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Three-way catalyst performance using LPG with two different sulphur levels

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Three-way catalyst performance using LPG with two different sulphur levels

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ABSTRACT

An experimental programme was carried out to determine the long-term impact of the level of sulphur present in LPG on the performance of three-way catalytic converters (TWCs) in terms of their elimination (conversion) of gaseous pollutants. Two TWCs were subjected to an engine dyno ageing procedure, with fuel of high (29 ppm m/m) or low (8 ppm m/m) sulphur content used for ageing. The performance of the TWCs was assessed before, during and after this ageing via emissions testing. Emissions testing was conducted on a passenger car (the type for which the two TWCs were designed), running on LPG fuel and tested on a chassis dynamometer over three different driving cycles. Emissions testing was performed in accordance with the European legislative method, supplemented by additional measurements and procedures, including continuous emissions measurements of undiluted gaseous pollutants.

With a single exception, the test vehicle met the applicable Euro 6 emissions limits when tested using its type approval procedure (NEDC), for both TWCs, at all ageing stages. The exception to this came in the form of a single NMHC emissions result, which in one test was found to be above the applicable legislative limit following 250 ageing cycles; the two other repetitions of this test under the same conditions showed NMHC emissions below with the Euro 6 limits, and the mean of these 3 tests was also below the Euro 6 limits. While emissions results obtained using the WLTP test procedure were not legally applicable to the test vehicle, results obtained using that procedure were also below the Euro 6 limits, in all cases, with no exceptions. The relatively low emissions results occurring even after extended ageing indicate high TWC conversion efficiency and durability under the specific ageing conditions tested.

The results showed that the ageing cycle caused a tendency for slightly lower TWC conversion efficiency (and thus slightly higher emissions results). It was found that differences in conversion of regulated pollutants were greatest at low operating temperatures (i.e. during and following cold start) and that differences were very limited under thermally stabilised conditions.

As regards the impact of fuel sulphur level on TWC conversion efficiency, overall there appeared to be no significant difference between the two test objects. In certain cases differences in performance were apparent, but sometimes the High-sulphur TWC outperformed its Low-sulphur counterpart. Even focusing on the results obtained from the cold start phases, no consistent, significant difference between the two test objects could be observed. It was concluded that the fuel’s sulphur content had not exerted a clear, significant impact on TWC performance.

A possible explanation for this is that the high speed, high load driving simulated in the engine dyno ageing cycle (but which can also be met under real driving conditions, e.g. during highway driving) led to continuous desulphatation of the TWCs tested, hence leading to a potential non-harmful effect of sulphur content on the TWC conversion efficiency. A complementary study was performed to evaluate the relevance of this explanation (details in the appendix). It consisted in chemical analyses of the aged TWCs, using advanced laboratory methods. Unfortunately, this study remained inconclusive, as it were unable to directly link the sulphur level measured in the TWCs to their conversion efficiency loss. Consequently, lacking a clear and systematic explanation about the effect of sulphur on the TWC conversion efficiency, this study cannot be 100% conclusive regarding the harmful/non-harmful effect of sulphur content in LPG on the TWC conversion efficiency, even if the engine/vehicle tests tend to show that a higher sulphur content is not harmful.

KEYWORDS

LPG, three-way catalyst, sulphur, ageing, conversion efficiency

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1. DESCRIPTION AND IDENTIFICATION OF THE OBJECTS TESTED

The objects of the tests were two original aftertreatment systems (three-way catalysts, TWCs) dedicated to the Fiat Tipo 1.4 T-Jet LPG application. Denoted as 'Low S', and 'High S', the two test objects are identified in Table 1. The TWCs were purchased by BOSMAL and were delivered on the 7th of March 2018.

Table 1 Data of the test objects

Parameter	TWC Low S	TWC High S
Exhaust aftertreatment system type	Close-coupled three-way catalytic converter	
Approx. monolith volume [dm^3]	1.4	
Total PGM content [g/ft^3]; [g/dm^3]	150; 5.30	
PGM content (Pt:Pd:Rh)	0:145:5	
Intended application	Aftertreatment system for Fiat Tipo 1.4 T-Jet LPG (see Table 2)	

The platinum group metal (PGM) content of the test objects identified in Table 1 was typical in terms of the fact that no platinum (Pt) was used [1-4]. The ratio of palladium (Pd) to rhodium (Rh) of 145:5 (or 29:1) appeared to be higher than the average figure for that parameter (in comparison to the limited available information on other systems [1-2], [4-5]). The total PGM content appeared to be high compared to other Euro 6 TWC aftertreatment systems [1], [4-5]. A further consideration is the intended application of the test objects (bi-fuel LPG exhaust aftertreatment), for which typical specifications may differ slightly from that of mono-fuel petrol TWCs, especially in view of durability requirements and the elevated exhaust gas temperature that can result from combustion of LPG (compared to petrol). Notwithstanding the information presented in [1-5], as a general point, it should be noted that information on specification of typical market-available Euro 5/6 TWCs (for mono-fuel or bi-fuel applications) is rather limited. The specification of aftertreatment systems used in markets other than the EU (e.g. the USA) are of limited utility for comparisons with the test objects used in this study, due to several factors, namely: the existence of different emissions limits and test procedures in those markets; the tendency to use dual (close-coupled and underfloor) TWC systems; the very limited use of LPG for passenger cars in that market.

The two TWCs were tested on the specific vehicle type for which they were intended. Key technical data of the test vehicle are shown in Table 2. The test vehicle was supplied by BOSMAL and was not modified in any way, with the exception of mounting the two test objects identified in Table 1 for testing purposes.

Table 2 Data of the test vehicle

Vehicle type	Passenger car, category M, segment C
Commercial name	Fiat Tipo 1.4 T-Jet LPG
Vehicle identification number	ZFA35600006K20252
Engine type	Turbocharged 4-cylinder spark ignition, bi-fuel (LPG/petrol – indirect injection of both fuel types)
Engine displacement [dm^3]	1.368
Rated engine power [kW]	88
Unladen mass [kg]	1320
Emissions standard	Euro 6
Aftertreatment system	1 × close-coupled TWC
Year of manufacture	2017
Date of registration	19.12.2017
Mileage at start of testing [km]	4020
Tyres	Continental ContiEcoContact 5 225/45 R17 V XL
Details of vehicle fuelling system	Type approved as a bi-fuel vehicle (LPG/petrol). Engine cold start always occurs on petrol and switches over to LPG early in the test cycle (when LPG mode is selected).

2. OBJECTIVE OF THE TESTS

Periodic chassis dynamometer testing in order to determine exhaust emissions and fuel consumption with the two test objects (‘TWC Low S’ and ‘TWC High S’) fitted to the test vehicle (in turn). Specifically, calculation of the test units’ effectiveness in the elimination of regulated pollutants (i.e. conversion efficiency) before, during and following execution of an engine dyno TWC ageing procedure using two different LPG fuels, varying only in terms of sulphur content. Evaluations of the long-term impact were conducted, as fuel of varying sulphur content were used for ageing, while essentially sulphur-free fuel was used for testing. The inherent details of the test programme do not allow identification of the short-term emissions impacts of exposure to LPG fuel of varying sulphur content; this study examines long-term effects.

3. SCOPE AND METHODS OF THE TESTS

Exhaust emissions testing carried out in accordance with Regulation (EC) 715/2007 and Regulation (EC) 692/2008 – UNECE Regulation No. 83 and Regulation (EU) 2017/1151 in the range of exhaust emissions, carbon dioxide emissions and carbon balance fuel consumption measurements. Furthermore, a constant speed driving cycle was also used for emissions testing. The legislative test methods were used as the base procedure; additional measurements of emissions of undiluted pollutants from sampling points upstream and downstream of the TWC were also carried out. The sampling and measurement setup used for all emissions testing is shown in Figure 1

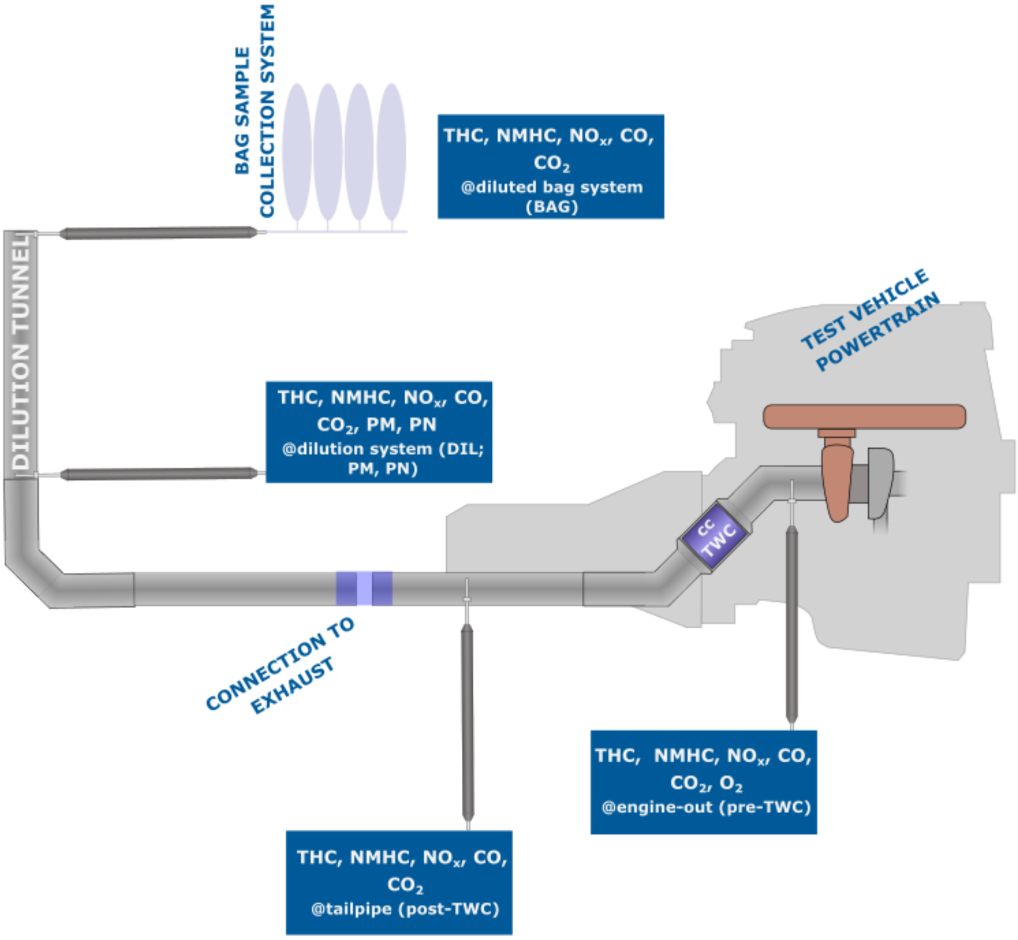

Figure 1 Schematic of the emissions sampling layout

For clarity, the test vehicle and chassis dynamometer are not shown in Figure 1. The test object (‘CC TWC’) is shown mounted to the engine in its close-coupled configuration. The vehicle’s tailpipe is connected to the emission system as shown in the figure. The legislative measurement for exhaust emissions from vehicles of this type (i.e. bag measurement) was supplemented with continuous measurements at three points: pre-TWC, post-TWC and diluted, the latter including measurement of particulates (PM, PN).

Measurements relating to the above-mentioned points were carried out on the test vehicle with either the Low S or High S TWC installed, tested under closely-controlled laboratory conditions over predefined driving cycles. All emissions testing was conducted while the vehicle was fuelled with reference LPG (LPG A, as defined in Regulation (EU) 2017/1151). The activity matrix for each TWC is shown in Table 3. The emissions testing procedure was identical in every aspect for both TWCs; the ageing procedure used was also identical in both cases, with the only variable being the sulphur level of the LPG used for engine dyno ageing.

Table 3 Activity matrix

Step No.	Activity	Details
1	Initial TWC preconditioning	12 consecutive repetitions of the EUDC cycle as preconditioning, performed using reference LPG; no emissions measurement
2	Initial emissions tests (0 cycle stage)	1 preconditioning cycle (WLTC) 3 WLTC emissions tests 3 NEDC emissions tests 2 constant speed tests
3	Ageing - 50 cycles	Execution of engine dyno ageing
4	Interim emissions tests (50 cycle stage)	1 preconditioning cycle (WLTC) 3 WLTC emissions tests
5	Ageing - 50 cycles	Execution of engine dyno ageing
6	Interim emissions tests (100 cycle stage)	1 preconditioning cycle (WLTC) 3 WLTC emissions tests
7	Ageing - 75 cycles	Execution of engine dyno ageing
8	Interim emissions tests (175 cycle stage)	1 preconditioning cycle (WLTC) 3 WLTC emissions tests
9	Ageing - 75 cycles	Execution of engine dyno ageing
10	Final emissions tests (250 cycle stage)	1 preconditioning cycle (WLTC) 3 WLTC emissions tests 3 NEDC emissions tests 2 constant speed tests

Step No. 1 represents the industry standard approach for preparing a completely fresh aftertreatment system for emissions testing, i.e. execution of 12 EUDC cycles, thereby covering a distance of 84 km at a mean speed of 62.6 km/h, with speeds reaching up to 120 km/h, but with a deceleration to standstill and a short period of idling occurring every 7 km. This preconditioning was performed using reference LPG as fuel (although the cold start event occurred on petrol). Note that the first item of each block of emissions testing (steps Nos. 2, 4, 6, 8, 10) consisted of running one WLTC test cycle with no emissions measurement, as preconditioning. This procedure was chosen to provide a balance between the need to prepare the test vehicle and stabilise the TWC for emissions testing and the desire to perform emissions testing on the aged TWC in its "as received" condition. The exact same test conditions and fuel were used for the preconditioning as for the subsequent emissions tests; preconditioning cycles always commenced from cold start.

Engine dyno ageing of the TWCs was carried out on an engine of identical type to the engine fitted to the vehicle used for emissions testing (see Table 2). The engine was run on a computer-controlled engine dyno, running a repeating cycle designed to simulate accelerated TWC ageing at high-speed, high-load vehicle operation. Figure 2 shows the essential characteristics of the cycle. Each cycle lasted just over 75 minutes and thus the full 250 cycles lasted approximately 314 hours.

During the cycles the engine dyno simulates the road load resistance which would be experienced by the vehicle. The distance covered by each cycle is 177 km and thus 250 cycles equates to 44,400 km. However, the highly demanding conditions recreated by the ageing cycle mean that an equivalence factor of 1.6 is applicable in order to convert to less demanding driving conditions. Thus, the total number of kilometres of typical driving may be estimated as being 44,400×1.6=71,040 km

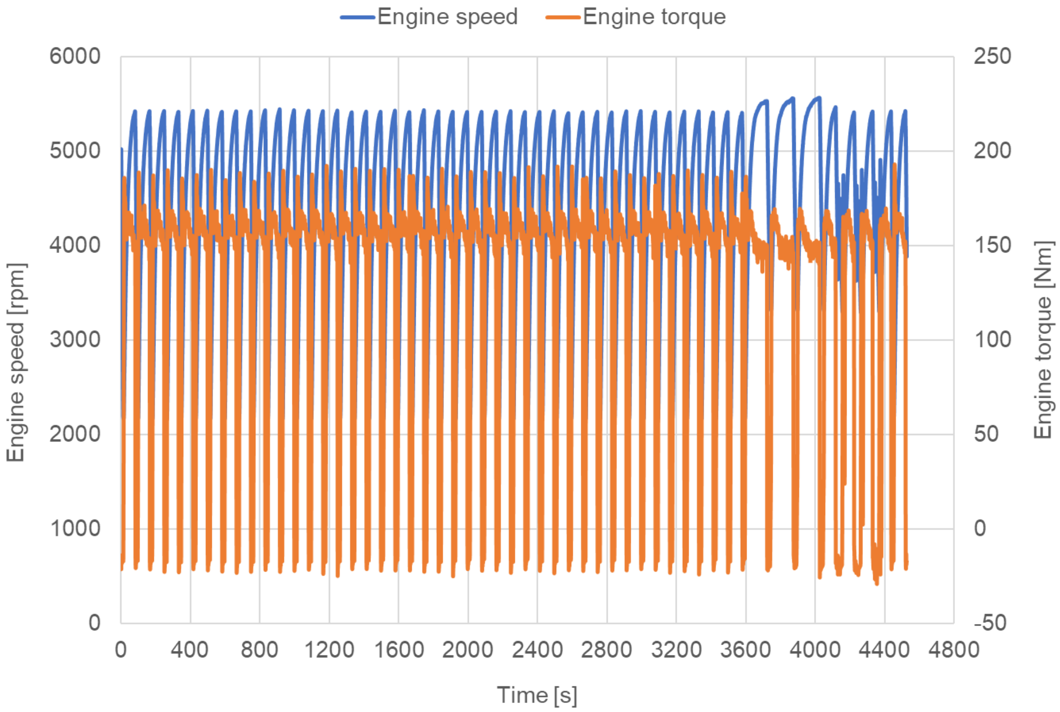

Figure 2 Essential characteristics (rotational speed, torque) of the engine dyno TWC ageing cycle used in this study

Figure 3 shows the temperatures of the exhaust gas during the ageing cycle. For the majority of each ageing cycle, the temperature of the exhaust gas entering the TWC oscillated between approximately 630°C and 750°C and the temperature of the exhaust gas downstream of the TWC oscillated between approximately 650°C and 730°C. The mean value of the temperature of the exhaust gas upstream of the TWC during each cycle was 709°C and the 75th percentile temperature value was 745°C, meaning that temperatures exceeded that level for 25% of the total ageing time. The 99th percentile temperature value was 755°C, meaning that temperatures exceeded that level for only 1% of the total ageing time.

The temperature of the exhaust gas (and indeed of the monolith itself) is of paramount importance for thermal ageing as well as for deactivation (poisoning) processes. Temperature and exhaust gas chemistry (i.e. λ, sulphur content) can affect the accumulation of inhibiting species such as S atoms and sulphur-based compounds, as well as their removal. A review of industry opinion and available literature [6-9] on Pd-Rh TWCs revealed that under conditions of alternating rich/lean conditions, the test objects used in this study would likely have begun to desulphate (i.e undergo physicochemical reactions leading to the removal of sulphur atoms and sulphur-bearing compounds from the catalytically active layer of the monolith) at a temperature within the range 650-700°C. As shown in Figure 3 and discussed below, such temperatures are achieved (and in fact exceeded) during the ageing cycle employed in this study and also during certain real-world driving scenarios.

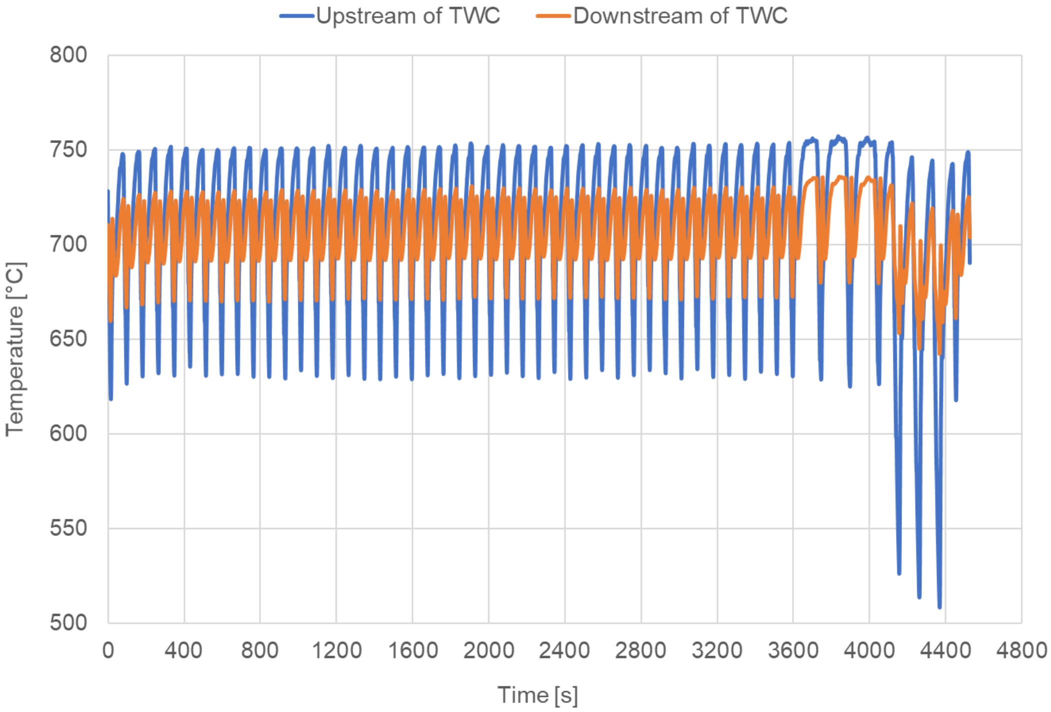

Figure 3 Temperature profile (upstream – i.e. TWC inlet and downstream – i.e. WC outlet) of the engine dyno TWC ageing cycle used in this study

The same engine was used for all ageing of the test objects, with engine oil and filter replacement carried out at regular intervals (approximately every 120 hours of engine operation). Ageing on the fuel with the lower sulphur content was carried out, in full, before exposing the engine to the fuel of higher sulphur content. A completely fresh set of spark plugs was used for ageing on each fuel. Each TWC was equipped with its own oxygen (λ) sensors, which were used during all ageing activities; the test vehicle was equipped with oxygen (λ) sensors, which were used for all emissions testing. Thus, the oxygen (λ) sensors used during emissions testing were not exposed to exhaust gas resulting from the ageing process (and vice-versa).

While λ was not monitored continuously during the ageing, certain key facts are known. During all portions of high load – i.e. the acceleration events – λ was always

<1, taking values in the range 0.75-0.8. During the relatively brief yet frequent periods of negative torque demand (fuel cut-off), λ obviously took values >>1. Thus, the ageing cycle's λ profile can be described as variable, but while the engine was being fuelled, λ generally took values <1, due to the cycle's inherent high power demand. Such a situation is typical for spark-ignition engines operating on LPG or petrol, while CNG-fuelled engines normally use much less enrichment, since such engines typically develop full power at λ>1.

In line with the project strategy, exhaust emissions were not measured during engine ageing. Stability of engine operation was monitored via continuous observations of temperatures, pressures, the fuel flow rate, etc.

Industry experts with considerable experience in the field of automotive aftertreatment systems for light duty vehicles were asked to comment on the ageing procedure. The consensus was that the engine speed and load profiles were typical for ageing procedures used on TWCs. However, the engine used in this study was in its production configuration, with no modifications to induce higher exhaust gas temperatures (i.e. injection of additional air, modification of valve timing) and thus the temperatures experienced by the test objects during ageing are somewhat lower than during ageing procedures conducted in other studies and reported elsewhere.

While lower temperatures reduce the severity of TWC ageing *(ceteris paribus)*, the temperatures encountered in the ageing cycle employed in this study have the advantage of not being artificially elevated, i.e. they could be experienced by a passenger car in normal real-world usage scenarios (i.e. high speed motorway driving, especially when driving uphill and/or with significant payload). Furthermore, it has been shown that the temperature experienced by the TWC monolith is, for the most part, appreciably higher than the temperature of the exhaust gas itself [10]. Thus, for the majority of the ageing cycle, the exhaust gas temperature can be considered a minimum temperature value for the thermal conditions experienced by the TWC monolith.

The ECU of the test vehicle reported two thermal parameters (both of which are modelled rather than directly measured). The temperature traces of these parameters over the cold start WLTC followed immediately by one EUDC (the second phase of the NEDC) are shown in Figure 4. (Note that the speed trace shown in Figure 4 is merely a demonstration of temperature trends and was not used for any emissions testing.)

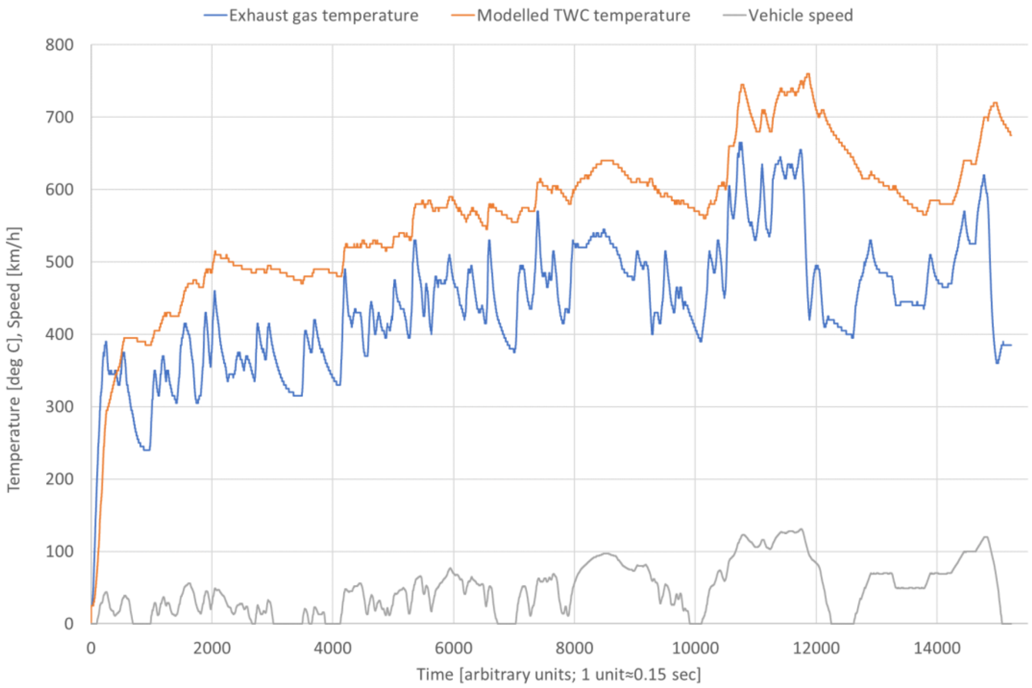

Figure 4 Profile of the temperature of the exhaust gas and the TWC monolith reported by the test vehicle's ECU over the WLTC and the EUDC phase of the NEDC.

As is evident from Figure 4, the temperature of the TWC very quickly comes to exceed that of the exhaust gas itself following cold start. The temperatures experienced by the TWC monolith during the 4th phase of the WLTC (10,000 to 12,200 time units on the x-axis) reached values up to 750°C and were ≥650°C for approximately 2.5 uninterrupted minutes. Over the EUDC (10,000 to 12,200 time units on the x-axis) the maximum TWC monolith temperature reached was just over 710°C (following the acceleration to 120 km/h); the previous acceleration (from 70 to 100 km/h) caused temperatures which reached approximately 640°C. The veracity and accuracy of the temperature modelling approach is discussed in [10] – while there may be overestimations of the temperature under non-stoichiometric conditions, generally speaking, the modelled temperature is considered accurate and valid.

