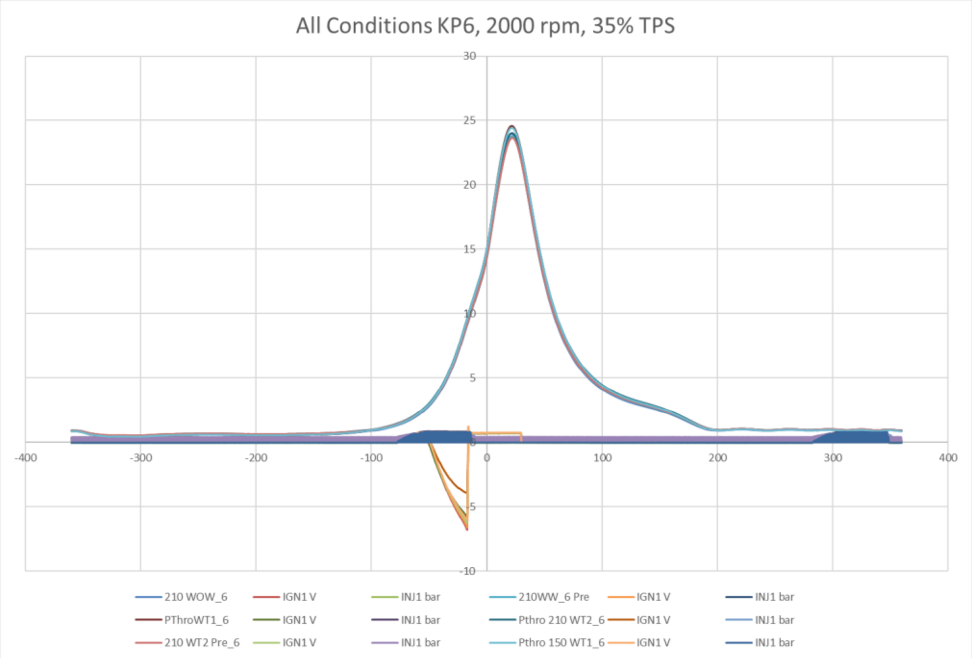
KP4	210 WOW_4	210WW_4 Pre	PThroWT1_4	Pthro 210 WT2_4	210 WT2 Pre_4	Pthro 150 WT1_4
SPEED	2000.52	2000.46	2000.63	2000.64	2000.44	2000.58
CDMCOUNT	2880.00	2880.00	2880.00	2880.00	2880.00	2880.00
CYCTIME	15034.52	15074.03	15075.26	15070.64	15039.93	15043.54
CYCDUR	59.98	59.99	59.98	59.98	59.99	59.98
IGTI1	-5488.82	-5620.40	-6113.83	-5193.38	-5373.69	-6229.12
SPARK1	-28.42	-28.41	-28.38	-28.43	-28.43	-28.37
ITI1	-8359.37	-8359.37	-7800.16	-8552.00	-8204.77	-8486.62
ITU1	0.22	0.22	0.48	0.00	0.39	0.04
ITIPRE1	-8432.95	-8432.93	-8160.73	-8552.00	-8347.88	-8517.98
ITUPRE1	0.00	0.00	0.01	0.00	0.01	0.00
ITIPOS1	-8432.95	-8432.93	-8160.73	-8552.00	-8347.88	-8517.98
ITUPOS1	0.00	0.00	0.01	0.00	0.01	0.00
PMAX1	11.49	11.10	17.64	17.50	10.93	17.72
APMAX1	15.61	16.27	15.15	15.38	16.17	15.47
RMAX1	0.36	0.33	0.62	0.60	0.32	0.61
ARMAX1	-1.93	-2.19	-0.68	-0.51	-2.42	-0.18
IMEP1	2.13	2.11	3.13	3.19	2.08	3.19
IMEPH1	2.69	2.65	3.68	3.72	2.61	3.73
IMEPL1	-0.56	-0.54	-0.55	-0.53	-0.53	-0.54
AI05%_1	-4.49	-3.78	-6.00	-5.41	-3.55	-5.69
AI10%_1	-0.75	0.02	-2.88	-2.27	0.23	-2.55
AI50%_1	16.96	17.89	11.85	12.61	18.17	12.06
AI90%_1	41.34	42.49	33.79	35.06	43.10	33.46

Figure A5.4: Data sets for 2000 rpm, 15% throttle position.