The two test objects (the 'Low S' and 'High S' TWCs) were subjected to the ageing procedures mentioned above, using two fuels which differed only in terms of sulphur content. A third fuel was used for emissions testing. All three fuels are identified in Table 4.

Table 4 Data of the LPG fuels used in this test programme

Parameter / Fuel name	LPG Low S	LPG High S	Reference LPG A
Fuel type	Commercially available LPG	Commercially available LPG	Certified reference fuel
Use in this study	Engine dyno ageing of TWC Low S	Engine dyno ageing of TWC High S	Chassis dyno emissions testing of TWC Low S and TWC High S
Total fuel sulphur content according to fuel certificate [mg/kg]	8.2	29.0	<1.0
Odour	Imperceptible	Perceptible	Not assessed
Odorant added?	Unknown	Yes	No
Assumed main source(s) of sulphur-bearing compounds	Crude oil	Crude oil, odorant	Trace impurities
Fuel certificates	Appendix 1, Appendix 2	Appendix 3, Appendix 4, Appendix 5, Appendix 6	Appendix 7, Appendix 8

Reference LPG A refers to the fuel specification given in Regulation (EU) 2017/1151, Annex IX, section A., point 1., Type: LPG, column ‘Fuel A’. The same fuel specification is also shown in UNECE Regulation No. 83, Annex 10a, point 1.1, Type: LPG, column ‘Fuel A’. Appendix 7 shows the standard certificate provided by the reference fuel supplier; Appendix 8 shows the results of detailed analyses of fuel parameters, including sulphur content. Reference LPG fuel was chosen to ensure that LPG of known, closely-controlled specification was used for all emissions tests, thereby reducing uncertainty and potential test-to-test variability. (Regular refuelling of the test vehicle with commercially available LPG would have introduced a significant source of uncertainty to the emissions measurements.) While type approval requirements stipulate that LPG-fuelled vehicles must be tested on both gaseous reference fuels (LPG A and LPG B), this study did not employ the full type approval procedure and thus it was deemed neither necessary nor technically appropriate to perform testing on both reference LPG fuels.

4. DESCRIPTION AND RESULTS OF THE TESTS

4.1. MEASURING EQUIPMENT

The specifications of the measuring equipment are shown in Table 5; the test vehicle undergoing emissions testing is shown in Fig. 5. (See also Figure 1).

Table 5 Data of measuring devices

Device Name	Type	Identifying No.	Measurement range	Accuracy of measurement
Chassis Dynamometer 2WD	AVL Zöellner	X/1141/BHT	0 - 200 km/h 0 - 10 kN	± 0.05 % ± 0.1 %
Exhaust Emission Analysis System:	AVL AMA i60	X/2624/BHT		± 2% of the measuring point or ± 1% of the full scale
CO Dilute	AVL IRD i60 CO L	L/2625/BHT	0 - 5 000 ppm	
CO_2 Dilute	AVL IRD i60 CO_2 H	L/2626/BHT	0 - 20%	
NO_x Dilute	AVL CLD i60 LHD	L/2628/BHT	0 - 1 000 ppm	
THC Dilute	AVL FID i60 LHD	L/2629/BHT	0 - 1 000 ppm	
CH_4 Dilute	AVL FID FID i60 LHD	L/2630/BHT	0 - 1 000 ppm	
CO High Pre	AVL IRD i60 CO H	L/2775/BHT	0 - 10 %	± 2% of the measuring point
CO Low Pre	AVL IRD i60 CO L	L/2781/BHT	0 - 1000 ppm	
CO_2 Pre	AVL IRD i60 CO2	L/2776/BHT	0 - 20 %	
NO_x Pre	AVL CLD i60	L/2778/BHT	0 - 6000 ppm	
THC Pre	AVL FID i60	L/2779/BHT	0 - 37000 ppm C1	
CH_4 Pre	AVL Cutter FID i60	L/2780/BHT	0 - 20000 ppm C1	
CO High Post	AVL IRD i60 CO H	L/2785/BHT	0 - 10 %	
CO Low Post	AVL IRD i60 CO L	L/2784/BHT	0 - 1000 ppm	
CO_2 Post	AVL IRD i60 CO2	L/2786/BHT	0 - 20%	
NO_x Post	AVL CLD i60	L/2788/BHT	0 - 6000 ppm	
THC Post	AVL FID i60	L/2789/BHT	0 - 10000 ppm	
CH_4 Post	AVL Cutter FID i60	L/2790/BHT	0 - 3000 ppm	

CVS Sampling System ESU with dilution tunnel and PM sampling system DLS	CVS i60 LD LE	X/2631/BHT	2 - 20 m^3/min	± 2%
	PSS i60 SD		50 - 100 l/min	± 5%
Microbalance	Sartorius M5P000V001	B/1915/BHT	0 - 2.7 g	0.0001 mg
Particle Number Counter	APC 489	L/2636/BHT	0 - 50 000 particles/cm^3	10%
Temperature and humidity transducer	VAISALA HMT 333	L/2637/BHT	-40 - +80 °C	± 0.2 °C
			0 - 100% relative humidity	± 1%
Electronic Barometer	VAISALA PTB 330	F/1543/BHT	500 - 1100 hPa	± 0.15 hPa

Figure 5 Fiat Tipo 1.4 bi-fuel vehicle during emission measurements in climate-controlled laboratory with an AVL Zöellner chassis dynamometer (2WD)

4.2. TEST RESULTS

4.2.1. Results of measurements of regulated exhaust emissions, carbon dioxide emissions and fuel consumption

All emission tests were carried out using the chassis dyno loading obtained from matching road load data provided by the vehicle manufacturer using the coast down method. The target road load data (F0,F1,F2) were the same for WLTP and NEDC testing, but in the case of WLTP testing a different inertia setting was used (taking into consideration the actual mass of the vehicle, mass representative of vehicle payload and the inertia of rotating powertrain components), in line with the requirements of Regulation (EU) 2017/1151. The inertia settings and final chassis dyno loading coefficients are presented in Table 6. Tyre pressure was checked – and, if necessary, adjusted – before the precondition cycle that commenced each batch of emissions testing. Thus, a constant level of tyre pressure was maintained through the test programme. Vehicle running resistance was checked following the preconditioning cycle that commenced each batch of emissions tests. Small differences in the running resistance were detected, but in view of their limited magnitude, it was decided not to change the chassis dyno loading and thus the same settings were used throughout the test programme (on both test objects).

Table 6 Data of load coefficients

Inertia	Chassis dyno loading coefficients			Power absorption by the chassis dynamometer at 80 km/h
	WLTP and constant speed testing			
[kg]	F0	F1	F2	[kW]
	[N]	[N/(km/h)]	$[N/(km/h)^2]$	
1509	45.1	-0.87	0.0390	5.0
	NEDC testing			
[kg]	F0	F1	F2	[kW]
	[N]	[N/(km/h)]	$[N/(km/h)^2]$	
1360	21.0	-1.13	0.0404	4.2

As outlined in Table 3, a single WLTC cycle was executed as preconditioning before each batch of testing commenced. All emissions tests commenced from cold start at an ambient temperature of 23°C and 40% relative humidity. To ensure complete cooling of the entire powertrain (including TWC), the standing time between periods of engine operation for cold start tests (WLTC, NEDC) was always ≥11 hours. All cabin accessories were turned off, including the ventilation system and the vehicle's lights were in 'Auto' mode. The cold start test cycles (NEDC, WLTC) were commenced with the test vehicle's battery fully charged; the battery was not charged immediately before the constant speed tests, which commenced from a hot start. The vehicle was always tested in LPG mode; all cold start events occurred with the engine running on petrol and the fuel supply was switched over to LPG automatically by the vehicle's ECU (i.e. with no driver intervention). It should be noted that such a fuelling strategy is typical for European petrol-LPG bi-fuel vehicles. Fuel switchover (petrol⟶LPG) occurred approximately 56 seconds after engine cranking when running over the WLTC and NEDC driving cycles, with very limited differences in the timing of fuel switchover between tests (regardless of the test cycle). During the constant speed tests there was no cold start and thus no fuelling with petrol while emissions measurements were being carried out. The vehicle's two original oxygen (λ) sensors were used for all emissions testing on both test objects – i.e., the sensors used during engine dyno ageing were not used for any emissions testing activity.

Measurements of exhaust emissions were carried out over the well-known, industry standard WLTC and NEDC driving cycles (Fig. 6 and Fig. 7) and also using a customised constant speed test procedure. The constant speed test procedure was conducted with the vehicle already fully warmed up (by running the NEDC test cycle, followed by a smooth, gradual acceleration to 80 km/h, application of 5th gear and approximately 9 minutes' driving at 80 km/h in 5th gear). Thereafter, emissions measurements were performed over two periods, while continuing to drive at a constant speed of 80 km/h in 5th gear. The distance covered during each measurement period was approximately 10 km, during which time the driver attempted to keep vehicle speed as constant as possible, with minimum throttle fluctuations.

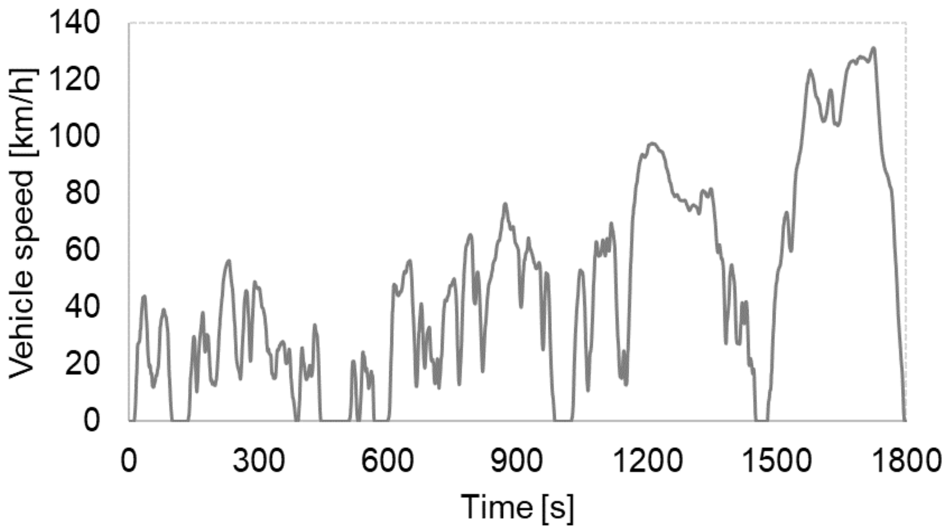

Figure 6 Worldwide harmonized Light vehicles Test Cycle (WLTC), part of the Worldwide harmonized Light vehicles Test Procedure (WLTP)

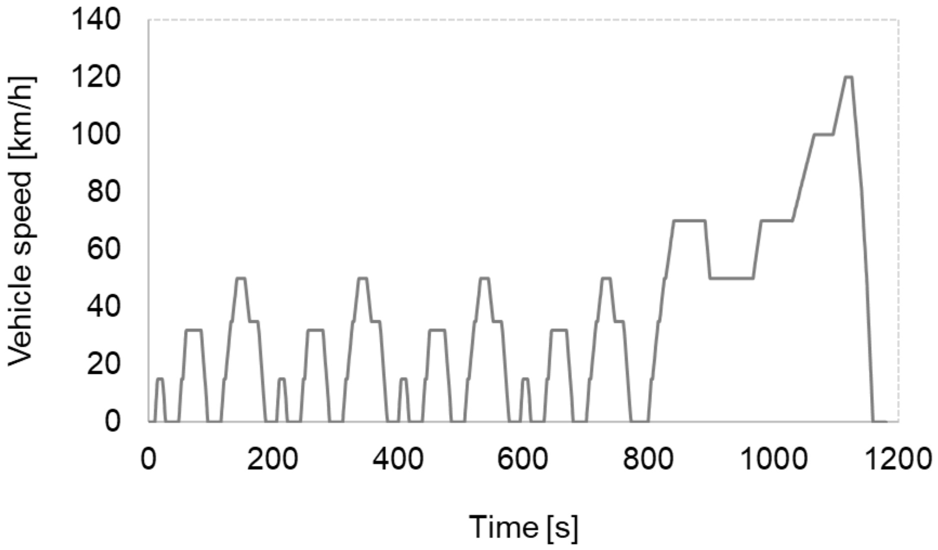

Figure 7 New European Driving Cycle (NEDC)

Tables 7 to 20, which can be found in the appendix, present exhaust emissions results for the test fuels obtained from the test vehicle, for the test cycles employed and their component phases. The aforementioned tables include the results of legislative measurements obtained via the CVS-bag method, diluted exhaust emissions measurements and results from measurements of undiluted exhaust emissions upstream and downstream of the TWC. Particulate matter emissions, while not regulated in the EU for this vehicle type, are also shown in terms of mass (PM) and number (PN); PM results are available for the entire test cycles, while PN results are available for the entire test cycles and their component phases. Carbon dioxide emissions and fuel consumption results calculated according to the legislative carbon balance method are also shown. The tables show the calculated mean and standard deviation from the obtained emissions results, as well as values of standard type A uncertainty obtained by means of statistical analysis, calculated using the following formula:

$$\boldsymbol{u_A^2(M)} = \frac{\sqrt{\frac{1}{n-1}\sum_{j=1}^{n}\left(x_j - \bar{x}\right)^2}}{\sqrt{n}}$$

where:

$u^2_A(M)$ = type A evaluation of standard uncertainty (for measured quantity M, where M represents regulated emissions, CO_2 or fuel consumption),

n = number of tests,

x_j = result from test *j*,

$\bar{X}$ = arithmetic mean of all tests.

Figures 8 to 31 show emissions results for the based on the legislative bag measurements of regulated compounds THC, NMHC, CO and NO_x; results are shown for the entire NEDC and the initial, cold start phase of that cycle (UDC), as well as the entire WLTC and the initial, cold start phase of that cycle (WLTC Low). The graphic representations' error bars are defined as the standard type A uncertainty values shown in Tables 7 to 20.

Figures 8 to 19 show results obtained from the Low S test object.

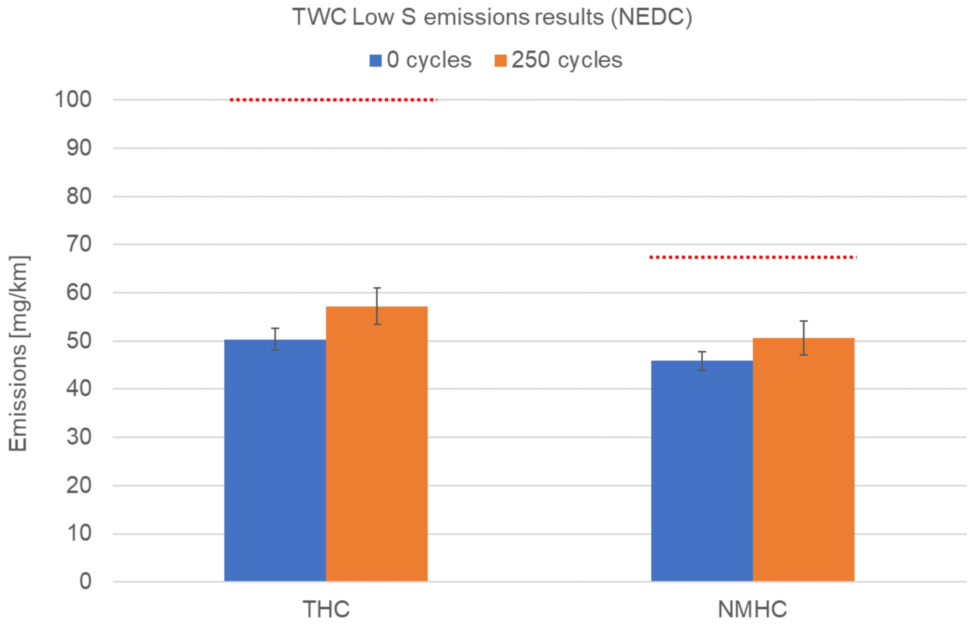

Figure 8 THC and NMHC emissions results for TWC Low S, tested over the entire NEDC. The Euro 6 limits are shown for comparison.

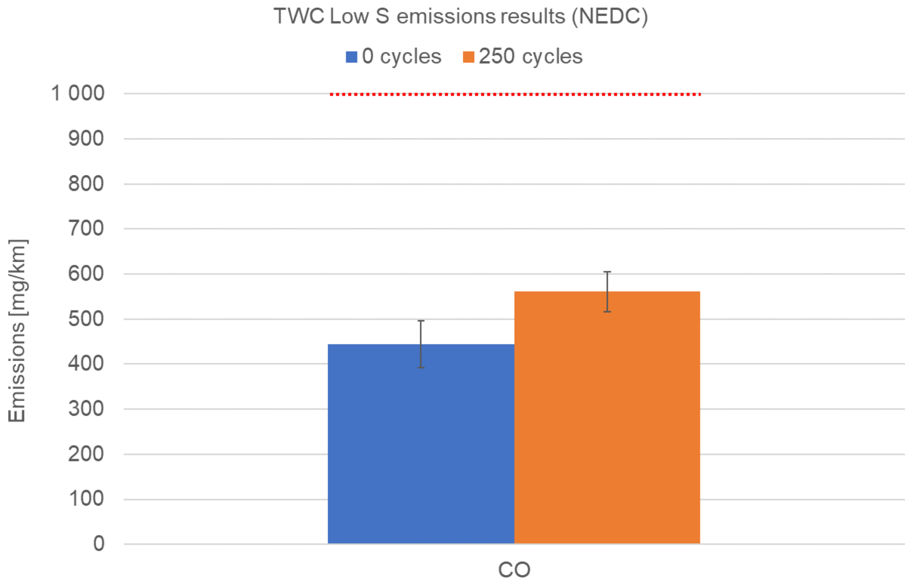

Figure 9 CO emissions results for TWC Low S, tested over the entire NEDC. The Euro 6 limit is shown for comparison.

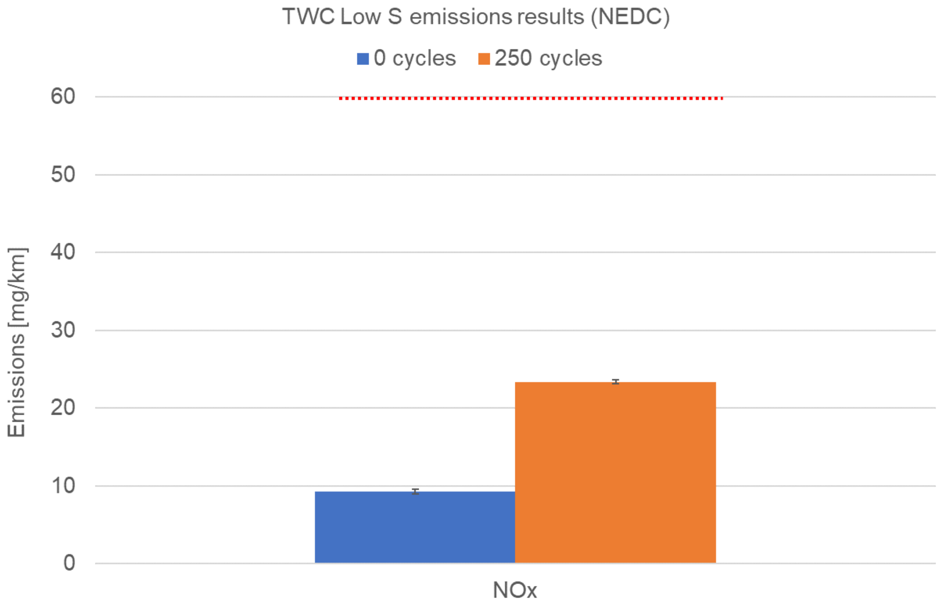

Figure 10 NO$_x$ emissions results for TWC Low S, tested over the entire NEDC. The Euro 6 limit is shown for comparison

As shown above, execution of 250 ageing cycles using low sulphur fuel caused measurable increases in emissions of THC, NMHC, CO and NO$_x$ when tested over the NEDC. Emissions remained below the applicable Euro 6 limits following 250 ageing cycles – by a considerably margin the case of THC, CO and NO$_x$ and by a smaller margin the case of NMHC. Taking into account the number of repeat tests (n=3) and the derived uncertainty of the results, differences between the THC, NMHC and CO results at 0 cycles and at 250 cycles were limited. The difference was more apparent for NO$_x$, with the difference being significantly larger than the uncertainty in the mean results. Similar trends were observed during the first, cold start phase of the NEDC – the UDC, as shown in Figures 11-13. While measured emissions of THC, NMHC and CO were all higher at the 250 cycle stage than at the 0 cycle stage, the magnitude of the difference was small in comparison to the uncertainty of the results, while NO$_x$ showed a clear difference, with emissions more than doubling following 250 ageing cycles.

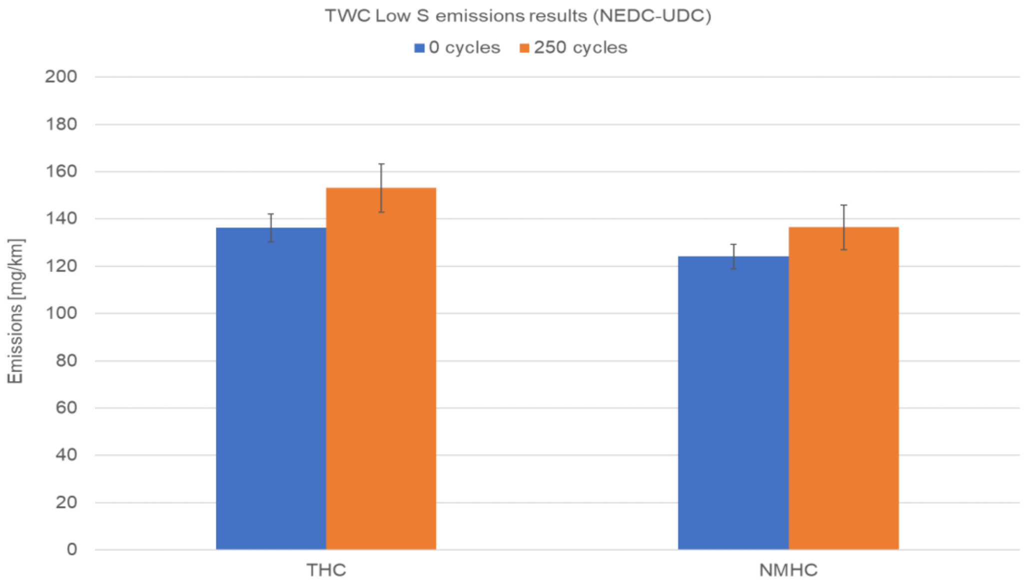

Figure 11 THC and NMHC emissions results for TWC Low S, tested over the UDC phase of the NEDC.

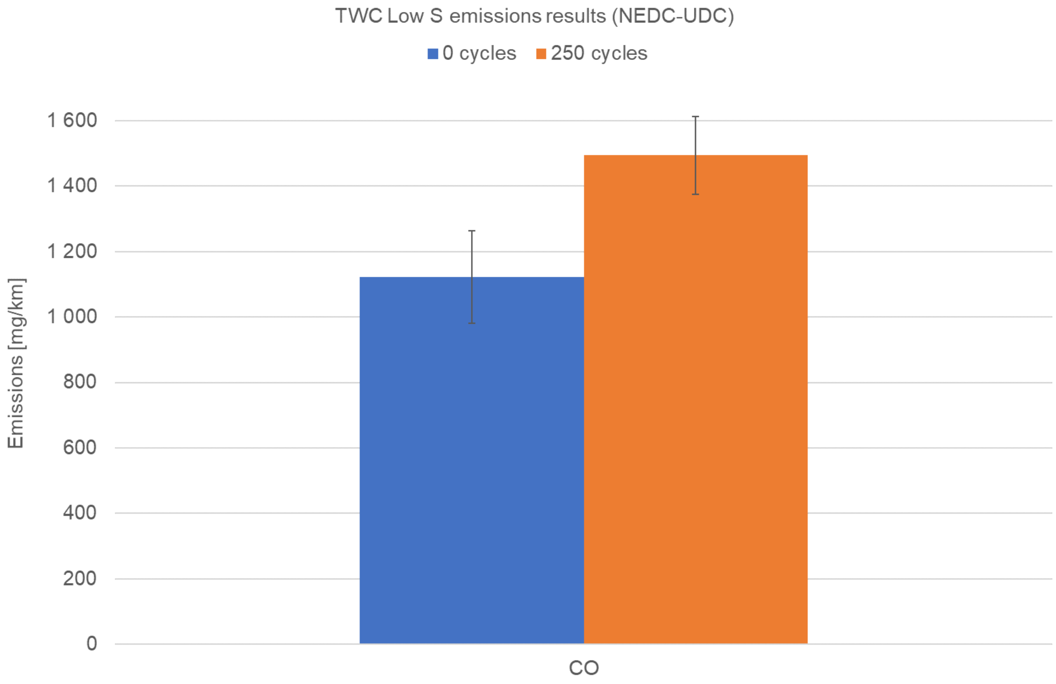

Figure 12 CO emissions results for TWC Low S, tested over the UDC phase of the NEDC.

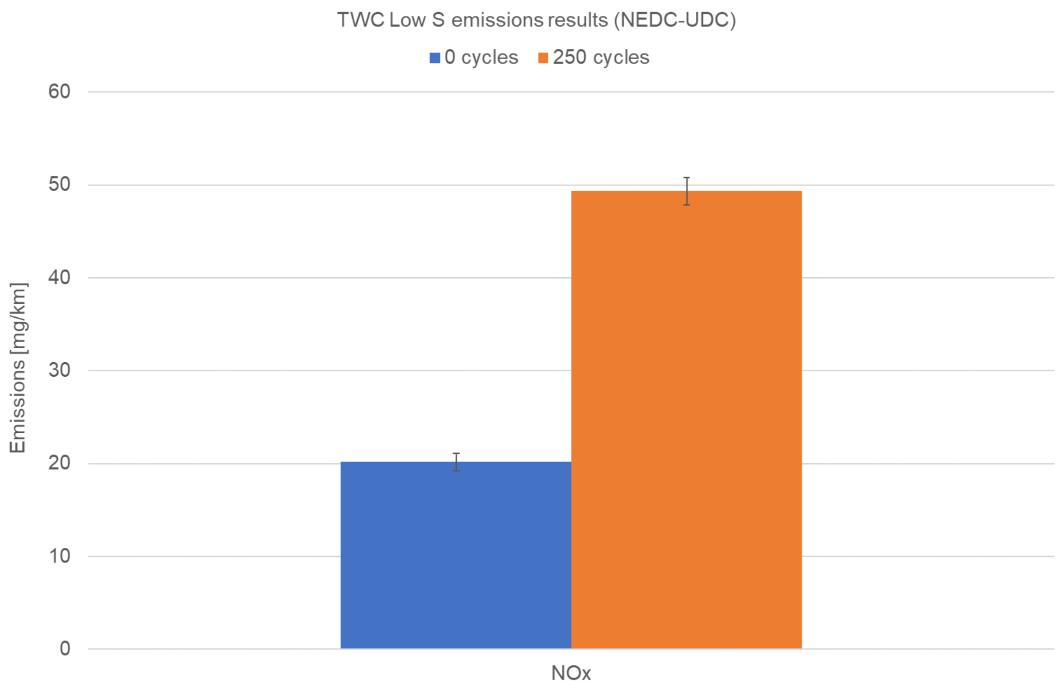

Figure 13 NO$_x$ emissions results for TWC Low S, tested over the UDC phase of the NEDC.

WLTC results as a function of the number of ageing cycles are available at higher resolution (as interim testing was conducted over the WLTC only). As shown in Figures 14-15, THC, NMHC, and CO increased monotonically from 0 to 100 cycles, while the result at 175 cycles was essentially indistinguishable from the result at 100 cycles. The results for THC and NMHC in fact decreased at the 250 cycle stage, being at a level close to that of the 50 cycle stage. For CO, the trend was slightly different, as emissions reached a plateau starting at 100 cycles and there was no significant variation for the next two measurement points (175, 250 cycles). As shown in Figure 16, for NO$_x$, a noticeable increase occurred between 0 and 50 cycles, but thereafter emissions fell somewhat at 100 cycles, while emission sat 175 cycles were slightly higher and indistinguishable from each other. While the Euro 6 emissions limits are not directly applicable to this test vehicle when tested over the WLTC, it is noteworthy that those limits were not exceeded at any ageing stage.

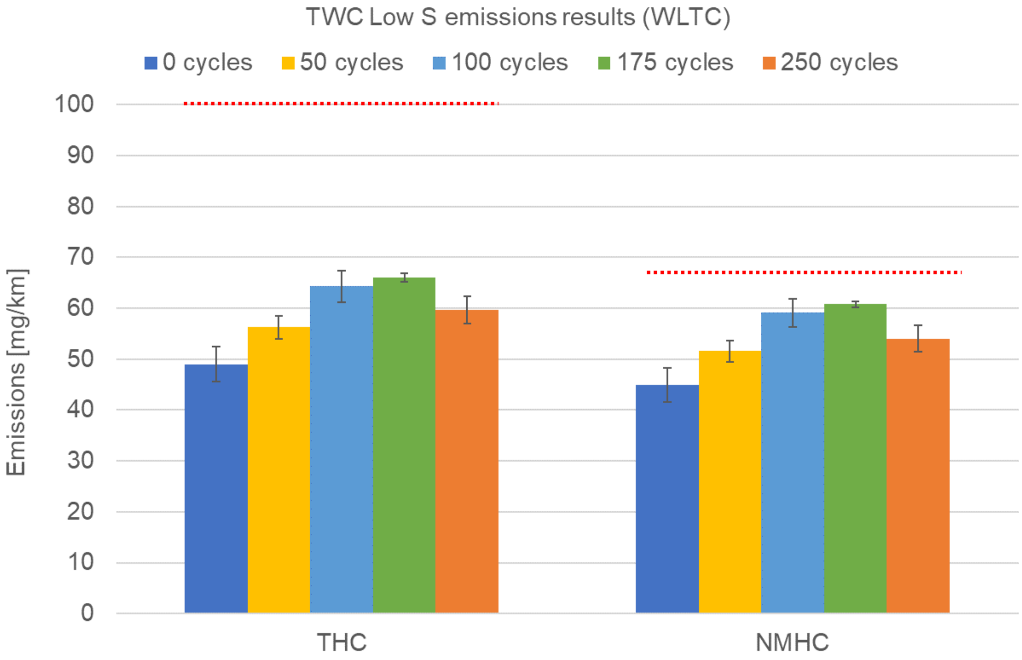

Figure 14 THC and NMHC emissions results for TWC Low S, tested over the entire WLTC. The Euro 6 limits are shown for information only.

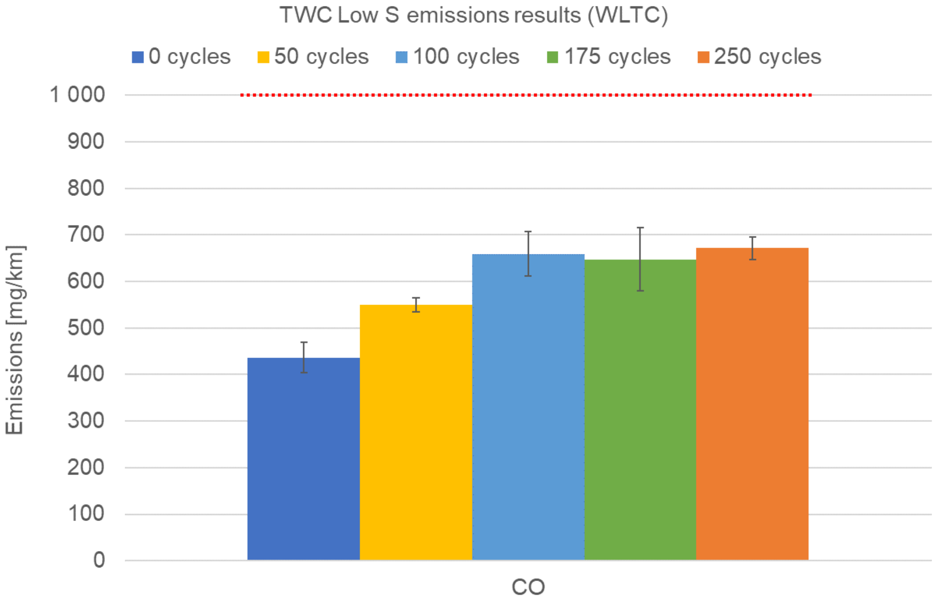

Figure 15 CO emissions results for TWC Low S, tested over the entire WLTC. The Euro 6 limit is shown for information only.

Figure 16 NO$_x$ emissions results for TWC Low S, tested over the entire WLTC. The Euro 6 limit is shown for information only.

Partially contrasting trends were observed the first, cold start phase of the WLTC (i.e. Low phase), as shown in Figures 17-19. THC and NMHC showed the same trend as over the entire WLTC (i.e. a monotonic increase up to 100 cycles, a very small increase at 175 cycles and a marked decrease in emissions at 250 cycles, meaning that results at 250 cycles were essentially the same as at 50 cycles. CO and NOx showed interrupted monotonic increases in the range 0-250 cycles, although the rate of increase slowed significantly after the first 50 cycles. Differences in CO and NOx emissions between the 175 and 250 cycle stages appeared to be insignificant.

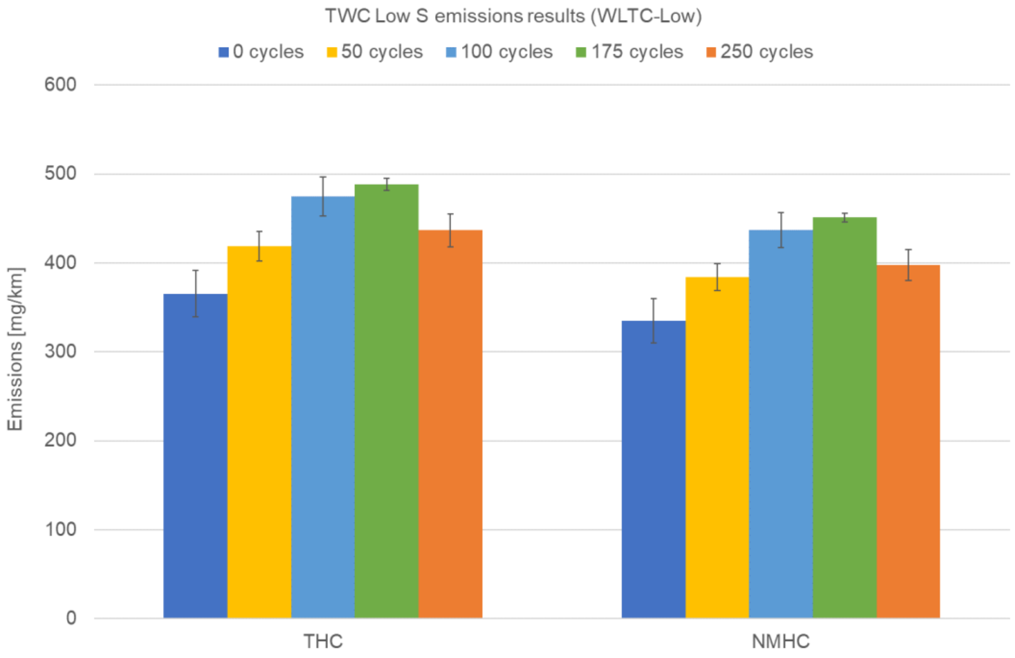

Figure 17 THC and NMHC emissions results for TWC Low S, tested over the Low phase of the WLTC.

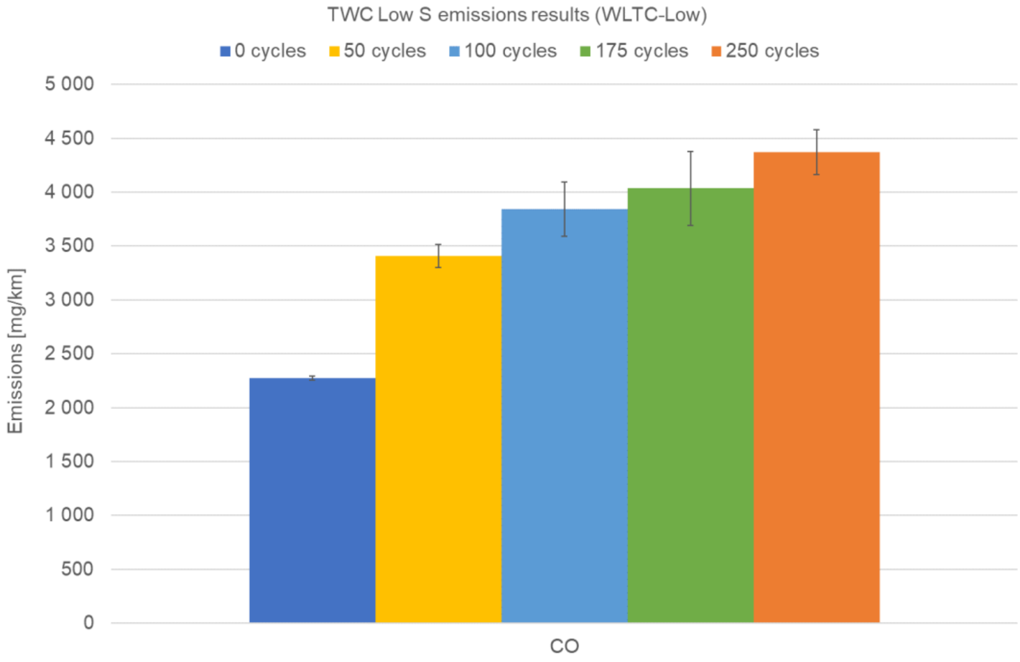

Figure 18 CO emissions results for TWC Low S, tested over the Low phase of the WLTC

Figure 19 NO$_x$ emissions results for TWC Low S, tested over the Low phase of the WLTC.

Results for the test object aged using fuel of high sulphur content (TWC High S) are presented in Figures 20-31. When tested over the NEDC, there was a clear increase in emissions of THC, NMHC, CO and NOx following 250 ageing cycles. In the case of NMHC, mean emissions at the 250 cycle stage were very close to the Euro 6 limit (and in fact exceeded that limit during one test). Specifically, the NMHC emissions result during test L1-0004 (NEDC test number 3 at the 250 cycle stage on TWC High S); that result is shown in red in Table 14. The NMHC results for NEDC test numbers 1 & 2 at the 250 cycle stage were significantly below the Euro 6 limit, such that the mean NMHC result of all three NEDC tests was 59 mg/km, i.e. 87% of the limit. Given the generally high variability of the emissions results at the 250 cycle stage, reflected in the standard deviation and type A uncertainty values, this result should be treated with caution. Further testing would be required to fully determine NMHC emissions compliance with the Euro 6 limit for TWC High S at the 250 cycle stage. It should also be noted that the NMHC emissions during test L1-0004 were elevated for the UDC (cold start, urban) phase of the NEDC; emissions results for the EUDC (extra-urban) phase were very low and essentially identical for all three NEDC tests at the 250 cycle stage for the High S test object. The measured engine-out (pre TWC) NMHC emissions for test L1-0004 were comparable to those from NEDC test numbers 1 & 2 at the same stage; the temperature traces for the three NEDC tests in question also revealed no significant differences.

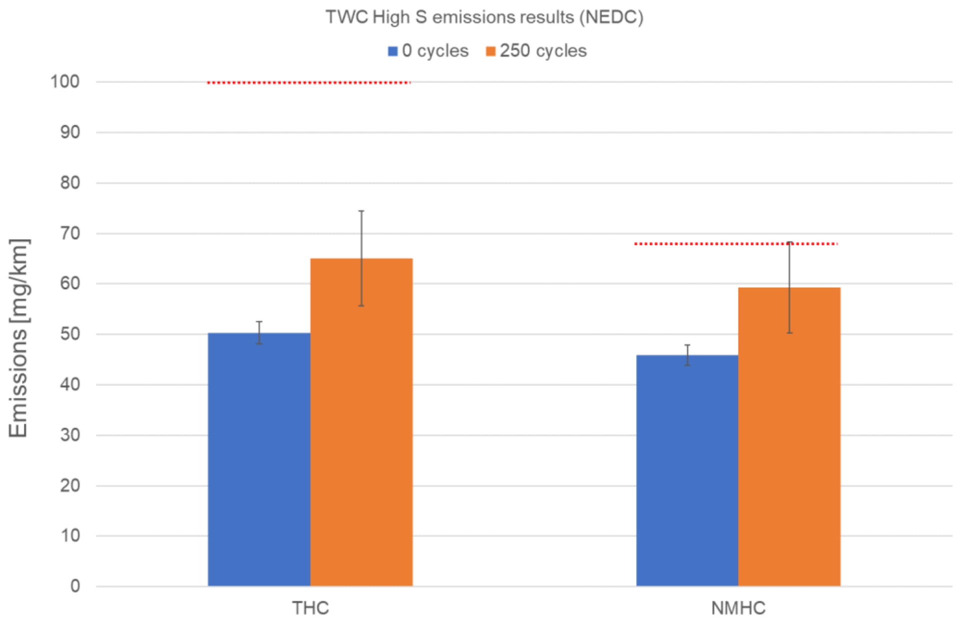

Figure 20 THC and NMHC emissions results for TWC High S, tested over the entire NEDC. The Euro 6 limits are shown for comparison

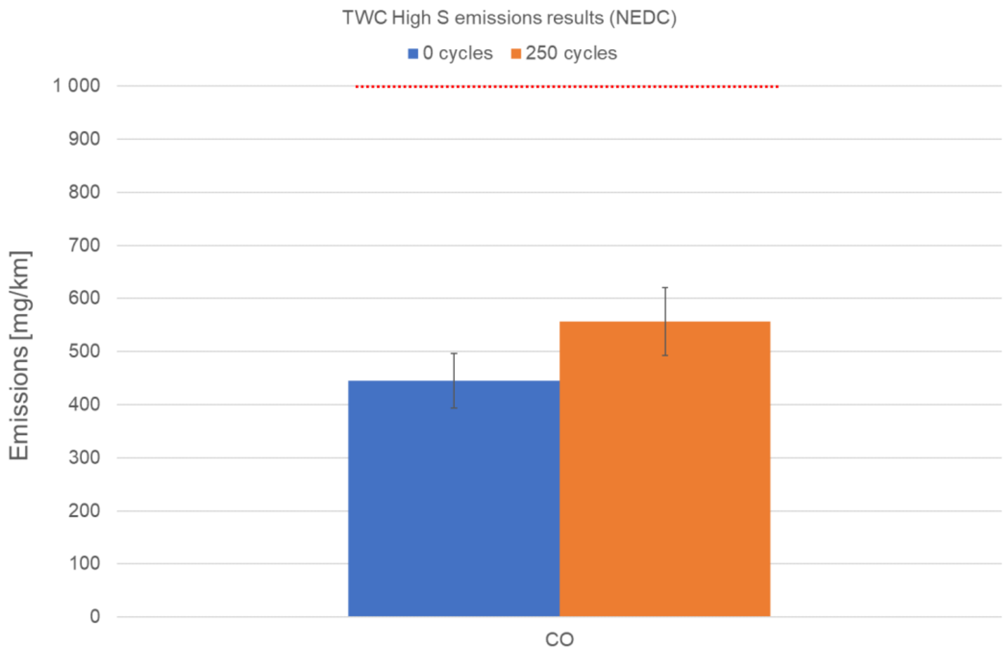

Figure 21 CO emissions results for TWC High S, tested over the entire NEDC. The Euro 6 limit is shown for comparison

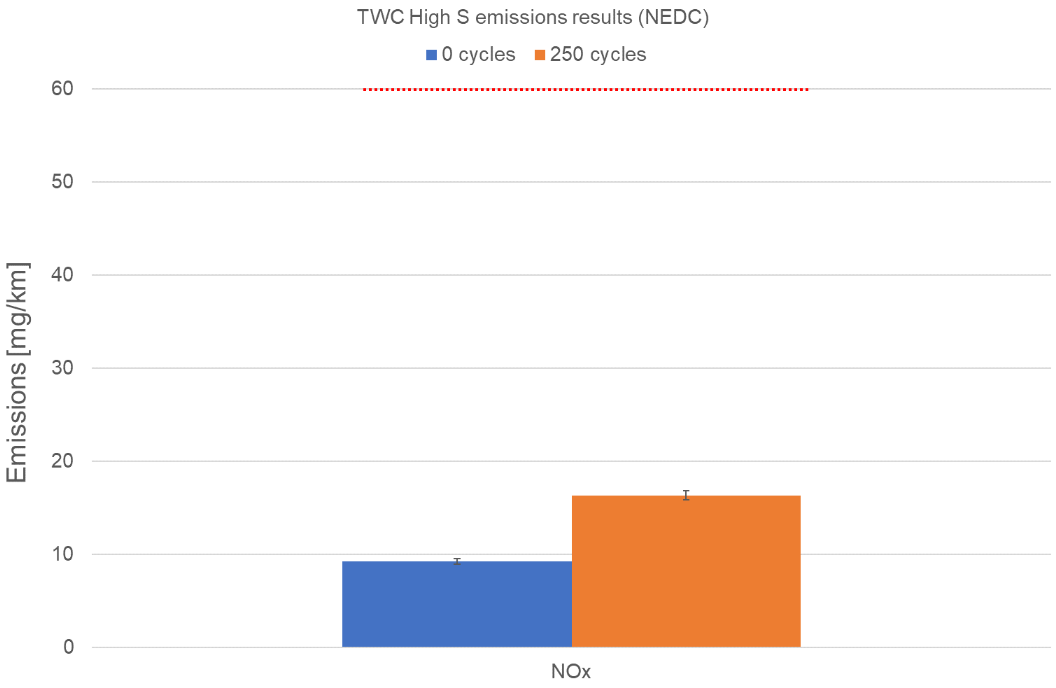

Figure 22 NO$_x$ emissions results for TWC High S, tested over the entire NEDC. The Euro 6 limit is shown for comparison.

Trends observed over the UDC phase of the NEDC were essentially identical, with clear increases at 250 cycles, with particularly large relative increases observed in the case of NO$_x$.

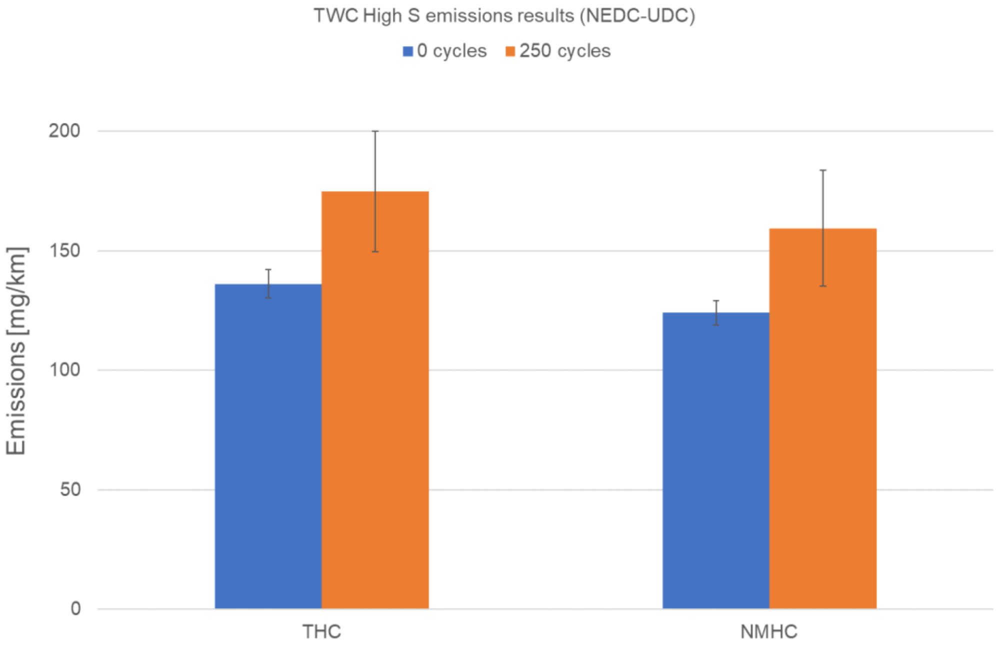

Figure 23 THC and NMHC emissions results for TWC High S, tested over the UDC phase of the NEDC.

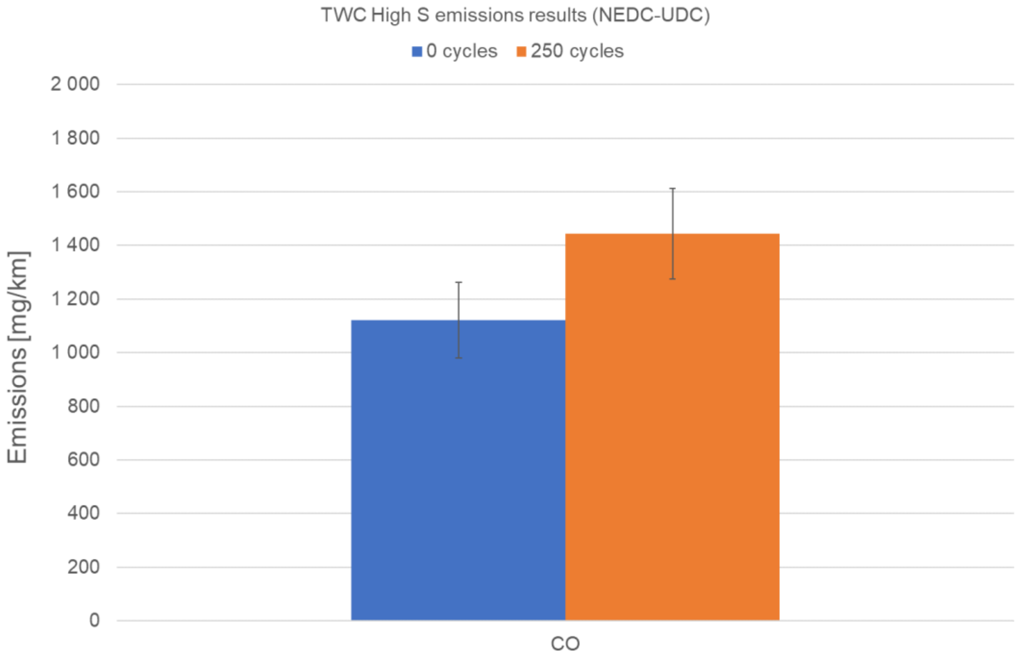

Figure 24 CO emissions results for TWC High S, tested over the UDC phase of the NEDC.

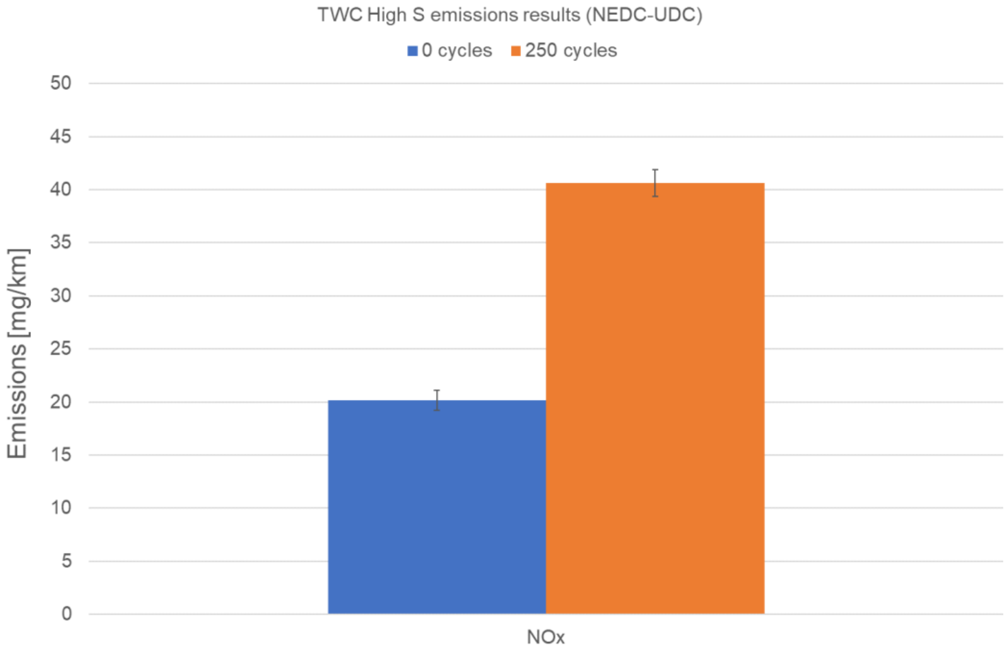

Figure 25 NO_x emissions results for TWC High S, tested over the UDC phase of the NEDC.