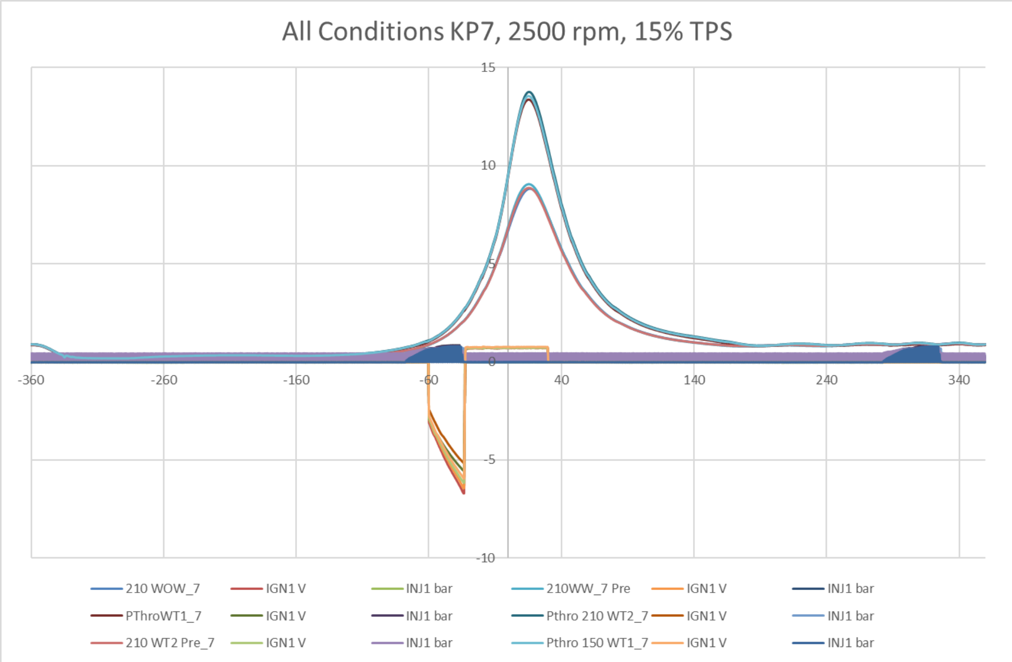
KP5	210 WOW_5	210WW_5 Pre	PThroWT1_5	Pthro 210 WT2_5	210 WT2 Pre_5	Pthro 150 WT1_5
SPEED	2000.42	2000.64	2000.65	2000.64	2000.31	2000.66
CDMCOUNT	2880.00	2880.00	2880.00	2880.00	2880.00	2880.00
CYCTIME	15078.28	15034.35	15031.26	15055.34	15040.25	15076.91
CYCDUR	59.99	59.98	59.98	59.98	59.99	59.98
IGTI1	-468.96	-353.63	-136.91	173.48	-386.51	-1460.28
SPARK1	-7.77	-7.77	-7.80	-7.78	-7.76	-7.84
ITI1	-7616.37	760.78	-4544.46	-8552.00	-7807.64	-8359.64
ITU1	1.09	-144.17	2.44	0.00	0.84	0.11
ITIPRE1	-7972.24	-867.83	-6471.29	-8552.00	-8090.72	-8449.80
ITUPRE1	0.02	-228.84	-32.71	0.00	0.01	0.00
ITIPOS1	-7972.24	-456.66	-6471.28	-8552.00	-8090.72	-8449.80
ITUPOS1	0.02	-343.53	-32.71	0.00	0.01	0.00
PMAX1	11.25	11.08	12.59	12.32	10.89	12.72
APMAX1	24.49	24.36	25.85	23.41	22.58	26.56
RMAX1	0.26	0.26	0.29	0.30	0.26	0.29
ARMAX1	-21.92	-21.80	-20.30	-19.17	-21.73	-20.43
IMEP1	3.60	3.58	4.17	4.10	3.55	4.23
IMEPH1	4.13	4.08	4.64	4.57	4.04	4.69
IMEPL1	-0.53	-0.50	-0.47	-0.46	-0.49	-0.46
AI05%_1	11.39	11.89	11.50	11.67	11.99	11.18
AI10%_1	15.12	15.71	15.14	15.45	15.86	14.90
AI50%_1	34.50	34.98	34.42	35.20	35.65	33.96
AI90%_1	56.03	56.49	56.30	57.36	57.37	55.37

Figure A5.5: Data sets for 2000 rpm, 25% throttle position.