When tested over the WLTC, the following emissions trends were observed, as shown in Figures 26-31. For THC and NMHC, emissions increased for 0 to 50 cycles, but the result for 100 cycles was essentially identical to that at 50 cycles. Thereafter, at 175 cycles emissions fell to a level between that of 0 and 5-0 cycles, but a substantial increase occurred between 175 and 250 cycles. CO emissions increased noticeably from 0 to 50 cycles, fell at 100 cycles and then increased at 175 and 250 cycles (for which differences in the emissions level were of limited significance). For NO_x emissions there was little variation between the ageing stages, with the exception of 100 cycles, which showed the highest emissions results. NOx results from the final two stages (175, 250) were essentially identical.

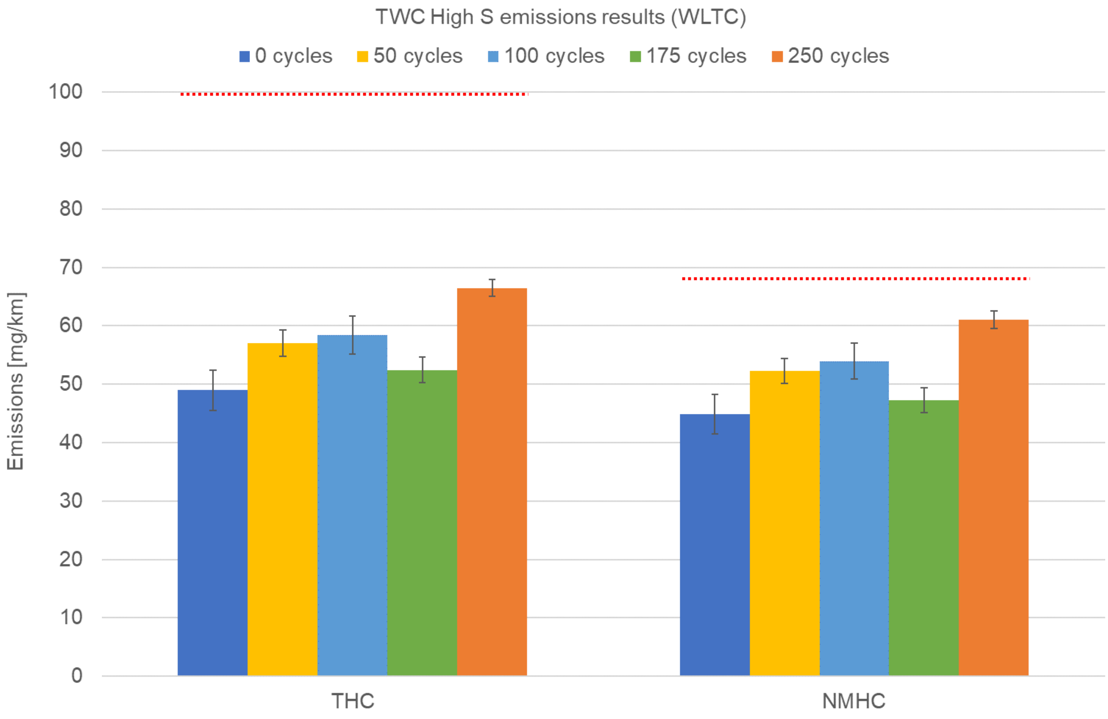

Figure 26 THC and NMHC emissions results for TWC High S, tested over the entire WLTC. The Euro 6 limits are shown for information only.

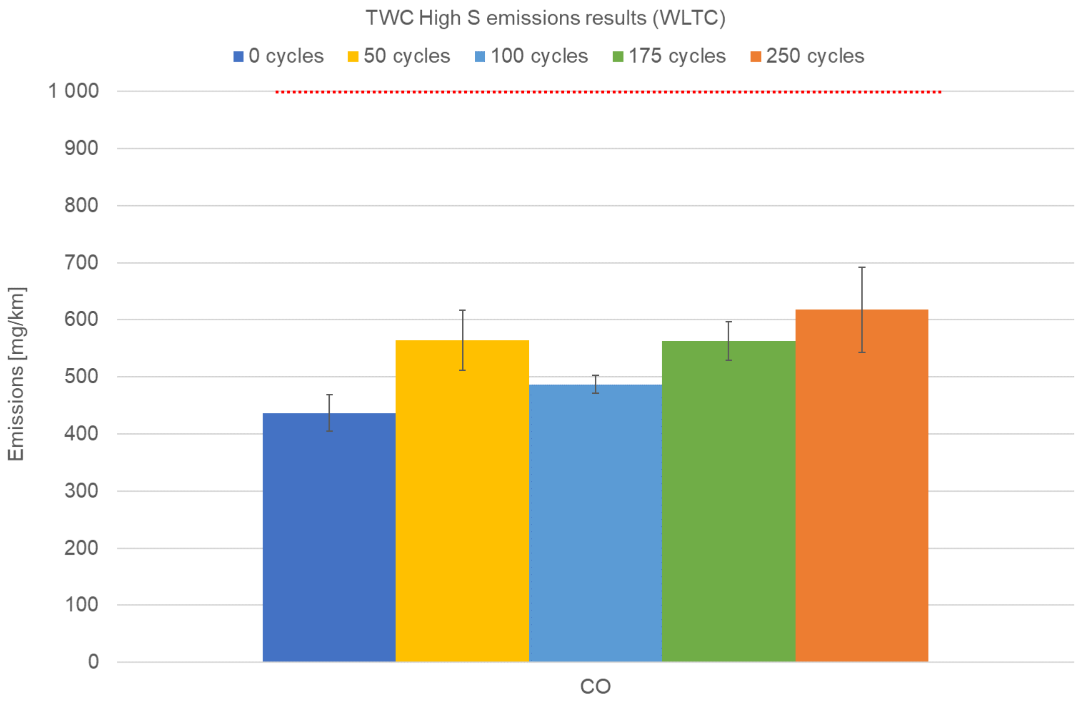

***Figure* 27** CO emissions results for TWC High S, tested over the entire WLTC. The Euro 6 limit is shown for information only.

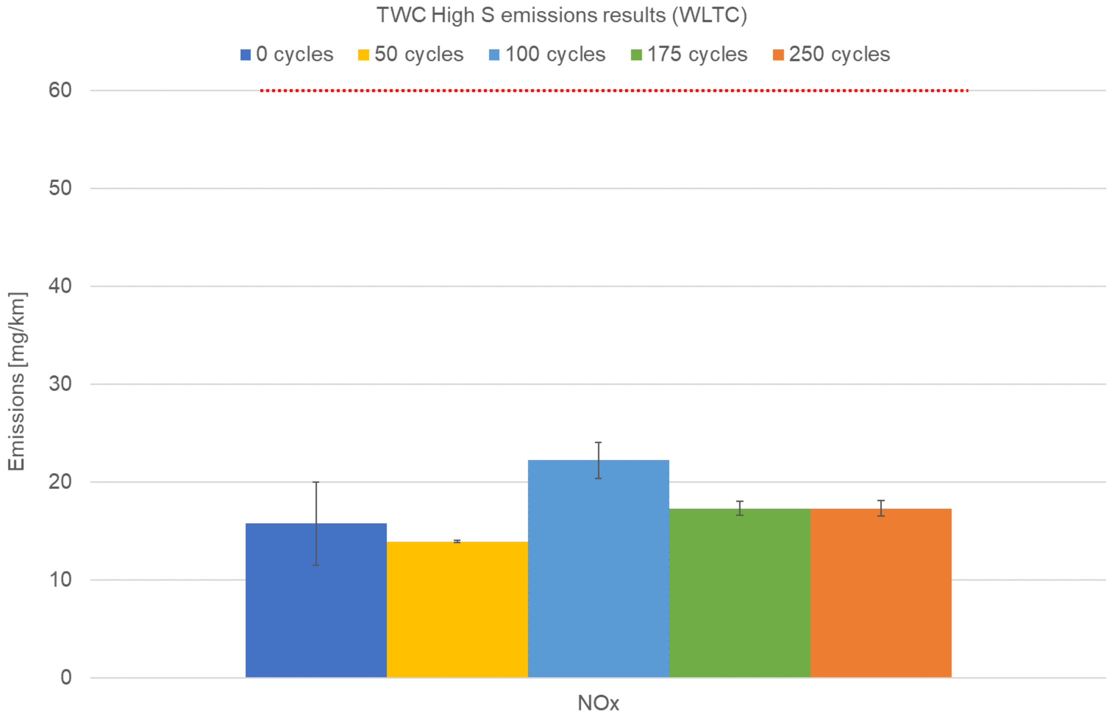

Figure 28 NO_x emissions results for TWC High S, tested over the entire WLTC. The Euro 6 limits are shown for information only.

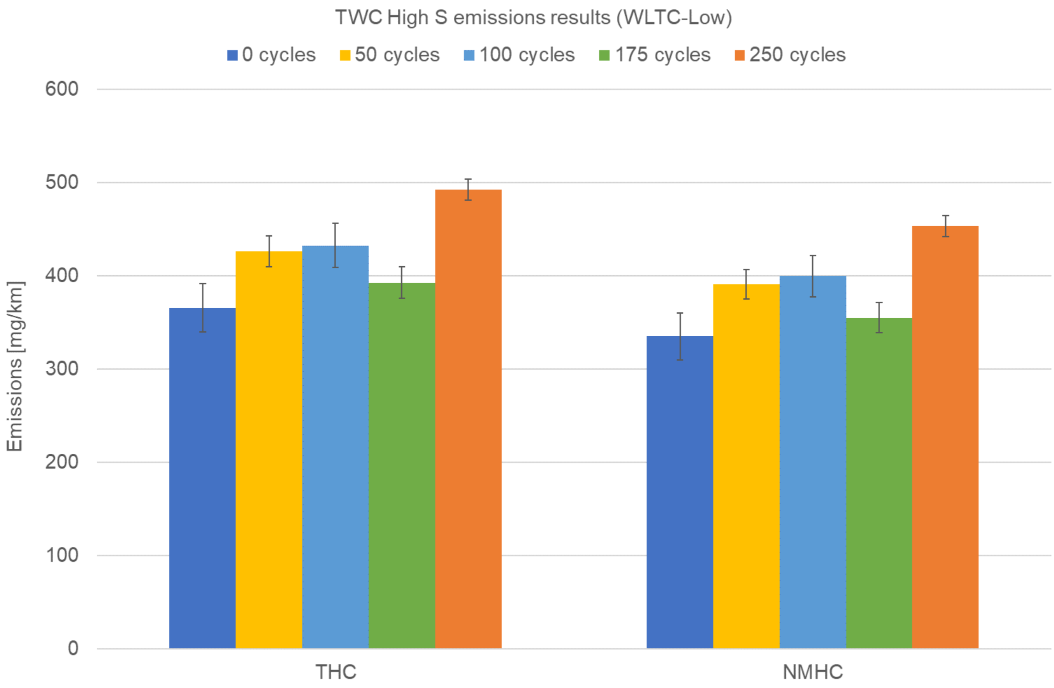

Figure 29 THC and NMHC emissions results for TWC High S, tested over the Low phase of the WLTC.

Figure 30 CO emissions results for TWC High S, tested over the Low phase of the WLTC.

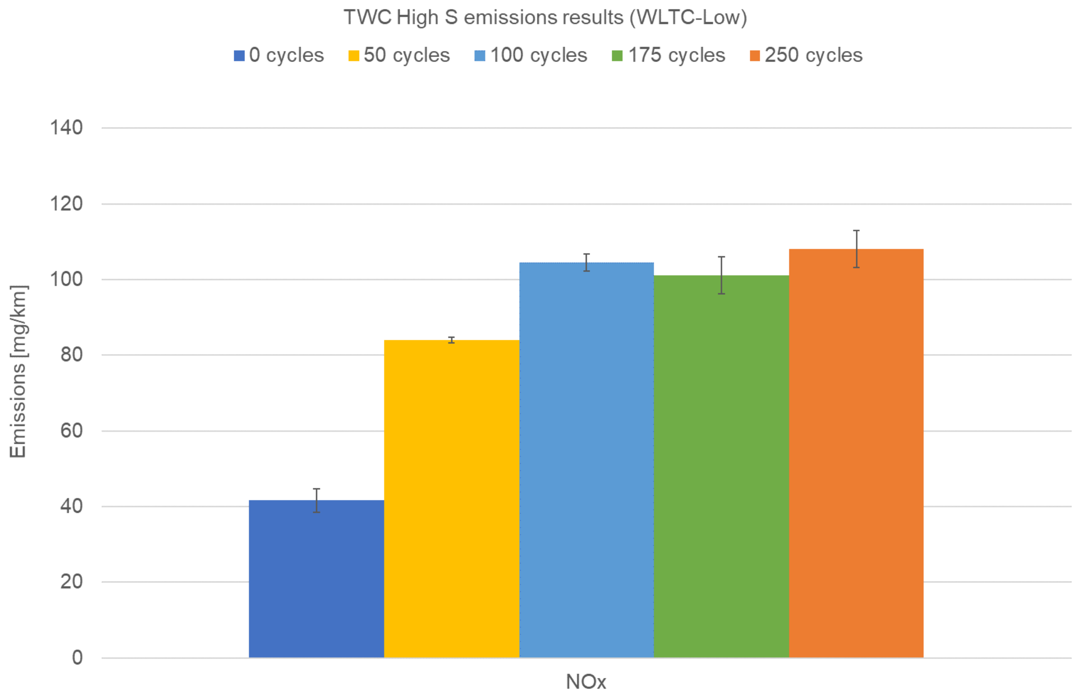

Figure 31 NO$_x$ emissions results for TWC High S, tested over the Low phase of the WLTC.

Emissions other than regulated gaseous emissions are discussed below, together with fuel consumption.

Emissions other than regulated gaseous emissions are discussed below, together with fuel consumption.

Emissions of particulate matter (by mass and number; PM and PN) were both stable and consistently relatively low throughout the entire test programme, with no apparent correlation to the number of ageing cycles. It should be noted that vehicles of the type used for testing are not subject to PM or PN limits in the EU. The test vehicle's mean PM and PN results met the EU limits for M-category vehicles, over both test the NEDC and WLTC, with both test units mounted. PM and PN emissions were lower still for constant speed testing, due to the lack of cold start in that test procedure. Due to the above considerations, PM and PN emissions are not shown graphically, but numerical results are presented in Tables 7-20.

Carbon dioxide emissions (Figures 32 and 33) and fuel consumption (Figures 34 and 35) were relatively stable during the test programme. There was a slight tendency for those parameters to fall as ageing progressed, but the magnitude of the differences was small (approximately 3% when comparing 0 cycles to 250 cycles). As the test programme was conducted, vehicle mileage increased by some 45% compared to the mileage at start of testing, which would generally be expected to cause running resistance to reduce somewhat. Nevertheless, the periodic coast down verifications showed very limited differences in running resistance and, as mentioned previously, no changes were made to the chassis dyno loading during testing. A further tendency of note relates to the fact that as emissions of THC and CO increase, CO$_2$ emissions fall slightly, since less CO$_2$ is formed in the TWC via the oxidation of THC and CO. The observed decreases in CO_2 emissions can be attributed to the combined impact of the two aforementioned effects.

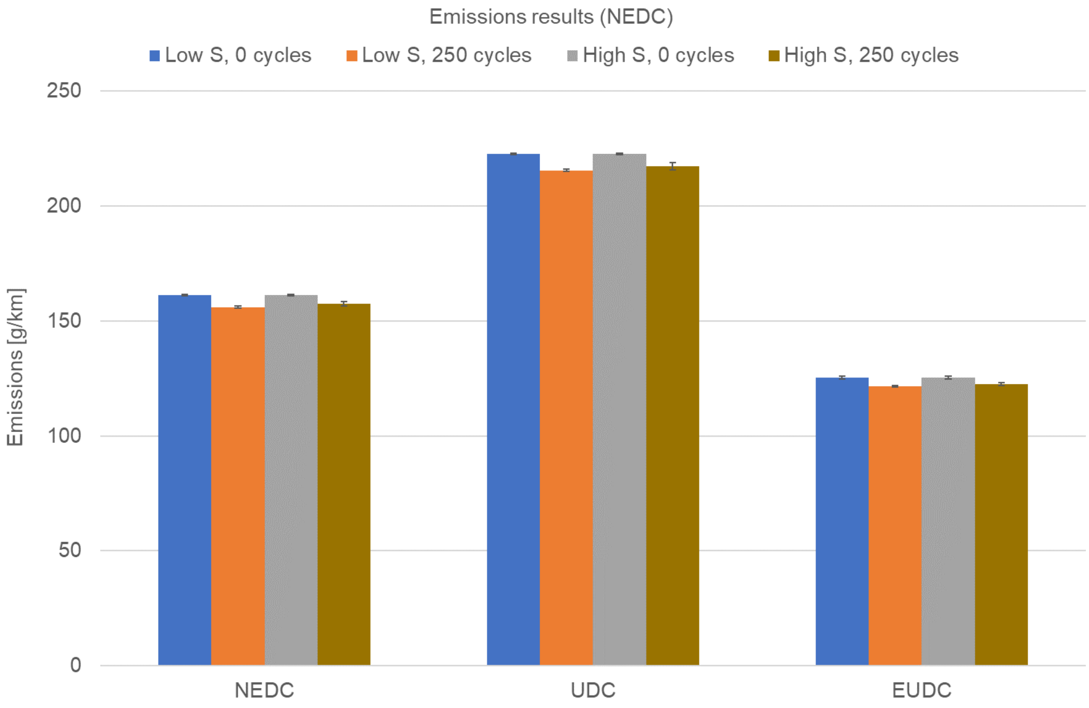

Figure 32 CO_2 emissions results for TWC Low S and TWC High S, tested over the NEDC and its component phases.

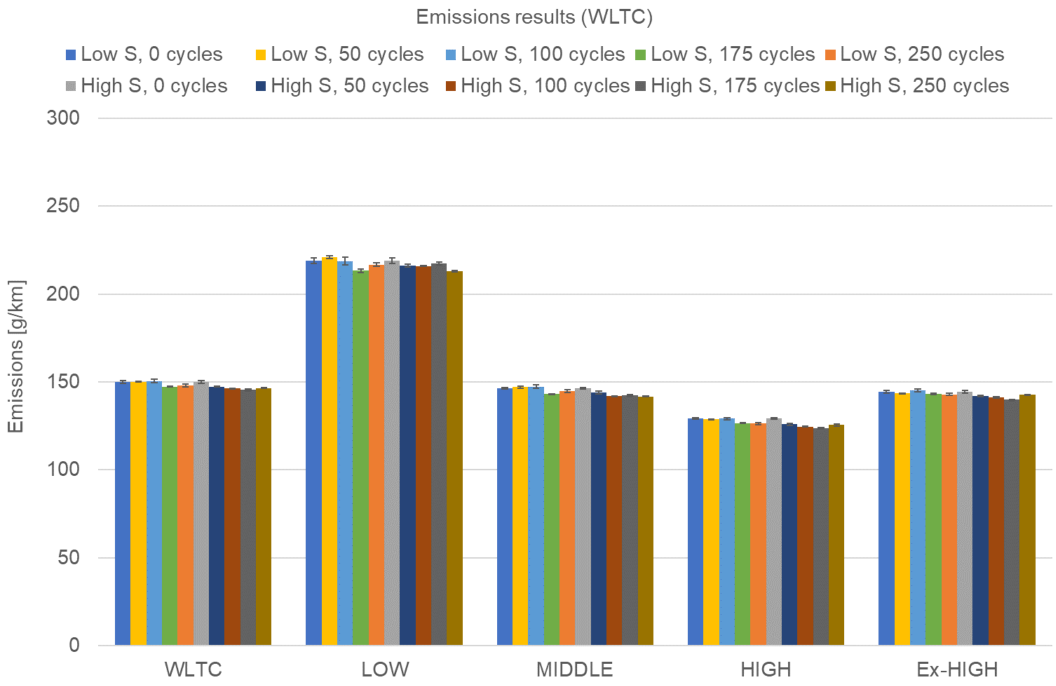

Figure 33 CO_2 emissions results for TWC Low S and TWC High S, tested over the WLTC and its component phases.

Fuel consumption calculated according to the legislative carbon balance method takes emissions of THC and CO (as well as CO_2) into consideration. Thus, the slight fall in fuel consumption as ageing progressed can be attributed to the slight reduction in friction that occurred as vehicle mileage increased, together with the effects resulting from test-to-test variations which are unavoidable when using a human driver. As a final point, the number of repeat tests NEDC and WLTC testing (n=3 in both cases) should be borne in mind.

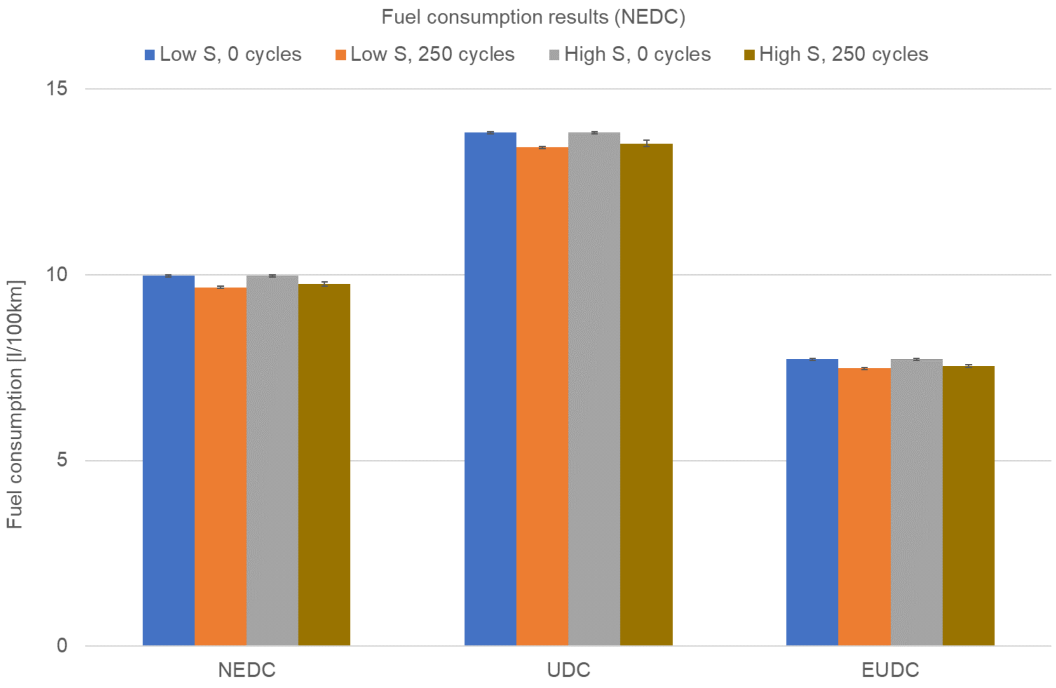

Figure 34 Fuel consumption results for TWC Low S and TWC High S, tested over the NEDC and its component phases.

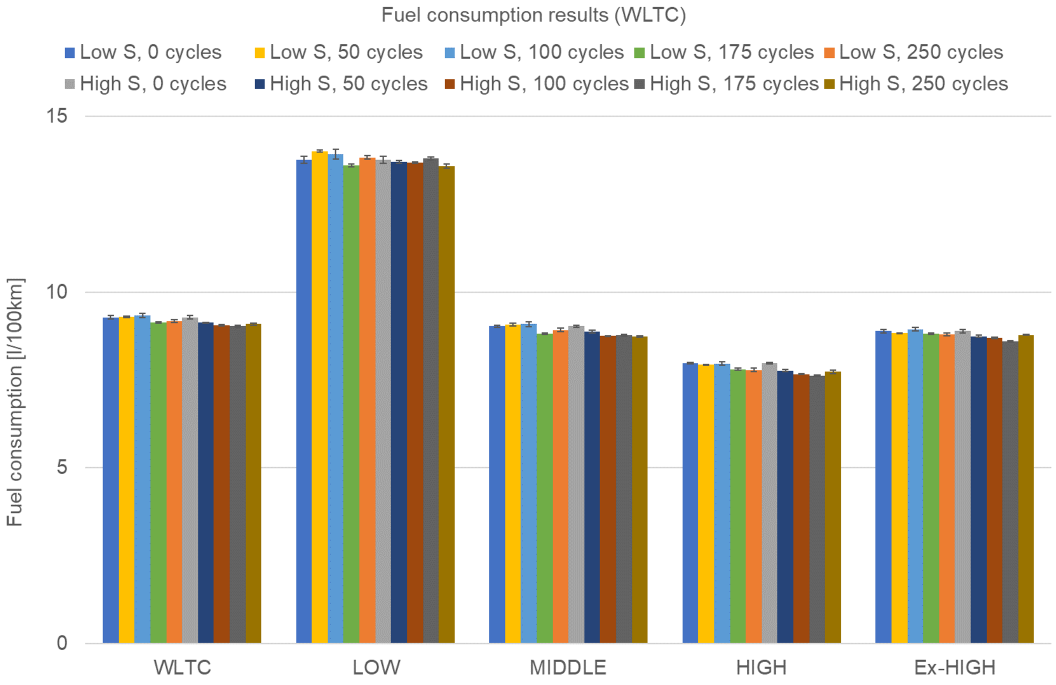

Figure 35 Fuel consumption results for TWC Low S and TWC High S, tested over the WLTC and its component phases.

4.2.2. Results of calculated TWC conversion efficiency

Tables 7 to 20 show the test objects' conversion efficiency, calculated in two ways:

- by comparing the measurements of undiluted exhaust emissions upstream with the CVS-bag measurements of diluted exhaust emissions of the TWC (labelled 'pre-bag'),
- by comparing the measurements of undiluted exhaust emissions upstream and downstream of the TWC (labelled 'pre-post').

Figures 36 to 55 show TWC conversion efficiency ('pre-post', as defined above); the graphic representations show the mean results, with error bars defined as the minimum and maximum measured values (not type A uncertainty).

WLTC results are available at higher resolution, as shown in Figures 36-43. For THC, NMHC and CO, the raw results showed no overall trend as to which test object performed better (i.e. Low S<High S and High S<Low S both occurred), but there was an observable overall trend for a gradual and quasi-monotonic decrease in conversion efficiency as ageing progressed from 0 to 250 cycles, visible in the figures below.

Figure 36 TWC conversion efficiency calculated from THC emissions results for both test objects, tested over the entire WLTC.

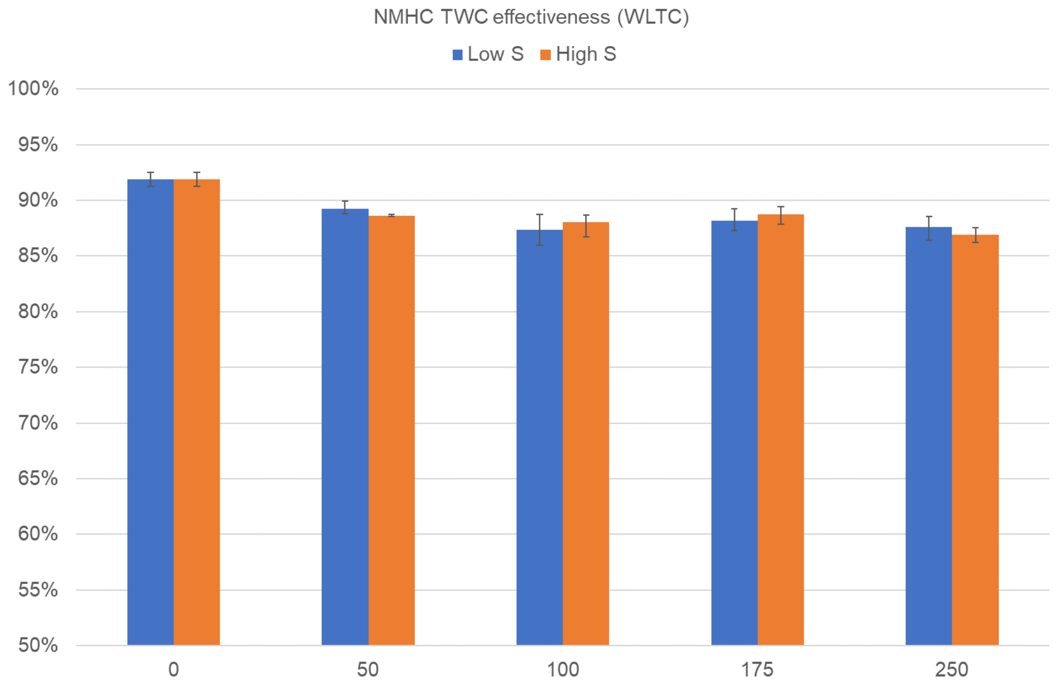

Figure 37 TWC conversion efficiency calculated from NMHC emissions results for both test objects, tested over the entire WLTC.

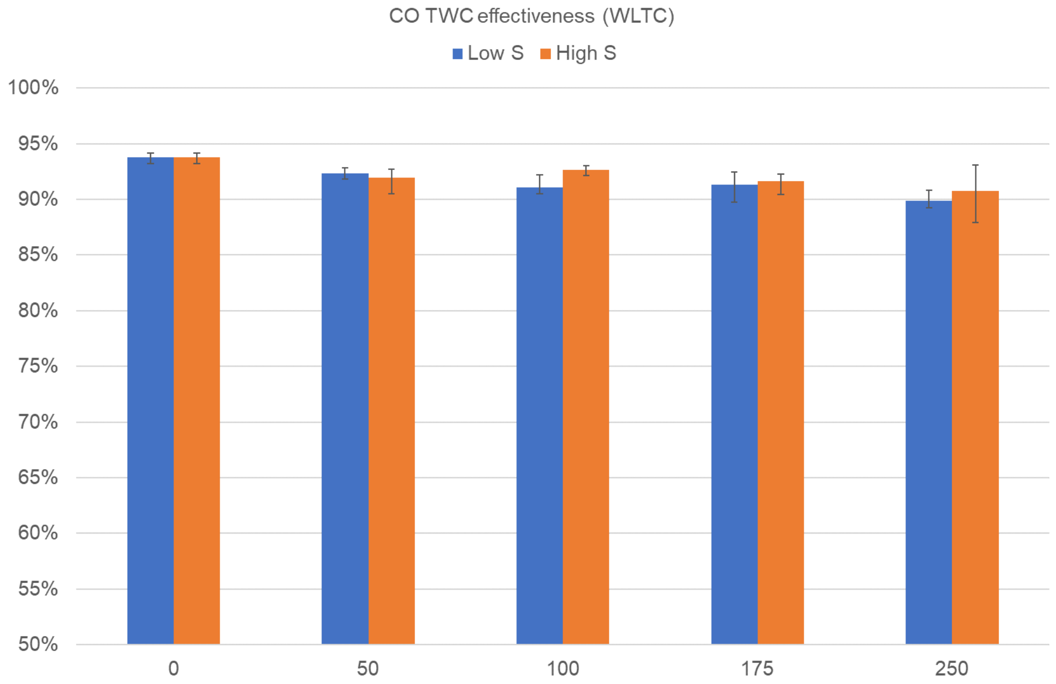

Figure 38 TWC conversion efficiency calculated from CO emissions results for both test objects, tested over the entire WLTC.

For NO_x, the picture was somewhat more complicated, as the High S TWC appeared to outperform its counterpart at three ageing stages (50, 175 and 250 cycles). The trend was non-monotonic and the difference between 0 and 250 cycles was limited, especially in the case of TWC High S.

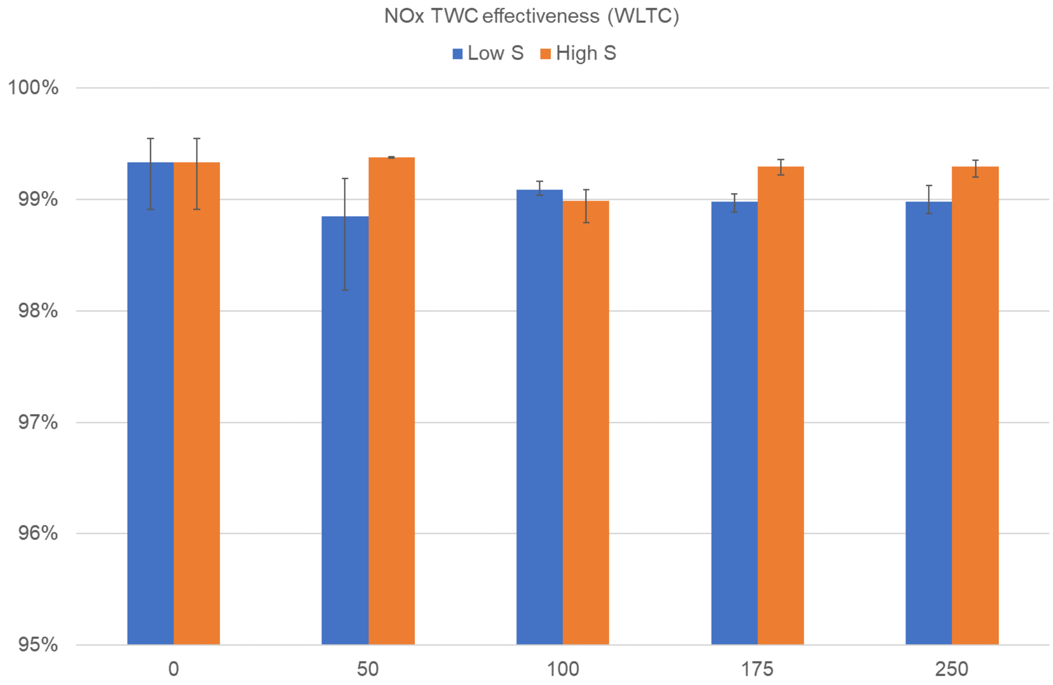

Figure 39 TWC conversion efficiency calculated from NO_x emissions results for both test objects, tested over the entire WLTC.

As shown in Figures 40-43, trends were broadly similar over the WLTC's Low phase, but differences were numerically much greater and generally more evident, due to the much lower conversion efficiency during the Low phase, which contains the cold start event (meaning the TWC's temperature is equal to ambient temperature at the very beginning of the test).

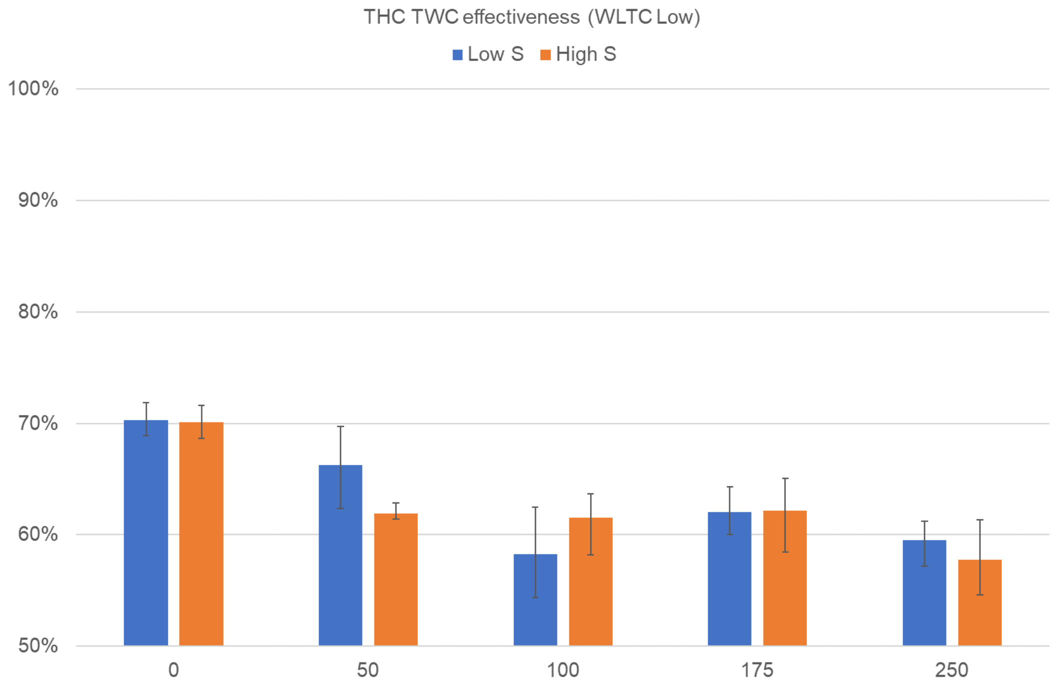

Figure 40 TWC conversion efficiency calculated from THC emissions results for both test objects, tested over the Low phase of the WLTC.

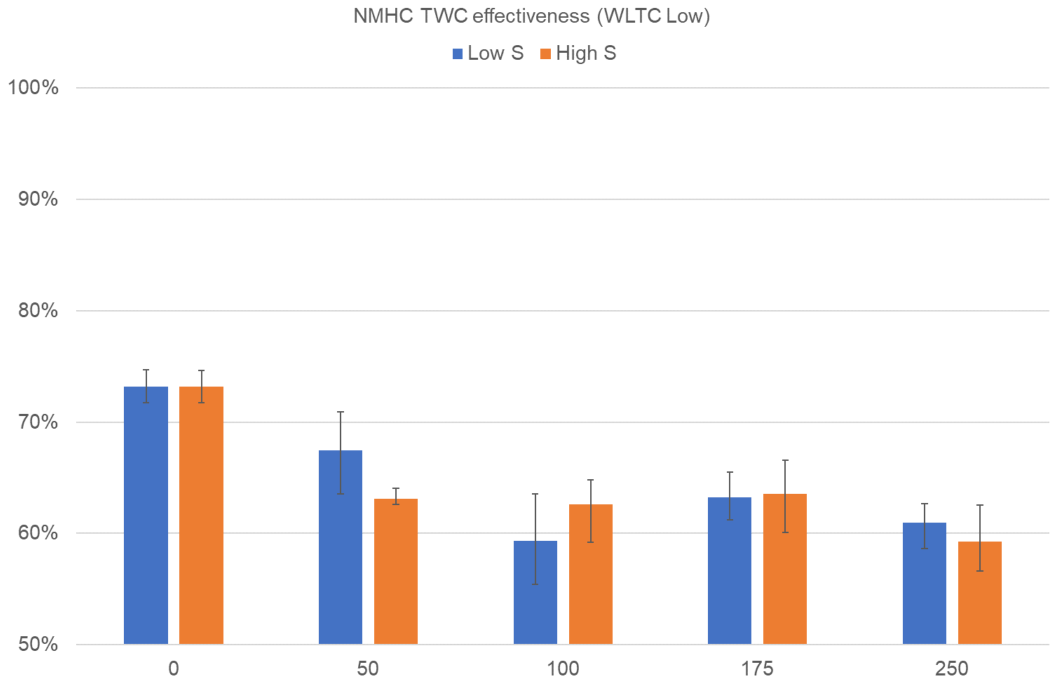

Figure 41 TWC conversion efficiency calculated from NMHC emissions results for both test objects, tested over the Low phase of the WLTC.

Figure 42 TWC conversion efficiency calculated from CO emissions results for both test objects, tested over the Low phase of the WLTC.

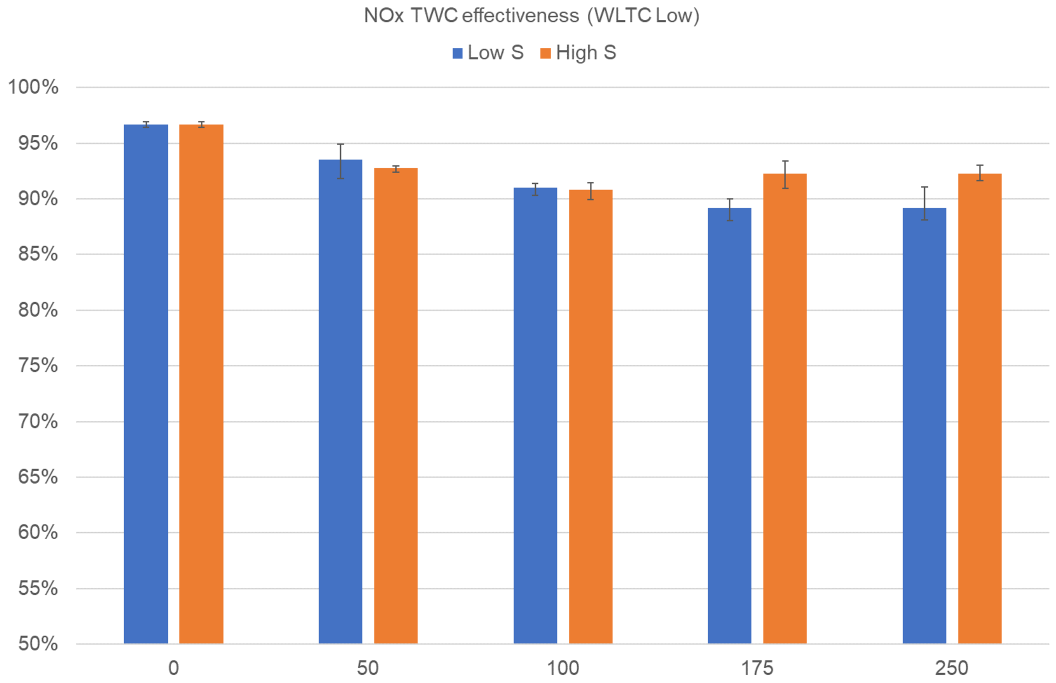

Figure 43 TWC conversion efficiency calculated from NO_x emissions results for both test objects, tested over the Low phase of the WLTC.

As regards conversion efficiency over the NEDC, only two sets of results are available (0 and 250 cycle stages), as shown in Figures 44-47. At the 0 cycle stage the agreement between the two test objects was excellent, as expected. At the 250 cycle stage, conversion efficiency for THC, NMHC and CO was noticeably lower than at 0 cycles, with very limited differences between the two test objects. For NO_x the situation was similar, with the exception that conversion efficiency was noticeably higher for the High S TWC.

Figure 44 TWC conversion efficiency calculated from THC emissions results for both test objects, tested over the entire NEDC.

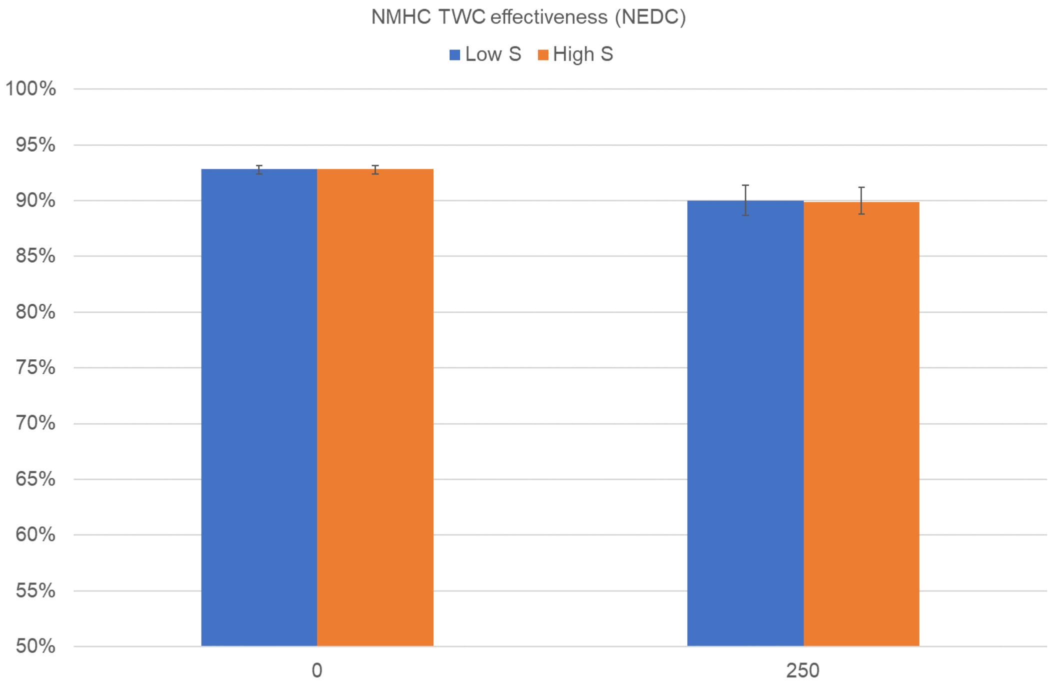

Figure 45 TWC conversion efficiency calculated from NMHC emissions results for both test objects, tested over the entire NEDC.

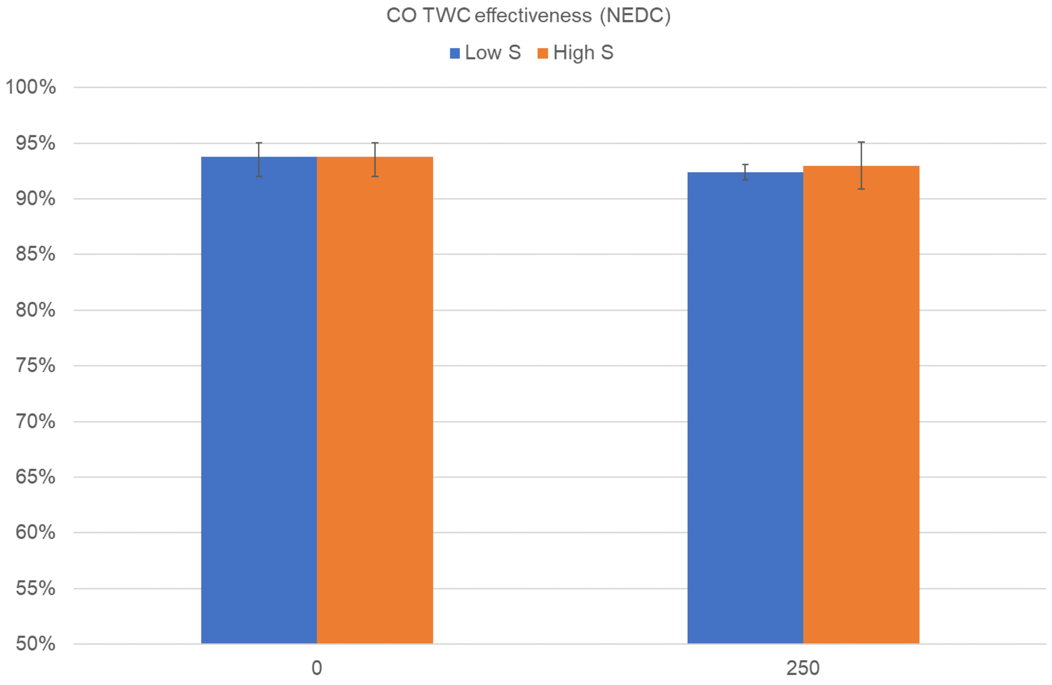

Figure 46 TWC conversion efficiency calculated from CO emissions results for both test objects, tested over the entire NEDC.

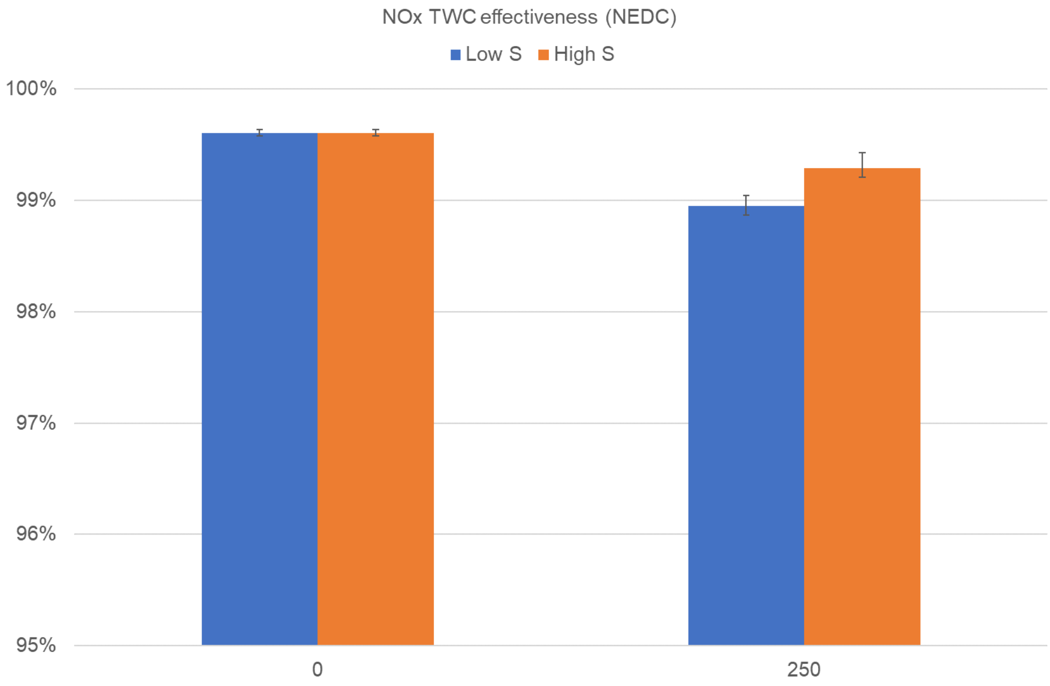

Figure 47 TWC conversion efficiency calculated from NO_x emissions results for both test objects, tested over the entire NEDC.

Essentially the same trends were observed over the UDC phase of the NEDC, as shown in Figures 48-51. Conversion efficiency fell at 250 cycles, but with very good agreement for the two test objects in the case of THC, NMHC and CO, although the decrease for CO was small. In the case of NO_x, conversion efficiency also fell, but at 250 cycles the High S TWC outperformed its counterpart by a margin which may have been significant.

Figure 48 TWC conversion efficiency calculated from THC emissions results for both test objects, tested over the UDC phase of the NEDC.

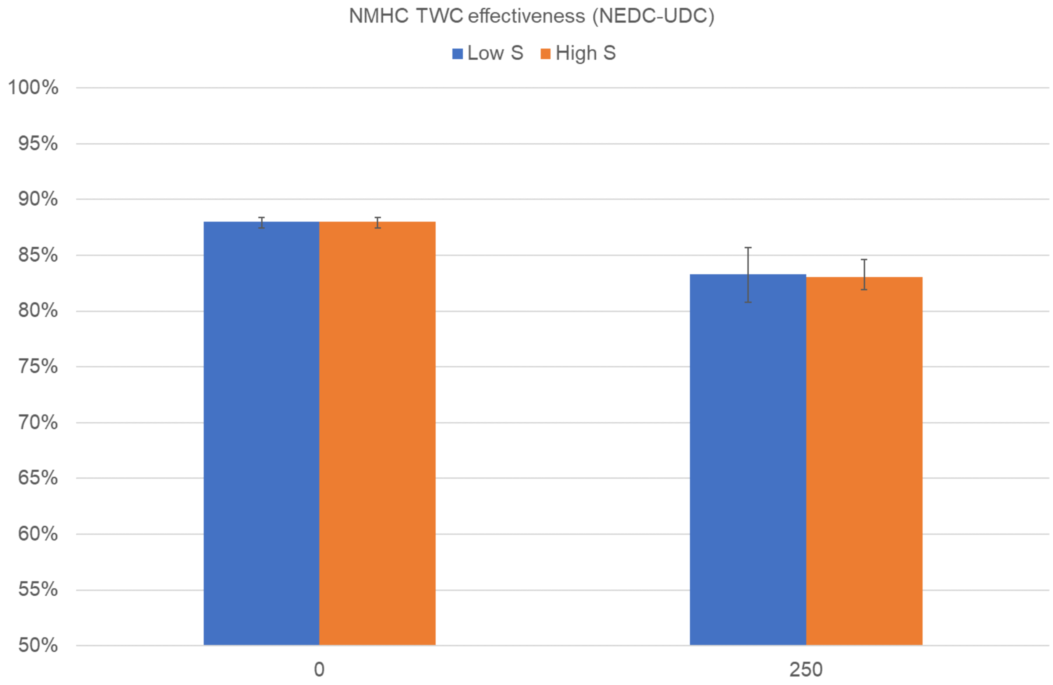

Figure 49 TWC conversion efficiency calculated from NMHC emissions results for both test objects, tested over the UDC phase of the NEDC.