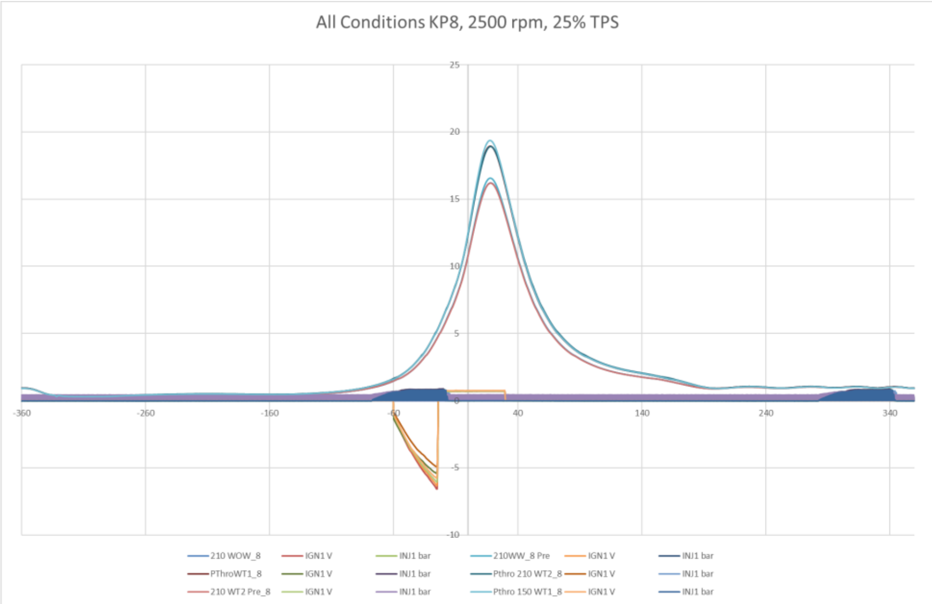
KP6	210 WOW_6	210WW_6 Pre	PThroWT1_6	Pthro 210 WT2_6	210 WT2 Pre_6	Pthro 150 WT1_6
SPEED	2000.48	2000.42	2000.59	2000.62	2000.49	2000.67
CDMCOUNT	2880.00	2880.00	2880.00	2880.00	2880.00	2880.00
CYCTIME	15038.07	15038.31	15028.37	15078.90	15043.59	15028.22
CYCDUR	59.99	59.99	59.98	59.98	59.99	59.98
IGTI1	-3574.09	-2849.35	-1817.82	-3642.53	-3261.14	-2932.44
SPARK1	-16.96	-16.92	-16.94	-16.98	-16.95	-16.93
ITI1	-8166.74	903.18	-6405.88	-8552.00	-8149.71	-8519.31
ITU1	0.45	-127.37	1.33	0.00	0.45	0.02
ITIPRE1	-8330.29	-668.87	-7443.89	-8552.00	-8295.22	-8535.00
ITUPRE1	-16.38	-65.04	-16.35	0.00	0.01	0.00
ITIPOS1	-8330.29	-284.28	-7443.89	-8552.00	-8295.19	-8535.00
ITUPOS1	-16.38	-81.45	-16.35	0.00	0.01	0.00
PMAX1	24.12	23.95	24.72	24.15	23.80	24.57
APMAX1	21.78	22.35	22.00	22.30	22.43	22.12
RMAX1	0.69	0.65	0.69	0.66	0.65	0.68
ARMAX1	5.18	5.83	5.32	4.83	5.66	5.14
IMEP1	5.85	5.86	6.10	6.14	5.88	6.17
IMEPH1	6.27	6.26	6.55	6.50	6.25	6.58
IMEPL1	-0.42	-0.39	-0.45	-0.37	-0.37	-0.41
AI05%_1	1.02	1.66	1.32	1.69	1.60	1.33
AI10%_1	4.02	4.71	4.39	4.82	4.69	4.46
AI50%_1	18.65	19.25	19.25	20.18	19.49	19.55
AI90%_1	36.94	38.14	37.91	39.99	38.72	38.50

Figure A5.6: Data sets for 2000 rpm, 35% throttle position.



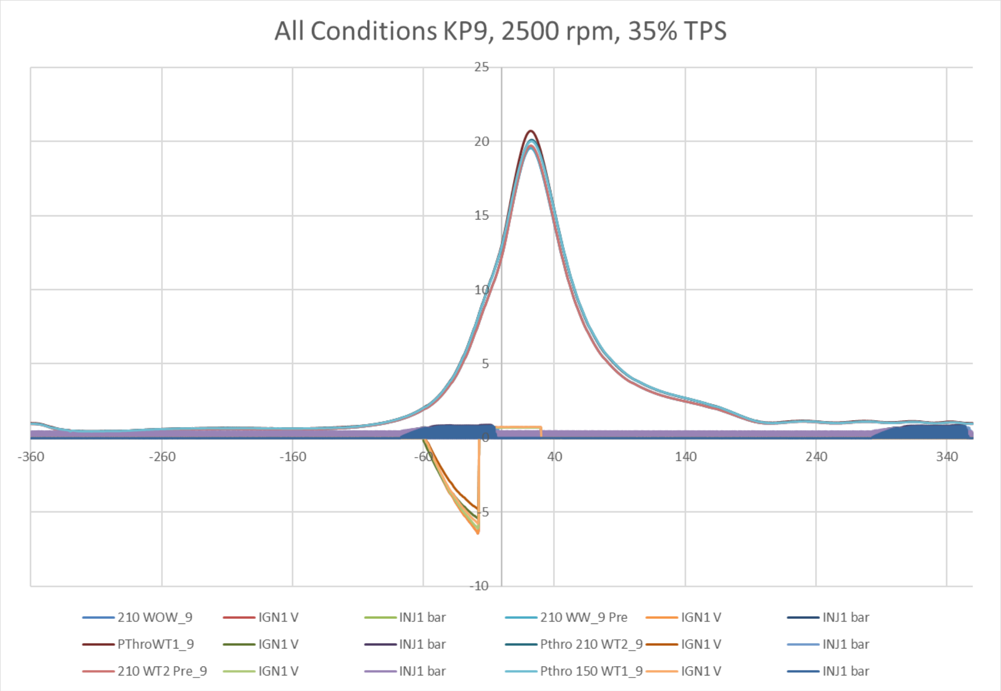
KP7	210 WOW_7	210WW_7 Pre	PThroWT1_7	Pthro 210 WT2_7	210 WT2 Pre_7	Pthro 150 WT1_7
SPEED	2500.21	2500.70	2500.58	2500.60	2500.14	2500.54
CDMCOUNT	2880.00	2880.00	2880.00	2880.00	2880.00	2880.00
CYCTIME	12031.55	12054.68	12039.50	12035.82	12065.82	12022.77
CYCDUR	48.00	47.99	47.99	47.99	48.00	47.99
IGTI1	-8252.00	-8252.00	-8252.00	-8252.00	-8252.00	-8186.62
SPARK1	-33.51	-33.36	-33.44	-33.34	-33.51	-33.34
ITI1	-8496.96	889.99	-8552.00	-8552.00	-8386.89	-8552.00
ITU1	0.06	-25.88	0.00	0.00	0.19	0.00
ITIPRE1	-8517.95	-3223.04	-8552.00	-8552.00	-8449.86	-8552.00
ITUPRE1	0.00	-98.06	0.00	0.00	0.00	0.00
ITIPOS1	-8517.95	-2639.70	-8552.00	-8552.00	-8449.86	-8552.00
ITUPOS1	0.00	-130.82	0.00	0.00	0.00	0.00
PMAX1	8.89	9.13	13.47	13.86	8.95	13.64
APMAX1	15.98	15.19	15.32	15.68	15.17	15.31
RMAX1	0.25	0.27	0.45	0.45	0.26	0.45
ARMAX1	-6.40	-4.85	-0.75	-0.40	-6.00	-0.63
IMEP1	1.48	1.50	2.31	2.38	1.46	2.32
IMEPH1	2.12	2.11	2.93	3.02	2.07	2.96
IMEPL1	-0.64	-0.62	-0.62	-0.64	-0.62	-0.64
AI05%_1	-3.04	-4.15	-6.14	-5.69	-3.76	-5.80
AI10%_1	0.91	-0.26	-2.51	-2.09	0.09	-2.22
AI50%_1	19.48	18.43	13.44	13.75	19.02	13.63
AI90%_1	46.94	47.19	36.49	37.61	48.61	37.63

Figure A5.7: Data sets for 2500 rpm, 15% throttle position.