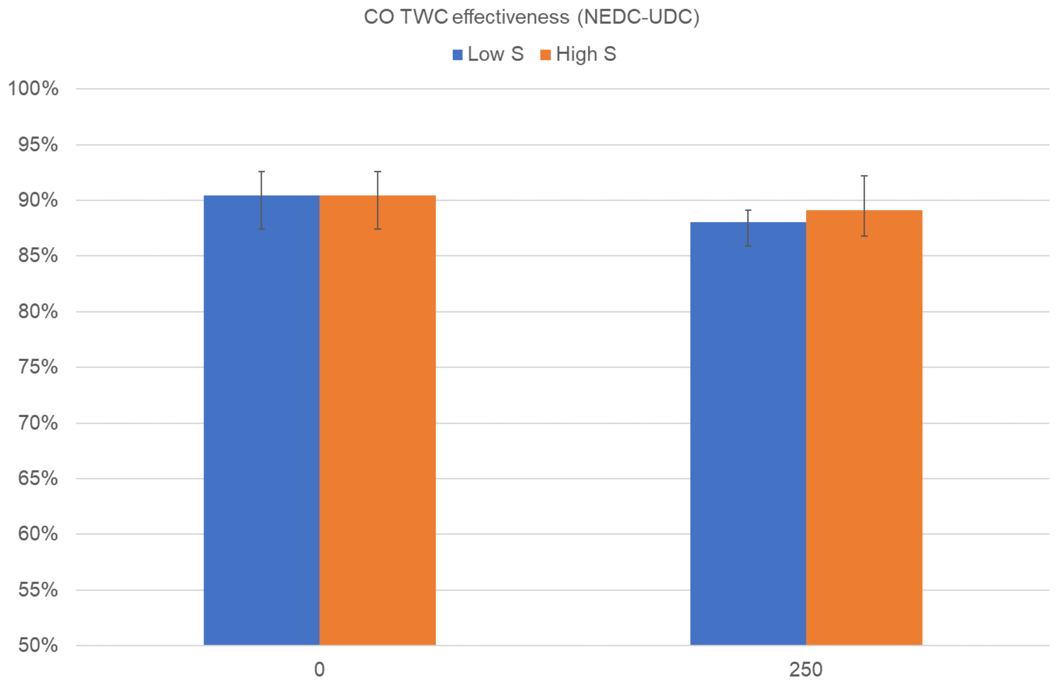

Figure 50 TWC conversion efficiency calculated from CO emissions results for both test objects, tested over the UDC phase of the NEDC.

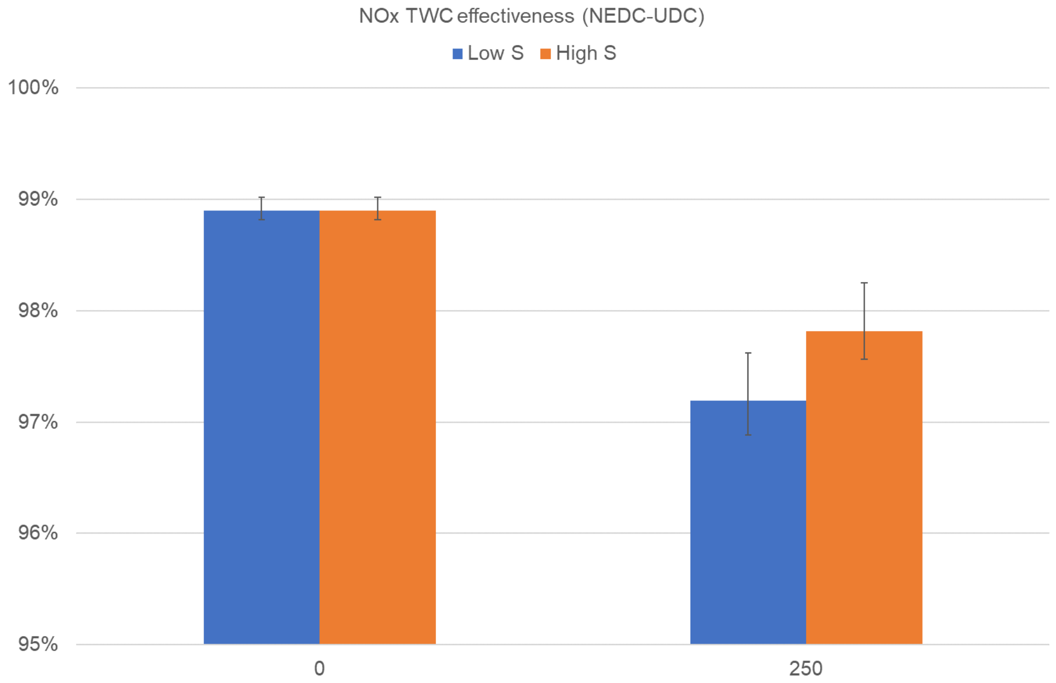

Figure 51 TWC conversion efficiency calculated from NO_x emissions results for both test objects, tested over the UDC phase of the NEDC.

As shown in Figures 52-55, TWC conversion efficiency over the constant speed cycle was very high in all cases, since the cycle was performed with a fully warmed up powertrain and at constant speed – i.e. under vehicle operating conditions which facilitate very stable engine operation (as well as low distance-specific fuel consumption). When driving at a constant speed of 80 km/h, there is no inertia to overcome and the power absorbed by the chassis dyno for the test vehicle was 5 kW, i.e. 5.7% of the rated power of the engine. Under such conditions, TWC performance was consistently very high, even after 250 ageing cycles. For both TWCs, at the 0 and 250 cycle stages, calculated TWC conversion efficiency did not fall below 98.4% for any of the measured gaseous compounds.

In the case of THC and NMHC, conversion efficiency was very close to 100% for both test objects at both stages. Slightly lower CO conversion efficiency of the High S TWC was observed, but this effect was also present at 0 cycles, i.e. before any ageing had been carried out. Nevertheless, the CO conversion efficiency for High S at 250 cycles was noticeably lower than at 0 cycles.

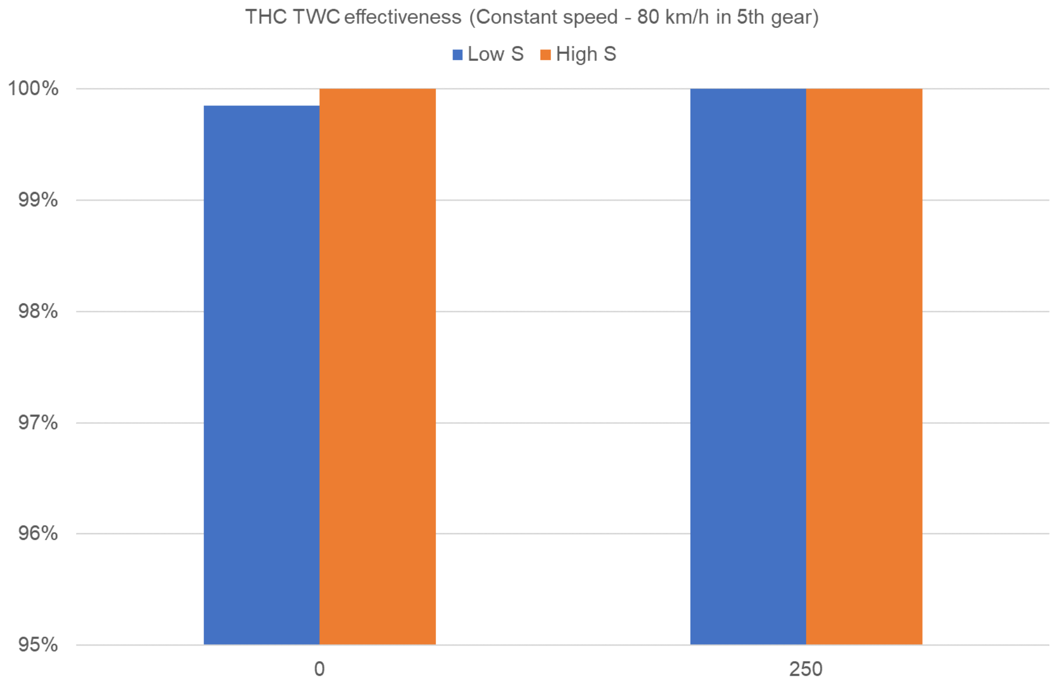

Figure 52 TWC conversion efficiency calculated from THC emissions results for TWC Low S, tested over the constant speed cycle.

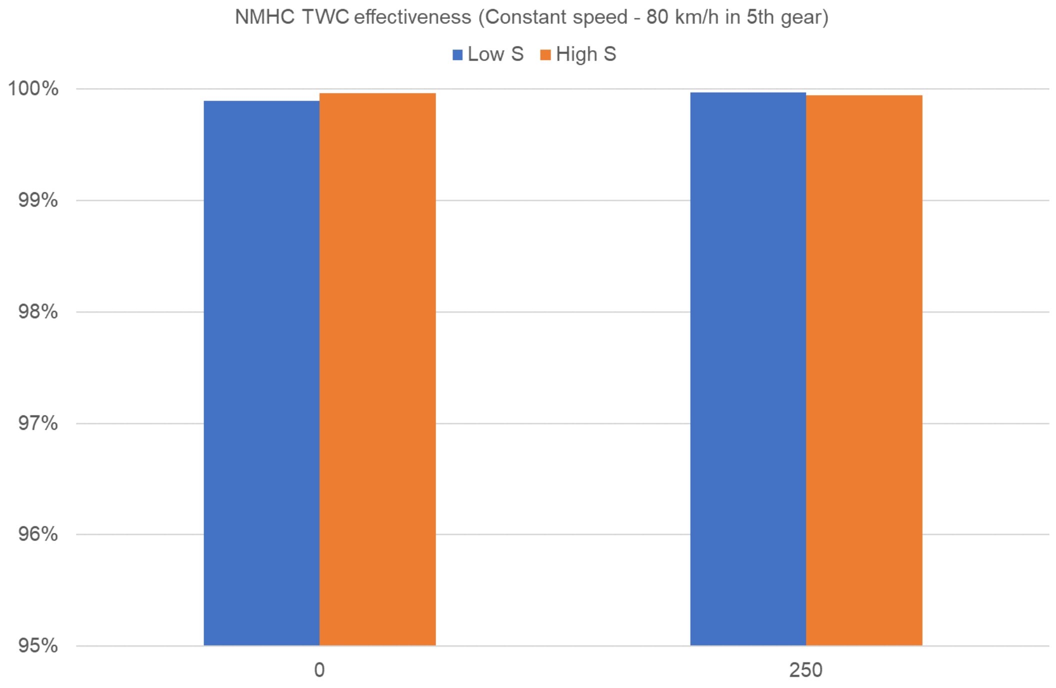

Figure 53 TWC conversion efficiency calculated from NMHC emissions results for TWC Low S, tested over the constant speed cycle.

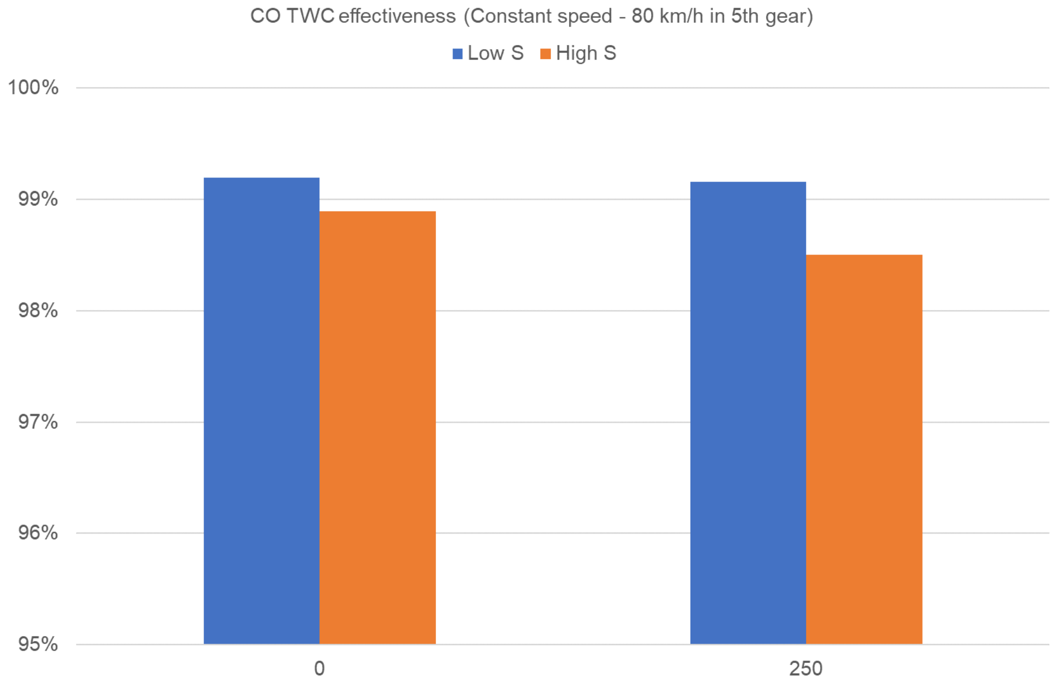

Figure 54 TWC conversion efficiency calculated from CO emissions results for TWC Low S, tested over the constant speed cycle.

As regards NO_x, the conversion efficiency was at a very high level for both test objects at both ageing stages and there only negligible differences following ageing. The very low magnitude of the differences and the fact that two repeat tests were performed (n=2) means no statistically significant differences were observed at regards NO_x elimination over the constant speed cycle.

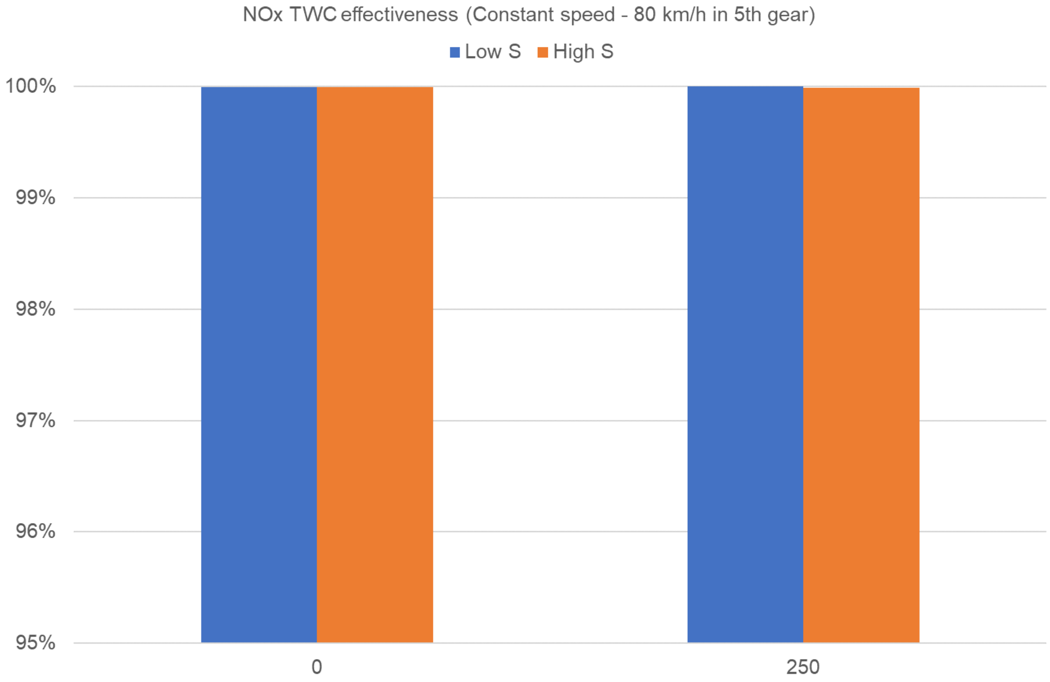

Figure 55 TWC conversion efficiency calculated from NO_x emissions results for TWC Low S, tested over the constant speed cycle.

4.2.3. Results of ECU parameter recordings

ECU parameters were logged for all emissions tests. Parameters such as engine speed, engine coolant temperature, etc showed high stability, with very limited test-to-test variations.

The temperature of the exhaust gas reported by the vehicle's ECU was recorded during emissions tests. As mentioned previously, the test vehicle did not feature a thermocouple and the reported temperature of the exhaust gas was a modelled parameter, designed to reflect the temperature of the exhaust gas upstream of the aftertreatment (TWC). This parameter is of critical importance for the functioning of the TWC for a cold start driving cycle. While the temperature traces were subject to slight variations from test to test, generally the temperature traces showed very low variability. Figures 56 and 57 show the temperature traces over the WLTC for four selected WLTC tests (two on each test object), while Figures 58 and 59 show the temperature traces over the NEDC for four selected NEDC tests (two on each test object). Lines of different thickness have been used in the plots to allow both curves to be seen, as differences are generally very limited.

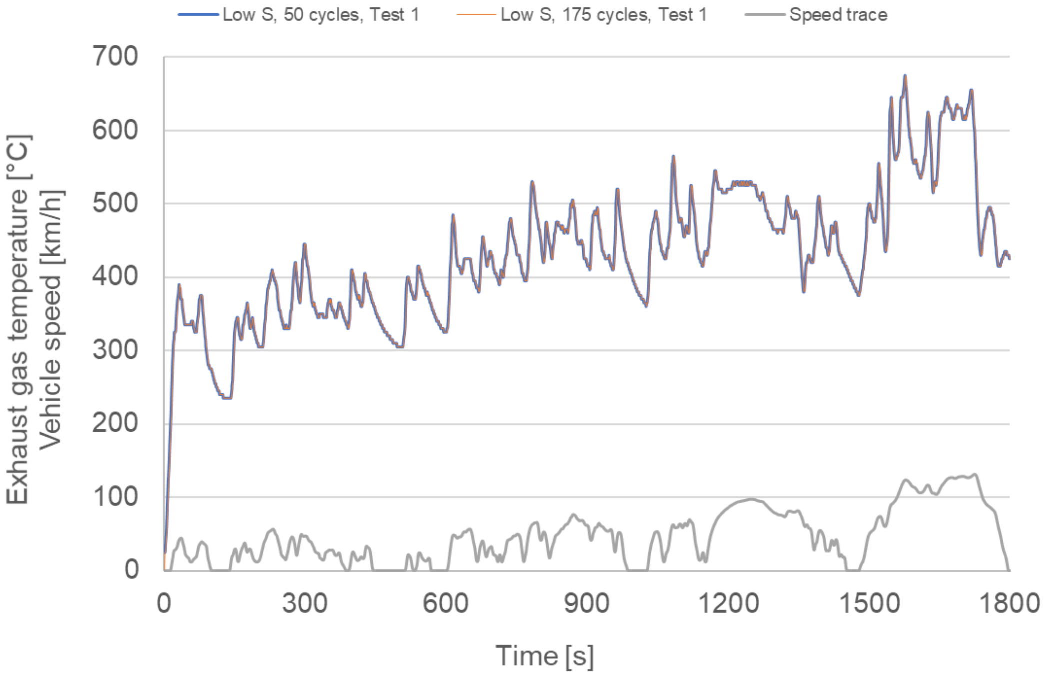

Figure 56 Two sample temperature traces (measured ECU parameter 'Exhaust gas temperature') for TWC Low S during WLTC emissions tests.

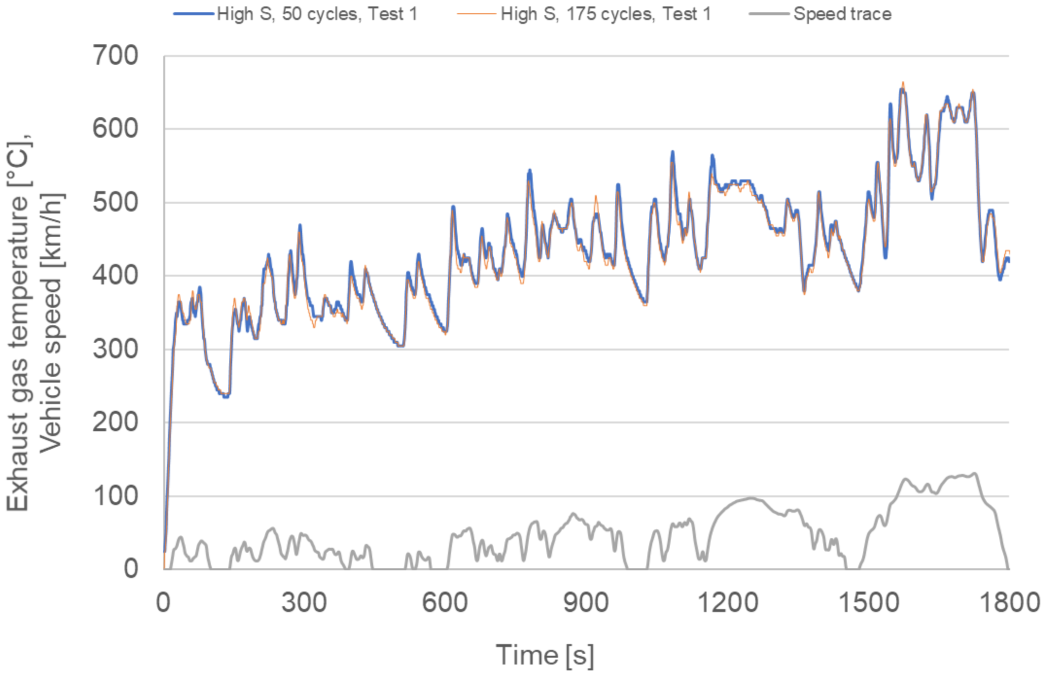

Figure 57 Two sample temperature traces (measured ECU parameter 'Exhaust gas temperature') for TWC High S during WLTC emissions tests.

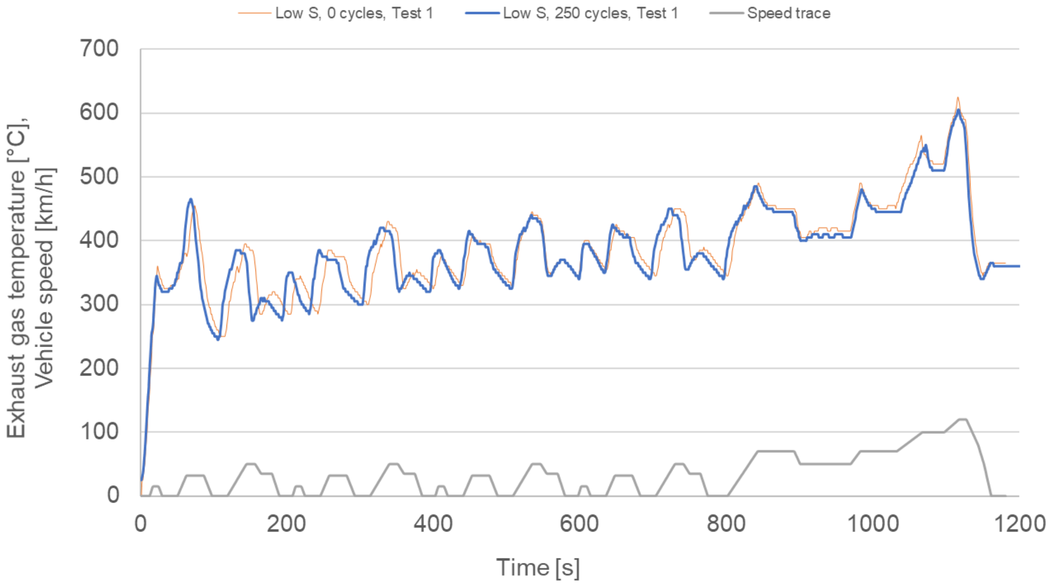

Fig. 58 Two sample temperature traces (measured ECU parameter 'Exhaust gas temperature') for TWC Low S during NEDC emissions tests.

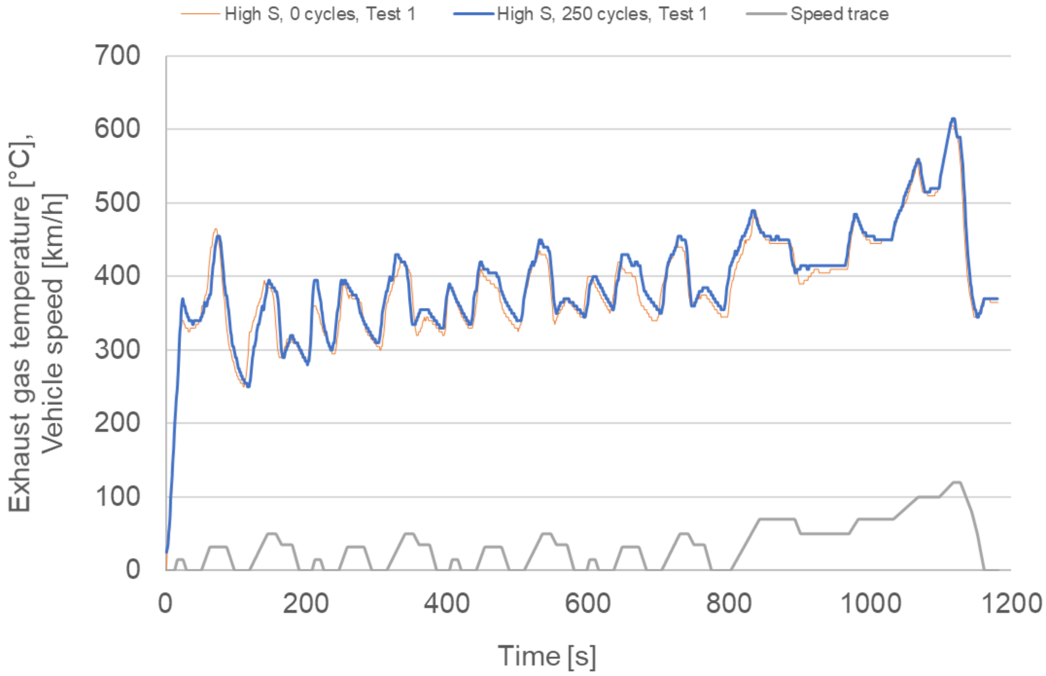

Figure 59 Two sample temperature traces (measured ECU parameter 'Exhaust gas temperature') for TWC High S during NEDC emissions tests.

In all cases, the initial increase in temperature from ambient to a value of approximately 350°C showed very little variation from test to test, and was in fact similar for both test cycles employed (WLTC, NEDC). As shown in Figures 56 and 57, for the majority of the WLTC the temperature oscillated between approximately 300°C and 550°C, rising to higher values during the final 300 seconds of the cycle (essentially corresponding to the Extra High phase of the WLTC). For the NEDC (Figures 58 and 59), for the majority of the cycle the temperature oscillated between approximately 300°C and 500°C, rising to higher values above 500°C only during the final portion of the cycle (where vehicle speed is ≥ 100 km/h). For constant speed testing, the temperature of the exhaust gas quickly stabilised at a value of approximately 470°C to 475°C during the early phases of the warmup period before emissions sampling commenced. During the emissions measurement phases themselves, there were very limited fluctuations outside the range 470-475°C.

As mentioned previously (shown in Figure 4 and discussed in [10]), under most engine operating conditions the temperature of the TWC monolith was likely to be noticeably higher than the reported temperature of the exhaust gas. Thus, the temperatures shown in Figures 56-59 can be treated as minimum likely TWC monolith temperatures, with the exception of the first 30 seconds or so immediately following cold start, during which the temperature of the monolith is lower than that of the exhaust gas.