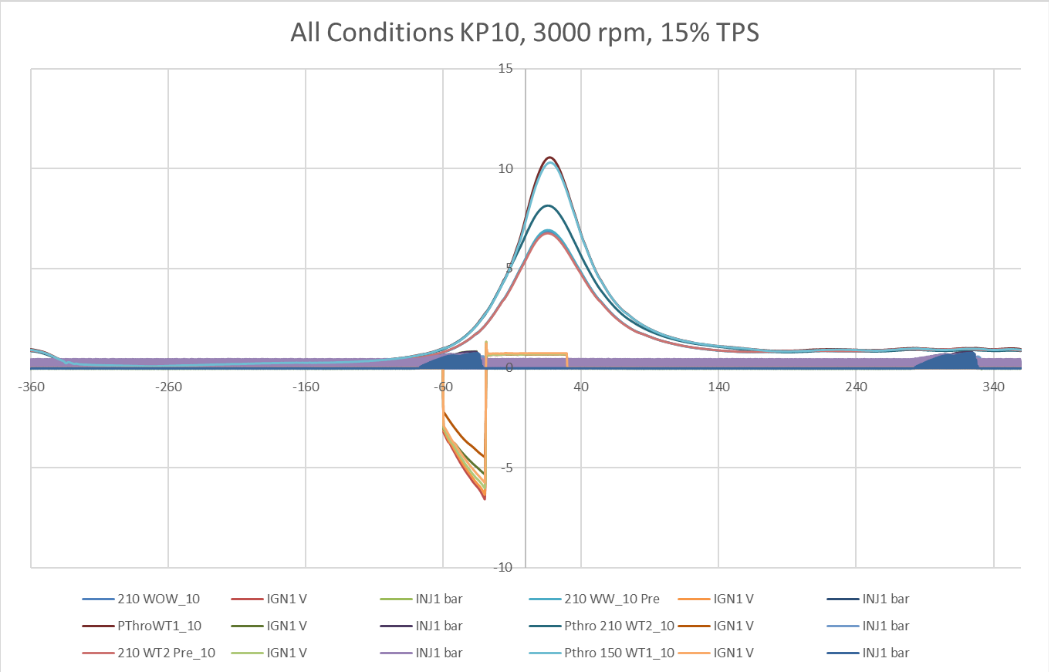
KP8	210 WOW_8	210WW_8 Pre	PThroWT1_8	Pthro 210 WT2_8	210 WT2 Pre_8	Pthro 150 WT1_8
SPEED	2500.47	2500.54	2500.66	2500.52	2500.52	2500.58
CDMCOUNT	2880.00	2880.00	2880.00	2880.00	2880.00	2880.00
CYCTIME	12022.82	12024.01	12020.82	12035.89	12025.96	12024.52
CYCDUR	47.99	47.99	47.99	47.99	47.99	47.99
IGTI1	-8252.00	-8252.00	-8252.00	-8252.00	-8252.00	-8186.62
SPARK1	-24.80	-24.78	-24.92	-24.88	-24.81	-24.92
ITI1	-8386.89	1209.07	-5445.16	-8552.00	-8441.93	-8552.00
ITU1	0.19	-142.38	1.98	0.00	0.13	0.00
ITIPRE1	-8449.71	-1509.45	-7076.89	-8552.00	-8483.91	-8552.00
ITUPRE1	0.00	-147.08	-147.41	0.00	0.00	0.00
ITIPOS1	-8449.71	-925.70	-7076.88	-8552.00	-8483.91	-8552.00
ITUPOS1	0.00	-97.88	-147.41	0.00	0.00	0.00
PMAX1	16.32	16.69	19.09	19.04	16.31	19.50
APMAX1	18.40	18.20	18.17	18.32	18.40	17.97
RMAX1	0.48	0.50	0.58	0.57	0.49	0.60
ARMAX1	1.86	1.86	2.07	2.23	1.55	2.21
IMEP1	3.34	3.36	3.95	4.04	3.32	4.02
IMEPH1	3.95	3.96	4.56	4.63	3.91	4.61
IMEPL1	-0.62	-0.60	-0.61	-0.58	-0.59	-0.59
AI05%_1	-2.15	-2.19	-2.41	-2.17	-2.17	-2.57
AI10%_1	1.29	1.16	0.84	1.16	1.20	0.66
AI50%_1	17.13	16.47	16.13	16.60	16.94	15.72
AI90%_1	39.71	38.83	37.74	38.44	39.74	37.27

Figure A5.8: Data sets for 2500 rpm, 25% throttle position.