5. CONCLUSIONS

Ageing equivalent to 71 thousand km of vehicle usage was carried out on two TWCs, each being aged on its own LPG fuel type, with the only significant difference between the two fuel types being the sulphur level. The fuels' sulphur levels were 8.2 ppm ('Low S') and 29.0 ppm ('High S').

The variability in the results of periodic emissions testing was deemed acceptable and typical for measurements of this type performed on such a test vehicle over cold start driving cycles. Variability was, generally speaking, greater at higher ageing stages (though not in all cases), which would be consistent with the theory that the TWC's conversion efficiency became increasingly sensitive to λ control as ageing progressed and oxygen storage capacity became compromised (lost, temporarily reduced or inhibited in terms of chemical kinetics).

With a single exception, the test vehicle met the applicable Euro 6 emissions limits when tested using its type approval procedure (NEDC), for both TWCs, at all ageing stages. The exception to this came in the form of a single NMHC emissions result, which in one test was found to be above the applicable legislative limit following 250 ageing cycles; the two other repetitions of this test under the same conditions showed NMHC emissions below with the Euro 6 limits, and the mean of these 3 tests was also below the Euro 6 limits. While emissions results obtained using the WLTP test procedure were not legally applicable to the test vehicle, results obtained using that procedure were also below the Euro 6 limits, in all cases, with no exceptions.

Despite being type approved at the Euro 6b level (for which the NEDC test is legally applicable), the test vehicle showed low emissions over the WLTC, with none of the results for either of the test objects (TWCs) obtained from that test type exceeding the Euro 6 limits at any ageing stage. As is well known, the relatively long distance covered by the WLTC (over 23 km – i.e. more than twice the 11 km distance covered by the NEDC) leads to a reduction in the impact of the cold start effect, which causes emissions associated with cold start to be subject to a low distance-specific weighting.

The test vehicle proved itself to be stable. No vehicle malfunctions or ECU errors were present before, during or after any emissions test and the vehicle MIL lamp did not illuminate at any point. Carbon dioxide emissions and fuel consumption results were generally stable throughout the test programme.

The relatively low emissions results occurring even after extended ageing indicate high TWC conversion efficiency and durability under the specific ageing conditions employed here. There was an overall tendency for emissions to slightly increase as the number of ageing cycles increased, but trends were not monotonic in all cases. As regards the impact of fuel sulphur level on TWC conversion efficiency, overall there appeared to be no significant difference between the two test objects. In certain cases, differences in performance were apparent but sometimes the High S TWC outperformed its Low S counterpart. This suggests that the thermal degradation induced by the ageing procedure was more relevant to the performance of the TWCs tested in this study than the fuel sulphur level. A possible explanation offered for this is that the temperatures achieved during the ageing procedure permitted periodic desulphation of the test objects [6-9], meaning that the long-term impact of the sulphur present in the LPG fuel on TWC performance was low. When evaluating the impact of the ageing performed on the test objects, it is important to underline that a real engine, running under demanding real world operating conditions was used. The ageing cycle featured multiple periods of elevated temperature and generally high mean temperatures (as presented in Section 3 and specifically Figure 3), but, as shown in Figure 4, such temperatures can also be reached during normal, real-world driving at speeds >100 km/h, even without additional load (i.e. uphill gradient and/or high vehicle payload). As a single WLTC preconditioning cycle was carried out prior to every batch of emissions tests, there was some further exposure to elevated temperatures prior to the emissions tests, as well as during the emissions tests themselves (as shown in Figures 56 and 57). Results in this study showed no overall trend of TWC conversion efficiency increasing from test to test within a given test batch (as might be expected if the TWC were being gradually purged of sulphur and thereby progressively recovering its conversion efficiency).

Notwithstanding the small differences observed over the test cycles employed, there was a more visible tendency for ageing to increase emissions over the cold start phases of the two tests (WLTC Low, NEDC UDC). This period is characterised by generally high engine out emissions and low TWC conversion efficiency (mainly due to the thermal state of the monolith following cold start). Differences in emissions and TWC conversion efficiency were of somewhat greater magnitude for WLTC Low and NEDC UDC. Nevertheless, focusing on the results obtained from the aforementioned cold start phases, no consistent, significant difference between the two test objects could be observed. This supports the observation that the ageing procedure indeed reduced TWC performance, but that fuel sulphur level had no measurable overall impact. Under high load conditions, the TWC's temperature is well in excess of its light-off point. The conversion efficiency of both test objects for the WLTC High and Extra High phases decreased only very slightly (or not at all) as the two test objects were aged from 0 to 250 cycles. Comparing results at 0 and 250 cycles for the EUDC phase of the NEDC, reductions in conversion efficiency were of similar magnitude. Thus, when operating under conditions which were predominantly high load and which featured high exhaust gas temperatures, the ability of the test objects to perform their intended function showed very low sensitivity to ageing and exposure to sulphur.

As should be expected, there was excellent agreement between the results obtained from both TWCs at the 0 cycle stage. For both TWCs, the WLTC and NEDC results at the 250 cycle stage showed a deterioration compared to the 0 cycle stage – i.e. TWC conversion efficiency was lower and exhaust emissions were higher. For interim stages (50, 100, 175 cycles), trends were not always monotonic – some results showed higher TWC conversion performance at 175 cycles than at 100 cycles, although the magnitude of the uncertainty associated with the mean of the emissions results (n=3) should be kept in mind. A further point to mention is that the conversion of the High S TWC performed better than the Low S TWC at certain ageing stages and for certain compounds. Taking into account the spread of the results, quantified as the difference between the lowest and highest measured results, as well as the type A uncertainty, such differences are again unlikely to be statistically significant. Nevertheless, the fact remains that in some cases ageing on higher sulphur content LPG was associated with lower measured tailpipe emissions of regulated compounds, as well as higher TWC conversion efficiency.

Over the transient cold start driving cycles (NEDC, WLTC), TWC conversion efficiency was observed to fall somewhat as the test objects were subjected to ageing. However, during the constant speed tests, the TWC conversion efficiency at the 250 cycle stage was very close to that at the 0 cycle stage. Thus, there was no significant deterioration for either test object under these conditions. At temperatures well above the test units' light-off temperature and at stable λ, the performance (i.e. elimination of THC, NMHC, CO and NO_x) remained very high, even following extensive ageing on high sulphur fuel. This finding would appear to support the hypothesis that ageing primarily affected the performance temperature of the test objects at low temperatures. As a result of this, the dynamic cold start test procedures (NEDC, WLTC) revealed some deterioration in TWC performance, while the steady-state, thermally stabilised testing did not reveal such effects.

As it was assumed that the low sensitivity of the TWC conversion efficiency was related to a desulphatation process occurring at higher equivalence ratio and high temperature, a complementary study was performed to challenge this assumption (details in the appendix). It consisted in chemical analyses of the aged TWCs, using advanced laboratory methods. Unfortunately, this study remained inconclusive, as it were unable to directly link the sulphur level measured in the TWCs to their conversion efficiency loss. Consequently, lacking a clear and systematic explanation about the effect of sulphur on the TWC conversion efficiency, this study cannot be 100% conclusive regarding the harmful/non-harmful effect of sulphur content in LPG on the TWC conversion efficiency, even if the engine/vehicle tests tend to show that a higher sulphur content is not harmful.

6. REFERENCES

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APPENDIX - DETAILED EXHAUST EMISSIONS RESULTS

Table 7 Emissions and fuel consumption results from the Fiat Tipo 1.4 vehicle over the NEDC cycle for TWC Low S

BOSMAL Automotive R&D Institute Ltd
EXHAUST EMISSIONS LABORAOTRY

NEDC test (UNECE R83) - NEDC driving cycle

VIN: ZFA35600006K20252
Model: Vehicle model: Fiat Tipo 1.4 LPG
Emission standard: Euro 6
Tyres: Continental ContiEcoContact 5 225/45 R17 V XL

Inertia [kg] 1360				Emissions in the NEDC test										Emissions in the UDC phase					Emissions in the EUDC phase					CO$_2$ emissions			Fuel consumption			Note 1
Mileage [km]	Date	Chassis dyno F0/F1/F2	Test No.	Emissions values with DFs (*)				Emissions measured						Emissions measured					Emissions measured					[g/km]			[l/100 km] (**)			
				THC	NMHC	CO	NOx	THC	NMHC	CO	NOx	PM	PN	THC	NMHC	CO	NOx	PN	THC	NMHC	CO	NOx	PN	NEDC	UDC	EUDC	NEDC	UDC	EUDC	
				[mg/km]				[mg/km]						[mg/km]					[mg/km]											
Ageing stage: 0 cycles				BAG - MODAL DIL - PRE - POST																										
4 061	27.09.2018	21.0 -1.13 0.0401	L1-0435	73	66	846	15	56	51	564	10	0.54	4.32E+11	151	137	1449	22	1.14E+12	0	0	46	2	1.57E+10	161.4	223.1	125.3	9.99	13.89	7.71	Bags
								57	52	559	9	-	-	155	140	1433	22	-	0	0	48	2	-	161.9	223.0	126.1	10.02	13.88	7.76	Modal Dil
								702	667	7054	2376	-	-	1149	1087	11534	1875	-	441	421	4434	2669	-	153.4	210.4	120.1	10.25	14.27	7.90	Modal PRE cat
								70	63	601	11	-	-	188	169	1528	26	-	0	0	59	2	-	165.1	227.4	128.7	10.22	14.17	7.92	Modal TP
				TWC effectiveness (pre-bag)				92.1%	92.4%	92.0%	99.6%	-	-	86.9%	87.4%	87.4%	98.8%	-	99.9%	99.9%	99.0%	99.9%	-							TWC eff
				TWC effectiveness (pre-post)				90.1%	90.6%	91.5%	99.5%	-	-	83.6%	84.4%	86.8%	98.6%	-	99.9%	99.9%	98.7%	99.9%	-							TWC eff
4 083	03.10.2018	21.0 -1.13 0.0401	L1-0437	63	57	634	14	48	44	423	9	0.67	4.34E+11	131	119	1059	18	1.13E+12	0	0	50	3	2.41E+10	161.9	221.9	126.8	10.01	13.77	7.80	Bags
								49	45	423	8	-	-	134	122	1056	18	-	0	0	52	3	-	162.4	222.3	127.4	10.04	13.80	7.84	Modal Dil
								675	641	7330	2354	-	-	1065	1009	12085	1865	-	446	426	4547	2640	-	153.2	208.4	120.9	10.25	14.18	7.96	Modal PRE cat
								58	53	449	10	-	-	156	142	1110	22	-	0	0	62	3	-	165.6	226.6	129.9	10.24	14.07	8.00	Modal TP
				TWC effectiveness (pre-bag)				92.8%	93.1%	94.2%	99.6%	-	-	87.7%	88.2%	91.2%	99.0%	-	100.0%	100.0%	98.9%	99.9%	-							TWC eff
				TWC effectiveness (pre-post)				91.4%	91.8%	93.9%	99.6%	-	-	85.3%	86.0%	90.8%	98.8%	-	100.0%	99.9%	98.6%	99.9%	-							TWC eff
4 209	16.10.2018	21.0 -1.13 0.0401	L1-0450	61	56	522	15	47	43	348	10	0.29	2.93E+11	128	117	858	20	7.67E+11	0	0	52	4	1.95E+10	160.5	223.0	124.3	9.91	13.82	7.65	Bags
								48	44	347	10	-	-	129	118	854	20	-	0	0	54	4	-	161.0	223.3	125.0	9.95	13.84	7.70	Modal Dil
								648	617	7044	2309	-	-	1058	1005	11622	1767	-	411	393	4396	2623	-	151.9	208.8	119.0	10.14	14.16	7.82	Modal PRE cat
								52	48	353	11	-	-	143	130	854	23	-	0	0	63	4	-	164.1	227.5	127.5	10.14	14.10	7.85	Modal TP
				TWC effectiveness (pre-bag)				92.7%	93.0%	95.1%	99.6%	-	-	87.9%	88.4%	92.6%	98.9%	-	99.9%	99.9%	98.8%	99.9%	-							TWC eff
				TWC effectiveness (pre-post)				91.9%	92.3%	95.0%	99.5%	-	-	86.5%	87.1%	92.7%	98.7%	-	100.0%	99.9%	98.6%	99.9%	-							TWC eff
				Mean values				50	46	445	9	0.50	3.87E+11	136	124	1122	20	1.02E+12	0	0	50	3	1.97E+10	161.3	222.7	125.5	9.97	13.83	7.72	Bags
								52	47	443	9	-	-	139	127	1114	20	-	0	0	51	3	-	161.8	222.9	126.2	10.00	13.84	7.76	Modal Dil
								675	642	7143	2346	-	-	1091	1034	11747	1835	-	433	413	4459	2644	-	152.8	209.2	120.0	10.22	14.20	7.89	Modal PRE cat
								60	54	468	11	-	-	162	147	1164	23	-	0	0	61	3	-	164.9	227.2	128.7	10.20	14.11	7.92	Modal TP
				Standard deviation				3.9	3.4	89.7	0.5	0.16	6.59E+10	10.2	8.9	245.2	1.6	1.76E+11	0.1	0.1	2.5	0.5	3.43E+09	0.58	0.55	1.01	0.04	0.05	0.06	Bags
								4.2	3.6	87.8	0.5	-	-	11.2	9.7	240.0	1.6	-	0.1	0.1	2.4	0.5	-	0.57	0.39	0.95	0.04	0.03	0.06	Modal Dil
								22.2	20.2	132.6	27.8	-	-	41.3	37.5	241.7	48.7	-	15.5	14.5	64.1	19.0	-	0.66	0.86	0.76	0.05	0.05	0.06	Modal PRE cat
								7.2	6.3	102.2	0.5	-	-	19.2	16.7	277.9	1.5	-	0.0	0.0	1.9	0.6	-	0.62	0.37	0.99	0.04	0.04	0.06	Modal TP
				Type A uncertainty				2.2	2.0	51.8	0.3	0.09	3.80E+10	5.9	5.1	141.6	0.9	1.01E+11	0.1	0.1	1.5	0.3	1.98E+09	0.34	0.32	0.58	0.02	0.03	0.04	Bags
								2.5	2.1	50.7	0.3	-	-	6.5	5.6	138.5	0.9	-	0.1	0.1	1.4	0.3	-	0.33	0.23	0.55	0.02	0.02	0.03	Modal Dil
								12.8	11.7	76.5	16.0	-	-	23.9	21.7	139.5	28.1	-	8.9	8.4	37.0	11.0	-	0.38	0.49	0.44	0.03	0.03	0.03	Modal PRE cat
								4.2	3.6	59.0	0.3	-	-	11.1	9.6	160.5	0.9	-	0.0	0.0	1.1	0.3	-	0.36	0.22	0.57	0.03	0.02	0.03	Modal TP
				Mean TWC effectiveness (pre-bag)				92.6%	92.9%	93.8%	99.6%	-	-	87.5%	88.0%	90.4%	98.9%	-	99.9%	99.9%	98.9%	99.9%	-							
				Max. TWC effectiveness (pre-bag)				92.8%	93.1%	95.1%	99.6%	-	-	87.9%	88.4%	92.6%	99.0%	-	100.0%	100.0%	99.0%	99.9%	-							
				Min. TWC effectiveness (pre-bag)				92.1%	92.4%	92.0%	99.6%	-	-	86.9%	87.4%	87.4%	98.8%	-	99.9%	99.9%	98.8%	99.9%	-							
				Mean TWC effectiveness (pre-post)				91.1%	91.6%	93.4%	99.6%	-	-	85.1%	85.8%	90.1%	98.7%	-	100.0%	99.9%	98.6%	99.9%	-							
				Max. TWC effectiveness (pre-post)				91.9%	92.3%	95.0%	99.6%	-	-	86.5%	87.1%	92.7%	98.8%	-	100.0%	99.9%	98.7%	99.9%	-							
				Min. TWC effectiveness (pre-post)				90.1%	90.6%	91.5%	99.5%	-	-	83.6%	84.4%	86.8%	98.6%	-	99.9%	99.9%	98.6%	99.9%	-							
Ageing stage: 250 cycles				BAG - MODAL DIL - PRE - POST																										
5 293	26.03.2019	21.0 -1.13 0.0401	L1-0169					65	58	670	23	0.21	2.87E+11	175	157	1783	46	7.77E+11	2	1	25	10	3.03E+09	156.1	215.4	121.8	9.68	13.45	7.49	Bags
								67	60	670	22	-	-	180	161	1783	43	-	2	1	26	10	-	156.7	211.6	124.9	10.44	14.34	8.19	Modal Dil
								571	540	7235	2389	-	-	915	862	11901	1900	-	372	354	4533	2672	-	168.1	227.8	133.5	10.41	14.21	8.21	Modal PRE cat
								70	61	636	23	-	-	188	165	1678	45	-	2	1	32	10	-	156.5	215.9	122.0	9.70	13.49	7.51	Modal TP
				TWC effectiveness (pre-bag)				88.6%	89.2%	90.7%	99.0%	-	-	80.9%	81.8%	85.0%	97.6%	-	99.6%	99.7%	99.5%	99.6%	-							TWC eff
				TWC effectiveness (pre-post)				87.8%	88.7%	91.2%	99.0%	-	-	79.5%	80.8%	85.9%	97.6%	-	99.6%	99.8%	99.3%	99.6%	-							TWC eff
5 304	27.03.2019	21.0 -1.13 0.0401	L1-0172					57	50	519	23	0.30	4.70E+11	153	136	1379	50	1.27E+12	2	1	20	7	3.24E+09	156.9	216.5	122.3	9.71	13.48	7.52	Bags
								59	52	521	23	-	-	158	140	1381	50	-	2	1	21	7	-	157.2	216.9	122.5	9.73	13.50	7.54	Modal Dil
								607	577	7403	2140	-	-	1002	950	12749	1654	-	378	361	4297	2422	-	145.8	202.0	113.1	9.79	13.84	7.44	Modal PRE cat
								66	58	525	23	-	-	177	157	1387	48	-	1	1	24	8	-	160.2	221.1	124.9	9.92	13.77	7.68	Modal TP
				TWC effectiveness (pre-bag)				90.6%	91.3%	93.0%	98.9%	-	-	84.8%	85.7%	89.2%	97.0%	-	99.6%	99.8%	99.5%	99.7%	-							TWC eff
				TWC effectiveness (pre-post)				89.1%	89.9%	92.9%	98.9%	-	-	82.3%	83.4%	89.1%	97.1%	-	99.6%	99.8%	99.4%	99.7%	-							TWC eff
5 315	28.03.2019	21.0 -1.13 0.0401	L1-0175					49	43	494	24	0.25	3.04E+11	132	117	1321	52	8.06E+11	1	1	15	8	1.24E+10	155.3	214.8	120.7	9.61	13.36	7.43	Bags
								51	45	491	24	-	-	137	121	1312	51	-	2	1	16	8	-	155.9	215.8	121.2	9.65	13.43	7.45	Modal Dil
								584	557	7078	2107	-	-	953	905	11971	1633	-	371	355	4242	2382	-	144.2	199.3	112.3	9.66	13.59	7.38	Modal PRE cat
								55	48	490	24	-	-	147	130	1301	51	-	1	1	20	8	-	158.9	220.0	123.5	9.83	13.68	7.60	Modal TP
				TWC effectiveness (pre-bag)				91.6%	92.2%	93.0%	98.9%	-	-	86.2%	87.1%	89.0%	96.8%	-	99.6%	99.8%	99.6%	99.7%	-							TWC eff
				TWC effectiveness (pre-post)				90.6%	91.4%	93.1%	98.9%	-	-	84.6%	85.7%	89.1%	96.9%	-	99.6%	99.8%	99.5%	99.7%	-							TWC eff
				Mean values				57	51	561	23	0.25	3.53E+11	153	137	1494	49	9.52E+11	2	1	20	8	6.23E+09	156.1	215.6	121.6	9.66	13.43	7.48	Bags
								59	52	561	23	-	-	158	141	1492	48	-	2	1	21	8	-	156.6	214.8	122.9	9.94	13.76	7.73	Modal Dil
								588	558	7239	2212	-	-	957	906	12207	1729	-	373	357	4357	2492	-	152.7	209.7	119.6	9.95	13.88	7.68	Modal PRE cat
								63	56	550	23	-	-	171	151	1455	48	-	1	1	25	9	-	158.5	219.0	123.5	9.82	13.64	7.60	Modal TP
				Standard deviation				6.6	6.0	77.4	0.5	0.03	8.25E+10	17.8	16.3	205.2	2.5	2.27E+11	0.1	0.1	4.1	1.2	4.37E+09	0.67	0.72	0.63	0.04	0.05	0.04	Bags
								6.5	5.9	78.5	0.8	-	-	17.6	16.2	207.7	3.8	-	0.1	0.1	4.4	1.1	-	0.52	2.27	1.53	0.36	0.41	0.33	Modal Dil
								15.0	15.3	132.6	125.6	-	-	35.9	35.9	384.3	121.0	-	3.0	3.3	126.0	128.1	-	10.90	12.85	9.80	0.33	0.25	0.38	Modal PRE cat
								6.4	5.6	62.3	0.6	-	-	17.3	15.2	161.3	2.3	-	0.1	0.1	5.3	1.0	-	1.56	2.22	1.16	0.09	0.12	0.07	Modal TP
				Type A uncertainty				3.8	3.5	44.7	0.3	0.02	4.77E+10	10.3	9.4	118.5	1.5	1.31E+11	0.0	0.0	2.3	0.7	2.52E+09	0.39	0.42	0.36	0.03	0.03	0.02	Bags
								3.7	3.4	45.3	0.5	-	-	10.2	9.3	119.9	2.2	-	0.0	0.0	2.5	0.6	-	0.30	1.31	0.88	0.21	0.24	0.19	Modal Dil
								8.7	8.8	76.5	72.5	-	-	20.7	20.7	221.9	69.9	-	1.7	1.9	72.8	74.0	-	6.29	7.42	5.66	0.19	0.15	0.22	Modal PRE cat
								3.7	3.2	36.0	0.3	-	-	10.0	8.8	93.1	1.4	-	0.0	0.0	3.1	0.6	-	0.90	1.28	0.67	0.05	0.07	0.04	Modal TP
				Mean TWC effectiveness (pre-bag)				90.2%	90.9%	92.2%	98.9%	-	-	83.9%	84.9%	87.7%	97.1%	-	99.6%	99.8%	99.5%	99.7%	-							
				Max. TWC effectiveness (pre-bag)				91.6%	92.2%	93.0%	99.0%	-	-	86.2%	87.1%	89.2%	97.6%	-	99.6%	99.8%	99.6%	99.7%	-							
				Min. TWC effectiveness (pre-bag)				88.6%	89.2%	90.7%	98.9%	-	-	80.9%	81.8%	85.0%	96.8%	-	99.6%	99.7%	99.5%	99.6%	-							
				Mean TWC effectiveness (pre-post)				89.2%	90.0%	92.4%	99.0%	-	-	82.1%	83.3%	88.1%	97.2%	-	99.6%	99.8%	99.4%	99.7%	-							
				Max. TWC effectiveness (pre-post)				90.6%	91.4%	93.1%	99.0%	-	-	84.6%	85.7%	89.1%	97.6%	-	99.6%	99.8%	99.5%	99.7%	-							
				Min. TWC effectiveness (pre-post)				87.8%	88.7%	91.2%	98.9%	-	-	79.5%	80.8%	85.9%	96.9%	-	99.6%	99.8%	99.3%	99.6%	-							

	THC	NMHC	CO	NOx
Euro 6 SI limits [mg/km]	100	68	1000	60

(*) - as defined in Regulation (EC) 2007/595, applied only at the 0 cycle ageing stage (for informational purposes)

Table 8 Emissions and fuel consumption results from the Fiat Tipo 1.4 vehicle over the WLTC cycle for TWC Low S at 0 cycles

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BOSMAL Automotive Research and Development Institute Ltd

Exhaust Emissions Testing Laboratory

WLTP test (Reg 2017/1151) - WLTC driving cycle

VIN: ZFA35600006K20252 **Vehicle model:** **Fiat Tipo 1.4 LPG** **Emission standard: Euro 6** Tyres: Continental ContiEcoContact 5 225/45 R17 V XL