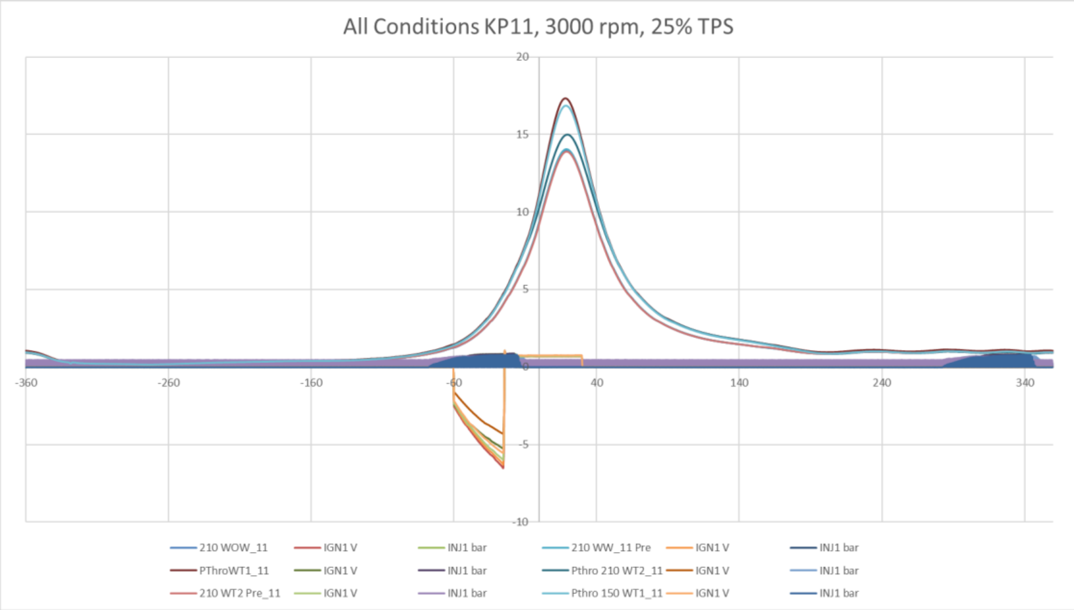
KP9	210 WOW_9	210 WW_9 Pre	PThroWT1_9	Pthro 210 WT2_9	210 WT2 Pre_9	Pthro 150 WT1_9
SPEED	2500.36	2500.36	2500.50	2500.73	2500.45	2500.51
CDMCOUNT	2880.00	2880.00	2880.00	2880.00	2880.00	2880.00
CYCTIME	12030.29	12030.29	12059.35	12035.62	12040.38	12026.38
CYCDUR	47.99	47.99	47.99	47.99	47.99	47.99
IGTI1	-8252.00	-8252.00	-8252.00	-8252.00	-8252.00	-8252.00
SPARK1	-18.19	-18.19	-18.24	-18.23	-18.20	-18.19
ITI1	1389.05	1389.05	-3888.13	-8552.00	-8304.33	-8552.00
ITU1	-93.30	-93.30	-13.46	0.00	0.29	0.00
ITIPRE1	-584.35	-584.35	-6235.73	-8552.00	-8398.75	-8552.00
ITUPRE1	-130.63	-130.63	-163.77	0.00	0.00	0.00
ITIPOS1	-127.03	-127.03	-6219.26	-8552.00	-8398.75	-8552.00
ITUPOS1	-97.82	-97.82	-147.37	0.00	0.00	0.00
PMAX1	19.71	19.71	20.86	20.25	19.88	20.16
APMAX1	22.24	22.24	22.28	23.09	22.39	22.81
RMAX1	0.51	0.51	0.54	0.49	0.52	0.49
ARMAX1	5.28	5.28	5.57	4.38	5.66	3.81
IMEP1	4.77	4.77	5.14	5.16	4.80	5.15
IMEPH1	5.30	5.30	5.67	5.67	5.32	5.65
IMEPL1	-0.53	-0.53	-0.53	-0.51	-0.52	-0.50
AI05%_1	2.08	2.08	2.25	2.64	2.15	2.46
AI10%_1	5.31	5.31	5.51	6.04	5.37	5.85
AI50%_1	20.50	20.50	20.87	21.84	20.30	21.85
AI90%_1	41.12	41.12	42.29	42.82	40.43	43.29

Figure A5.9: Data sets for 2500 rpm, 35% throttle position.



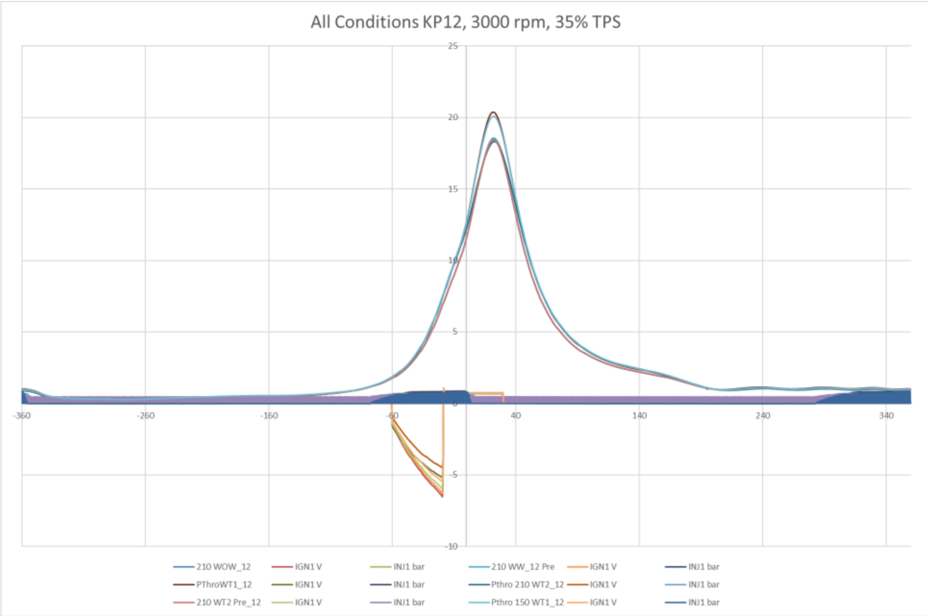
KP10	210 WOW_10	210 WW_10 Pre	PThroWT1_10	Pthro 210 WT2_10	210 WT2 Pre_10	Pthro 150 WT1_10
SPEED	3000.02	3001.81	3000.52	2999.54	2999.65	3000.44
CDMCOUNT	2880.00	2880.00	2880.00	2880.00	2880.00	2880.00
CYCTIME	10047.84	10042.88	10026.43	10057.62	10029.40	10044.79
CYCDUR	40.00	39.98	39.99	40.01	40.00	39.99
IGTI1	-1317.37	-1015.98	-6306.12	-636.27	-610.22	-1986.26
SPARK1	-29.83	-29.81	-29.85	-29.84	-29.79	-29.87
ITI1	-8552.00	-1349.03	-8552.00	-8552.00	-8552.00	-8552.00
ITU1	0.00	-9.65	0.00	0.00	0.00	0.00
ITIPRE1	-8552.00	-4532.42	-8552.00	-8552.00	-8552.00	-8552.00
ITUPRE1	0.00	-32.64	0.00	0.00	0.00	0.00
ITIPOS1	-8552.00	-4461.84	-8552.00	-8552.00	-8552.00	-8552.00
ITUPOS1	0.00	-49.01	0.00	0.00	0.00	0.00
PMAX1	6.90	6.99	10.62	8.32	6.81	10.38
APMAX1	14.60	14.84	17.23	14.06	14.77	17.55
RMAX1	0.19	0.19	0.31	0.22	0.19	0.30
ARMAX1	-12.22	-10.98	-1.31	-14.20	-11.74	-1.21
IMEP1	0.96	0.98	1.67	1.29	0.94	1.67
IMEPH1	1.71	1.72	2.44	2.00	1.68	2.43
IMEPL1	-0.75	-0.74	-0.77	-0.70	-0.75	-0.76
AI05%_1	-0.40	-0.67	-2.74	1.08	-0.24	-2.33
AI10%_1	3.59	3.37	0.56	4.97	3.76	0.98
AI50%_1	23.85	23.29	16.98	24.97	23.92	17.68
AI90%_1	51.98	51.54	39.62	53.14	53.06	40.24

Figure A5.10: Data sets for 3000 rpm, 15% throttle position.



KP11	210 WOW_11	210 WW_11 Pre	PThroWT1_11	Pthro 210 WT2_11	210 WT2 Pre_11	Pthro 150 WT1_11
SPEED	3000.42	3000.50	3000.58	3000.43	3000.40	3000.55
CDMCOUNT	2880.00	2880.00	2880.00	2880.00	2880.00	2880.00
CYCTIME	10039.04	10034.38	10028.46	10015.95	10034.48	10028.90
CYCDUR	39.99	39.99	39.99	39.99	39.99	39.99
IGTI1	-6774.27	-5731.45	-8055.87	-7417.90	-6055.13	-6118.94
SPARK1	-25.34	-25.39	-25.36	-25.34	-25.37	-25.37
ITI1	-8276.82	1564.88	-4881.60	-8552.00	-8524.48	-8552.00
ITU1	0.32	-41.49	2.32	0.00	0.03	0.00
ITIPRE1	-8381.50	-2109.28	-6613.64	-8552.00	-8534.95	-8552.00
ITUPRE1	0.01	-65.28	0.06	0.00	0.00	0.00
ITIPOS1	-8381.50	-1689.32	-6613.64	-8552.00	-8534.95	-8552.00
ITUPOS1	0.01	-81.61	0.06	0.00	0.00	0.00
PMAX1	14.10	14.15	17.45	15.10	14.00	16.99
APMAX1	19.20	19.16	18.49	19.57	19.33	18.91
RMAX1	0.40	0.40	0.52	0.40	0.39	0.50
ARMAX1	0.94	0.98	1.91	-1.17	0.97	1.87
IMEP1	2.59	2.60	3.20	3.09	2.57	3.24
IMEPH1	3.32	3.32	3.99	3.78	3.29	3.96
IMEPL1	-0.73	-0.72	-0.78	-0.69	-0.72	-0.72
AI05%_1	-2.00	-1.98	-2.49	-0.61	-1.82	-2.42
AI10%_1	1.44	1.45	0.76	2.90	1.57	0.89
AI50%_1	16.93	16.91	15.48	19.23	17.03	15.84
AI90%_1	36.42	36.54	36.19	40.71	36.70	35.35

Figure A5.11: Data sets for 3000 rpm, 25% throttle position.



KP12	210 WOW_12	210 WW_12 Pre	PThroWT1_12	Pthro 210 WT2_12	210 WT2 Pre_12	Pthro 150 WT1_12
SPEED	3000.60	3000.55	3000.74	3000.97	3000.48	3000.57
CDMCOUNT	2880.00	2880.00	2880.00	2880.00	2880.00	2880.00
CYCTIME	10024.48	10021.38	10048.65	10034.77	10024.84	10045.92
CYCDUR	39.99	39.99	39.99	39.99	39.99	39.99
IGTI1	-7344.75	-6722.71	-8219.31	-7450.28	-6998.34	-6628.71
SPARK1	-19.33	-19.33	-19.33	-19.31	-19.33	-19.33
ITI1	-8441.93	2076.47	-2737.22	-8552.00	-8552.00	-8552.00
ITU1	0.13	-26.28	3.72	0.00	0.00	0.00
ITIPRE1	-8500.13	-1056.09	-4731.30	-8552.00	-8552.00	-8552.00
ITUPRE1	-16.38	-33.62	-32.50	0.00	0.00	0.00
ITIPOS1	-8500.13	-888.98	-5526.81	-8552.00	-8552.00	-8552.00
ITUPOS1	-16.38	-15.96	-49.08	0.00	0.00	0.00
PMAX1	18.68	18.70	20.54	18.47	18.56	20.25
APMAX1	22.52	22.49	22.17	22.74	22.48	22.40
RMAX1	0.48	0.48	0.54	0.44	0.48	0.52
ARMAX1	5.38	5.75	5.52	-0.28	5.06	5.16
IMEP1	4.10	4.12	4.53	4.40	4.13	4.61
IMEPH1	4.79	4.79	5.26	5.09	4.78	5.27
IMEPL1	-0.69	-0.67	-0.73	-0.68	-0.65	-0.67
AI05%_1	1.67	1.74	1.45	2.42	1.67	1.56
AI10%_1	4.87	4.91	4.64	5.94	4.86	4.78
AI50%_1	19.42	19.42	19.08	21.98	19.57	19.61
AI90%_1	37.48	37.57	37.20	41.95	37.90	38.44

Figure A5.12: Data sets for 3000 rpm, 35% throttle position.