Inertia [kg]:	1509			Emission WLTC						Emission LOW					Emission MIDDLE					Emission HIGH					Emission Ex-HIGH					CO_2 emission					Fuel consumption					
Mileage[km]	Date	Chassis dyno F0/F1/F2	Test No.	[mg/km]						[mg/km]					[mg/km]					[mg/km]					[mg/km]					[g/km]					[l/100 km] (2)					Note 1
				THC	NMHC	CO	NOx	PM	PN	THC	NMHC	CO	NOx	PN	THC	NMHC	CO	NOx	PN	THC	NMHC	CO	NOx	PN	THC	NMHC	CO	NOx	PN	WLTC	LOW	MIDDLE	HIGH	Ex-HIGH	WLTC	LOW	MIDDLE	HIGH	Ex-HIGH	
Ageing stage: 0 cycles				BAG - MODAL DIL - PRE - POST																																				
4 094	2018-10-04	45.1	L1-0438	57	53	404	26	1.21	6.17E+11	426	394	2229	36	4.19E+12	0	0	181	4	1.37E+11	0	0	128	5	2.82E+10	1	1	90	54	6.54E+10	148.6	215.7	145.1	128.7	142.7	9.19	13.56	8.94	7.93	8.78	Bags
		-0.87		59	55	400	26	-	-	442	409	2198	35	-	1	0	181	4	-	0	0	128	5	-	1	1	89	53	-	149.1	216.3	144.9	128.6	144.1	9.22	13.60	8.93	7.92	8.87	Modal Dil
		0.0390		717	687	6992	2473	-	-	1665	1594	13826	1390	-	778	748	8354	1812	-	568	545	5706	2272	-	458	436	4769	3432	-	139.0	199.9	129.4	119.3	138.8	9.36	13.94	8.91	7.99	9.08	Modal PRE cat
				65	60	424	27	-	-	490	451	2234	42	-	0	0	190	5	-	0	0	151	4	-	0	1	120	54	-	152.1	220.7	147.8	131.2	147.0	9.41	13.88	9.11	8.08	9.05	Modal TP
TWC effectiveness (pre-bag)				**92.1%**	**92.3%**	**94.2%**	**98.9%**	-	-	**74.4%**	**75.3%**	**83.9%**	**97.4%**	-	**100.0%**	**100.0%**	**97.8%**	**99.8%**	-	**100.0%**	**100.0%**	**97.8%**	**99.8%**	-	**99.9%**	**99.9%**	**98.1%**	**98.4%**	-											TWC eff
TWC effectiveness (pre-post)				**90.9%**	**91.2%**	**93.9%**	**98.9%**	-	-	**70.6%**	**71.7%**	**83.8%**	**97.0%**	-	**100.0%**	**99.9%**	**97.7%**	**99.8%**	-	**100.0%**	**100.0%**	**97.4%**	**99.8%**	-	**99.9%**	**99.9%**	**97.5%**	**98.4%**	-											TWC eff
4 117	2018-10-09	45.1	L1-0441	47	43	515	10	1.02	6.01E+11	353	323	2315	40	4.11E+12	1	0	327	3	4.27E+10	0	0	428	6	8.40E+09	1	1	25	8	1.22E+11	150.1	218.8	146.9	129.1	144.4	9.29	13.75	9.07	7.98	8.88	Bags
		-0.87		50	45	510	10	-	-	367	336	2303	36	-	1	1	325	3	-	1	1	420	6	-	1	1	26	7	-	150.8	219.2	146.9	129.3	146.0	9.33	13.77	9.06	7.99	8.98	Modal Dil
		0.0390		700	669	7609	2436	-	-	1573	1499	15241	1314	-	759	726	9532	1836	-	584	560	6597	2152	-	442	421	4531	3444	-	139.7	201.4	130.6	118.2	140.4	9.46	14.15	9.10	8.02	9.16	Modal PRE cat
				56	51	515	11	-	-	417	379	2240	43	-	1	1	339	3	-	0	0	441	5	-	0	1	35	9	-	153.8	223.6	149.7	131.9	148.9	9.52	14.04	9.24	8.15	9.16	Modal TP
TWC effectiveness (pre-bag)				**93.2%**	**93.5%**	**93.2%**	**99.6%**	-	-	**77.5%**	**78.5%**	**84.8%**	**97.0%**	-	**99.9%**	**99.9%**	**96.6%**	**99.9%**	-	**99.9%**	**99.9%**	**93.5%**	**99.7%**	-	**99.9%**	**99.8%**	**99.4%**	**99.8%**	-											TWC eff
TWC effectiveness (pre-post)				**92.0%**	**92.4%**	**93.2%**	**99.6%**	-	-	**73.5%**	**74.7%**	**85.3%**	**96.7%**	-	**99.9%**	**99.9%**	**96.4%**	**99.9%**	-	**100.0%**	**99.9%**	**93.3%**	**99.8%**	-	**99.9%**	**99.8%**	**99.2%**	**99.7%**	-											TWC eff
4 131	2018-10-18	45.1	L1-0458	43	39	392	11	0.68	5.32E+11	317	289	2284	49	3.65E+12	1	0	189	10	5.47E+10	0	0	109	4	1.51E+10	1	1	46	3	8.98E+10	151.7	222.6	147.3	130.5	146.3	9.38	13.97	9.07	8.04	9.00	Bags
		-0.87		44	40	393	10	-	-	330	300	2287	46	-	1	1	191	10	-	1	0	111	4	-	1	0	46	3	-	152.5	224.1	147.2	130.9	147.6	9.43	14.07	9.07	8.06	9.08	Modal Dil
		0.0390		592	563	6830	2534	-	-	1318	1249	13600	1457	-	613	585	7620	1911	-	468	446	5676	2317	-	417	396	4848	3483	-	144.2	211.1	135.0	122.7	143.0	9.64	14.54	9.15	8.18	9.34	Modal PRE cat
				49	45	400	11	-	-	371	336	2285	52	-	0	0	206	10	-	0	0	112	4	-	0	0	57	4	-	155.5	228.5	150.0	133.4	150.6	9.61	14.34	9.24	8.22	9.27	Modal TP
TWC effectiveness (pre-bag)				**92.8%**	**93.1%**	**94.3%**	**99.6%**	-	-	**75.9%**	**76.9%**	**83.2%**	**96.6%**	-	**99.9%**	**99.9%**	**97.5%**	**99.5%**	-	**99.9%**	**99.9%**	**98.1%**	**99.8%**	-	**99.9%**	**99.9%**	**99.1%**	**99.9%**	-											TWC eff
TWC effectiveness (pre-post)				**91.7%**	**92.0%**	**94.1%**	**99.5%**	-	-	**71.9%**	**73.1%**	**83.2%**	**96.4%**	-	**99.9%**	**99.9%**	**97.3%**	**99.5%**	-	**100.0%**	**99.9%**	**98.0%**	**99.8%**	-	**100.0%**	**99.9%**	**98.8%**	**99.9%**	-											TWC eff
Mean values				49	45	437	16	0.97	5.83E+11	366	335	2276	42	3.99E+12	1	0	232	6	7.82E+10	0	0	222	5	1.72E+10	1	1	54	22	9.24E+10	150.1	219.0	146.4	129.4	144.4	9.28	13.76	9.03	7.98	8.89	Bags
				51	47	434	15	-	-	380	348	2263	39	-	1	1	232	6	-	1	0	220	5	-	1	1	54	21	-	150.8	219.9	146.3	129.6	145.9	9.32	13.81	9.02	7.99	8.98	Modal Dil
				670	640	7144	2481	-	-	1519	1447	14222	1387	-	717	686	8502	1853	-	540	517	5993	2247	-	439	418	4716	3453	-	140.9	204.1	131.7	120.1	140.7	9.48	14.21	9.05	8.06	9.19	Modal PRE cat
				57	52	446	16	-	-	426	389	2253	46	-	0	0	245	6	-	0	0	235	4	-	0	1	70	22	-	153.8	224.3	149.2	132.2	148.8	9.51	14.09	9.20	8.15	9.16	Modal TP
Standard deviation				5.9	5.8	55.3	7.4	0.22	3.68E+10	44.9	43.7	35.4	5.4	2.40E+11	0.2	0.1	67.2	3.3	4.21E+10	0.1	0.1	145.9	0.7	8.21E+09	0.0	0.0	27.0	23.0	2.32E+10	1.30	2.80	0.94	0.78	1.48	0.08	0.17	0.06	0.04	0.09	Bags
				6.1	6.1	53.8	7.4	-	-	46.5	45.4	46.4	5.0	-	0.2	0.1	65.8	3.1	-	0.1	0.2	141.5	0.7	-	0.0	0.1	26.4	22.7	-	1.40	3.20	1.00	0.93	1.45	0.08	0.19	0.06	0.06	0.09	Modal Dil
				55.5	54.6	335.6	40.5	-	-	146.8	145.8	726.5	58.6	-	73.9	72.2	787.7	42.1	-	51.3	50.6	427.2	69.3	-	16.9	16.4	134.9	22.0	-	2.29	4.95	2.40	1.93	1.72	0.12	0.25	0.10	0.09	0.11	Modal PRE cat
				6.5	6.3	49.4	7.4	-	-	49.1	47.2	22.9	4.3	-	0.2	0.1	67.0	3.0	-	0.1	0.1	146.8	0.6	-	0.1	0.1	36.0	22.3	-	1.39	3.22	1.00	0.92	1.45	0.08	0.19	0.06	0.05	0.09	Modal TP
Type A uncertainty				3.4	3.4	31.9	4.3	0.13	2.13E+10	25.9	25.3	20.5	3.1	1.38E+11	0.1	0.0	38.8	1.9	2.43E+10	0.1	0.1	84.3	0.4	4.74E+09	0.0	0.0	15.6	13.3	1.34E+10	0.75	1.62	0.55	0.45	0.85	0.05	0.10	0.04	0.03	0.05	Bags
				3.5	3.5	31.1	4.3	-	-	26.8	26.2	26.8	2.9	-	0.1	0.0	38.0	1.8	-	0.1	0.1	81.7	0.4	-	0.0	0.1	15.2	13.1	-	0.81	1.85	0.58	0.54	0.83	0.05	0.11	0.04	0.03	0.05	Modal Dil
				32.0	31.5	193.8	23.4	-	-	84.8	84.2	419.4	33.8	-	42.6	41.7	454.8	24.3	-	29.6	29.2	246.6	40.0	-	9.7	9.5	77.9	12.7	-	1.32	2.86	1.38	1.12	0.99	0.07	0.14	0.06	0.05	0.06	Modal PRE cat
				3.8	3.6	28.5	4.3	-	-	28.4	27.3	13.2	2.5	-	0.1	0.0	38.7	1.8	-	0.1	0.1	84.8	0.4	-	0.1	0.1	20.8	12.9	-	0.80	1.86	0.58	0.53	0.83	0.05	0.11	0.04	0.03	0.05	Modal TP
Mean TWC effectiveness (pre-bag)				**92.7%**	**93.0%**	**93.9%**	**99.4%**	-	-	**76.0%**	**76.9%**	**84.0%**	**97.0%**	-	**99.9%**	**99.9%**	**97.3%**	**99.7%**	-	**99.9%**	**99.9%**	**96.5%**	**99.8%**	-	**99.9%**	**99.9%**	**98.9%**	**99.4%**	-											
Max. TWC effectiveness (pre-bag)				**93.2%**	**93.5%**	**94.3%**	**99.6%**	-	-	**77.5%**	**78.5%**	**84.8%**	**97.4%**	-	**100.0%**	**100.0%**	**97.8%**	**99.9%**	-	**100.0%**	**100.0%**	**98.1%**	**99.8%**	-	**99.9%**	**99.9%**	**99.4%**	**99.9%**	-											
Min. TWC effectiveness (pre-bag)				**92.1%**	**92.3%**	**93.2%**	**98.9%**	-	-	**74.4%**	**75.3%**	**83.2%**	**96.6%**	-	**99.9%**	**99.9%**	**96.6%**	**99.5%**	-	**99.9%**	**99.9%**	**93.5%**	**99.7%**	-	**99.9%**	**99.8%**	**98.1%**	**98.4%**	-											
Mean TWC effectiveness (pre-post)				**91.5%**	**91.9%**	**93.8%**	**99.3%**	-	-	**72.0%**	**73.2%**	**84.1%**	**96.7%**	-	**99.9%**	**99.9%**	**97.2%**	**99.7%**	-	**100.0%**	**99.9%**	**96.2%**	**99.8%**	-	**99.9%**	**99.9%**	**98.5%**	**99.4%**	-											
Max. TWC effectiveness (pre-post)				**92.0%**	**92.4%**	**94.1%**	**99.6%**	-	-	**73.5%**	**74.7%**	**85.3%**	**97.0%**	-	**100.0%**	**99.9%**	**97.7%**	**99.9%**	-	**100.0%**	**100.0%**	**98.0%**	**99.8%**	-	**100.0%**	**99.9%**	**99.2%**	**99.9%**	-											
Min. TWC effectiveness (pre-post)				**90.9%**	**91.2%**	**93.2%**	**98.9%**	-	-	**70.6%**	**71.7%**	**83.2%**	**96.4%**	-	**99.9%**	**99.9%**	**96.4%**	**99.5%**	-	**100.0%**	**99.9%**	**93.3%**	**99.8%**	-	**99.9%**	**99.8%**	**97.5%**	**98.4%**	-											

Table 9 Emissions and fuel consumption results from the Fiat Tipo 1.4 vehicle over the WLTC cycle for TWC Low S at 50 cycles

BOSMAL
BOSMAL Automotive Research and Development Institute Ltd
Exhaust Emissions Testing Laboratory

WLTP test (Reg 2017/1151) - WLTC driving cycle

VIN: ZFA35600006K20252 — **Vehicle model:** **Fiat Tipo 1.4 LPG** — **Emission standard: Euro 6** — Tyres: Continental ContiEcoContact 5 225/45 R17 V XL

Inertia [kg]:	1509			Emission WLTC						Emission LOW					Emission MIDDLE					Emission HIGH					Emission Ex-HIGH					CO_2 emission					Fuel consumption					Note 1
Mileage[km]	Date	Chassis dyno F0/F1/F2	Test No.	[mg/km]						[mg/km]					[mg/km]					[mg/km]					[mg/km]					[g/km]					[l/100 km] (2)					
				THC	NMHC	CO	NOx	PM	PN	THC	NMHC	CO	NOx	PN	THC	NMHC	CO	NOx	PN	THC	NMHC	CO	NOx	PN	THC	NMHC	CO	NOx	PN	WLTC	LOW	MIDDLE	HIGH	Ex-HIGH	WLTC	LOW	MIDDLE	HIGH	Ex-HIGH	
Ageing stage: 50 cycles				**BAG - MODAL DIL - PRE - POST**																																				
4 603	2018-12-05	45.1 -0.87 0.0390	L1-0556	51	47	545	32	0.57	4.80E+11	379	348	3242	89	3.26E+12	1	1	350	3	4.51E+10	0	0	128	19	2.28E+10	1	1	9	39	8.60E+10	150.6	222.4	148.3	129.2	143.5	9.32	14.06	9.15	7.96	8.83	Bags
				54	*49*	*545*	*32*	-	-	*395*	*362*	*3230*	*90*	-	*2*	*1*	*351*	*3*	-	*1*	*1*	*130*	*19*	-	*1*	*1*	*9*	*39*	-	*151.5*	*223.0*	*148.6*	*129.6*	*145.4*	*9.38*	*14.10*	*9.17*	*7.99*	*8.94*	*Modal Dil*
				609	*579*	*7907*	*2349*	-	-	*1399*	*1323*	*17089*	*1320*	-	*644*	*613*	*10848*	*1599*	-	*474*	*453*	*6104*	*2107*	-	*410*	*391*	*4336*	*3378*	-	*138.6*	*205.2*	*132.8*	*115.9*	*136.6*	*9.40*	*14.53*	*9.34*	*7.81*	*8.90*	*Modal PRE cat*
				70	*65*	*608*	*43*	-	-	*526*	*485*	*3700*	*108*	-	*1*	*1*	*343*	*2*	-	*0*	*0*	*129*	*17*	-	*1*	*1*	*17*	*63*	-	*154.6*	*227.7*	*151.5*	*132.2*	*148.4*	*9.58*	*14.46*	*9.35*	*8.14*	*9.13*	*Modal TP*
TWC effectiveness (pre-bag)				**91.6%**	**91.9%**	**93.1%**	**98.6%**	-	-	**72.9%**	**73.7%**	**81.0%**	**93.2%**	-	**99.9%**	**99.9%**	**96.8%**	**99.8%**	-	**99.9%**	**99.9%**	**97.9%**	**99.1%**	-	**99.8%**	**99.8%**	**99.8%**	**98.8%**	-											*TWC eff*
TWC effectiveness (pre-post)				**88.4%**	**88.8%**	**92.3%**	**98.2%**	-	-	**62.4%**	**63.3%**	**78.3%**	**91.8%**	-	**99.9%**	**99.9%**	**96.8%**	**99.9%**	-	**99.9%**	**99.9%**	**97.9%**	**99.2%**	-	**99.9%**	**99.8%**	**99.6%**	**98.1%**	-											*TWC eff*
4 627	2018-12-06	45.1 -0.87 0.0390	L1-0558	57	53	520	21	0.52	5.72E+11	429	395	3320	91	4.00E+12	1	1	178	7	4.18E+10	0	0	105	9	1.79E+10	0	0	30	13	7.38E+10	150.2	221.2	146.7	128.9	144.0	9.30	14.01	9.04	7.94	8.86	Bags
				59	*53*	*520*	*20*	-	-	*433*	*397*	*3314*	*90*	-	*2*	*1*	*180*	*7*	-	*1*	*0*	*107*	*9*	-	*1*	*1*	*30*	*13*	-	*151.0*	*221.8*	*147.0*	*129.1*	*145.9*	*9.35*	*14.04*	*9.06*	*7.95*	*8.97*	*Modal Dil*
				597	*568*	*7066*	*2686*	-	-	*1533*	*1464*	*14519*	*1615*	-	*596*	*568*	*8309*	*2136*	-	*439*	*418*	*5910*	*2450*	-	*383*	*363*	*4564*	*3612*	-	*144.0*	*202.7*	*138.5*	*123.9*	*142.6*	*9.65*	*14.15*	*9.43*	*8.27*	*9.28*	*Modal PRE cat*
				62	*57*	*507*	*22*	-	-	*465*	*426*	*3133*	*98*	-	*1*	*1*	*194*	*7*	-	*0*	*0*	*120*	*9*	-	*0*	*1*	*39*	*12*	-	*155.5*	*220.1*	*153.4*	*134.4*	*150.8*	*9.62*	*13.92*	*9.45*	*8.28*	*9.28*	*Modal TP*
TWC effectiveness (pre-bag)				**90.4%**	**90.7%**	**92.6%**	**99.2%**	-	-	**72.0%**	**73.1%**	**77.1%**	**94.4%**	-	**99.8%**	**99.9%**	**97.9%**	**99.7%**	-	**100.0%**	**100.0%**	**98.2%**	**99.6%**	-	**99.9%**	**99.9%**	**99.4%**	**99.6%**	-											*TWC eff*
TWC effectiveness (pre-post)				**89.6%**	**90.0%**	**92.8%**	**99.2%**	-	-	**69.7%**	**70.9%**	**78.4%**	**93.9%**	-	**99.8%**	**99.8%**	**97.7%**	**99.7%**	-	**100.0%**	**99.9%**	**98.0%**	**99.6%**	-	**99.9%**	**99.8%**	**99.1%**	**99.7%**	-											*TWC eff*
4 650	2018-12-07	45.1 -0.87 0.0390	L1-0563	60	55	583	21	0.59	6.30E+11	448	409	3669	81	4.52E+12	1	1	195	10	3.79E+10	1	1	157	7	1.56E+10	1	1	20	17	4.28E+10	149.6	219.6	146.5	128.6	143.2	9.26	13.95	9.03	7.93	8.81	Bags
				63	*58*	*583*	*20*	-	-	*465*	*425*	*3661*	*77*	-	*3*	*2*	*196*	*10*	-	*2*	*1*	*158*	*7*	-	*1*	*1*	*20*	*17*	-	*150.4*	*220.4*	*146.9*	*128.9*	*144.9*	*9.32*	*13.99*	*9.05*	*7.94*	*8.91*	*Modal Dil*
				589	*561*	*7101*	*2670*	-	-	*1509*	*1433*	*15411*	*1676*	-	*578*	*551*	*8127*	*2137*	-	*456*	*436*	*5887*	*2468*	-	*366*	*347*	*4445*	*3526*	-	*144.4*	*206.1*	*139.1*	*124.2*	*141.8*	*9.68*	*14.44*	*9.45*	*8.29*	*9.22*	*Modal PRE cat*
				67	*61*	*579*	*22*	-	-	*501*	*456*	*3535*	*86*	-	*1*	*1*	*217*	*10*	-	*0*	*0*	*174*	*7*	-	*1*	*1*	*28*	*18*	-	*155.8*	*223.8*	*153.7*	*134.7*	*149.8*	*9.65*	*14.20*	*9.47*	*8.30*	*9.22*	*Modal TP*
TWC effectiveness (pre-bag)				**89.7%**	**90.2%**	**91.8%**	**99.2%**	-	-	**70.3%**	**71.4%**	**76.2%**	**95.2%**	-	**99.7%**	**99.8%**	**97.6%**	**99.5%**	-	**99.9%**	**99.9%**	**97.3%**	**99.7%**	-	**99.7%**	**99.7%**	**99.6%**	**99.5%**	-											*TWC eff*
TWC effectiveness (pre-post)				**88.6%**	**89.1%**	**91.9%**	**99.2%**	-	-	**66.8%**	**68.2%**	**77.1%**	**94.9%**	-	**99.8%**	**99.8%**	**97.3%**	**99.5%**	-	**99.9%**	**99.9%**	**97.0%**	**99.7%**	-	**99.8%**	**99.8%**	**99.4%**	**99.5%**	-											*TWC eff*
Mean values				56	52	550	25	0.56	5.61E+11	419	384	3410	87	3.93E+12	1	1	241	6	4.16E+10	0	0	130	12	1.88E+10	1	1	19	23	6.75E+10	150.1	221.1	147.2	128.9	143.6	9.29	14.00	9.08	7.94	8.83	Bags
				59	*53*	*549*	*24*	-	-	*431*	*395*	*3402*	*86*	-	*2*	*1*	*242*	*6*	-	*1*	*1*	*132*	*12*	-	*1*	*1*	*20*	*23*	-	*151.0*	*221.8*	*147.5*	*129.2*	*145.4*	*9.35*	*14.05*	*9.10*	*7.96*	*8.94*	*Modal Dil*
				598	*569*	*7358*	*2569*	-	-	*1480*	*1407*	*15673*	*1537*	-	*606*	*577*	*9095*	*1957*	-	*457*	*436*	*5967*	*2341*	-	*386*	*367*	*4448*	*3505*	-	*142.3*	*204.7*	*136.8*	*121.3*	*140.4*	*9.57*	*14.38*	*9.40*	*8.12*	*9.13*	*Modal PRE cat*
				67	*61*	*564*	*29*	-	-	*497*	*455*	*3456*	*97*	-	*1*	*1*	*251*	*7*	-	*0*	*0*	*141*	*11*	-	*1*	*1*	*28*	*31*	-	*155.3*	*223.9*	*152.9*	*133.8*	*149.7*	*9.62*	*14.19*	*9.43*	*8.24*	*9.21*	*Modal TP*
Standard deviation				3.9	3.6	26.0	5.4	0.03	6.14E+10	29.0	26.3	185.5	4.4	5.18E+11	0.3	0.2	77.3	3.0	2.96E+09	0.2	0.2	21.1	5.3	2.98E+09	0.3	0.2	8.5	11.6	1.82E+10	0.42	1.13	0.79	0.25	0.35	0.02	0.05	0.06	0.01	0.02	Bags
				4.0	*3.7*	*25.7*	*5.5*	-	-	*28.7*	*26.1*	*186.4*	*6.0*	-	*0.4*	*0.3*	*77.2*	*3.0*	-	*0.2*	*0.2*	*20.9*	*5.3*	-	*0.3*	*0.3*	*8.6*	*11.5*	-	*0.45*	*1.09*	*0.79*	*0.30*	*0.40*	*0.03*	*0.04*	*0.06*	*0.02*	*0.03*	*Modal Dil*
				8.2	*7.7*	*388.3*	*155.1*	-	-	*58.5*	*60.8*	*1065.3*	*155.3*	-	*27.8*	*26.1*	*1242.0*	*253.4*	-	*14.3*	*14.4*	*97.7*	*166.0*	-	*18.1*	*18.3*	*93.0*	*96.2*	-	*2.64*	*1.44*	*2.84*	*3.81*	*2.66*	*0.12*	*0.16*	*0.05*	*0.22*	*0.17*	*Modal PRE cat*
				3.4	*3.3*	*42.6*	*9.7*	-	-	*25.3*	*24.4*	*238.0*	*9.2*	-	*0.2*	*0.1*	*65.4*	*3.4*	-	*0.1*	*0.0*	*23.7*	*4.3*	-	*0.1*	*0.1*	*8.9*	*22.8*	-	*0.52*	*3.13*	*0.97*	*1.13*	*1.02*	*0.03*	*0.22*	*0.05*	*0.07*	*0.06*	*Modal TP*
Type A uncertainty				2.3	2.1	15.0	3.1	0.02	3.55E+10	16.7	15.2	107.1	2.5	2.99E+11	0.2	0.1	44.7	1.7	1.71E+09	0.1	0.1	12.2	3.1	1.72E+09	0.1	0.1	4.9	6.7	1.05E+10	0.24	0.65	0.46	0.14	0.20	0.01	0.03	0.03	0.01	0.01	Bags
				2.3	*2.1*	*14.8*	*3.2*	-	-	*16.6*	*15.0*	*107.6*	*3.5*	-	*0.2*	*0.2*	*44.6*	*1.7*	-	*0.1*	*0.1*	*12.1*	*3.1*	-	*0.2*	*0.2*	*5.0*	*6.6*	-	*0.26*	*0.63*	*0.46*	*0.17*	*0.23*	*0.01*	*0.03*	*0.03*	*0.01*	*0.01*	*Modal Dil*
				4.7	*4.5*	*224.2*	*89.6*	-	-	*33.8*	*35.1*	*615.0*	*89.7*	-	*16.1*	*15.1*	*717.0*	*146.3*	-	*8.3*	*8.3*	*56.4*	*95.9*	-	*10.5*	*10.6*	*53.7*	*55.6*	-	*1.52*	*0.83*	*1.64*	*2.20*	*1.53*	*0.07*	*0.09*	*0.03*	*0.13*	*0.10*	*Modal PRE cat*
				2.0	*1.9*	*24.6*	*5.6*	-	-	*14.6*	*14.1*	*137.4*	*5.3*	-	*0.1*	*0.1*	*37.8*	*2.0*	-	*0.0*	*0.0*	*13.7*	*2.5*	-	*0.1*	*0.0*	*5.2*	*13.2*	-	*0.30*	*1.81*	*0.56*	*0.65*	*0.59*	*0.02*	*0.13*	*0.03*	*0.04*	*0.04*	*Modal TP*
Mean TWC effectiveness (pre-bag)				**90.6%**	**90.9%**	**92.5%**	**99.0%**	-	-	**71.7%**	**72.7%**	**78.1%**	**94.3%**	-	**99.8%**	**99.9%**	**97.4%**	**99.7%**	-	**99.9%**	**99.9%**	**97.8%**	**99.5%**	-	**99.8%**	**99.8%**	**99.6%**	**99.3%**	-											
Max. TWC effectiveness (pre-bag)				**91.6%**	**91.9%**	**93.1%**	**99.2%**	-	-	**72.9%**	**73.7%**	**81.0%**	**95.2%**	-	**99.9%**	**99.9%**	**97.9%**	**99.8%**	-	**100.0%**	**100.0%**	**98.2%**	**99.7%**	-	**99.9%**	**99.9%**	**99.8%**	**99.6%**	-											
Min. TWC effectiveness (pre-bag)				**89.7%**	**90.2%**	**91.8%**	**98.6%**	-	-	**70.3%**	**71.4%**	**76.2%**	**93.2%**	-	**99.7%**	**99.8%**	**96.8%**	**99.5%**	-	**99.9%**	**99.9%**	**97.3%**	**99.1%**	-	**99.7%**	**99.7%**	**99.4%**	**98.8%**	-											
Mean TWC effectiveness (pre-post)				**88.9%**	**89.3%**	**92.3%**	**98.9%**	-	-	**66.3%**	**67.5%**	**77.9%**	**93.6%**	-	**99.8%**	**99.8%**	**97.3%**	**99.7%**	-	**99.9%**	**99.9%**	**97.6%**	**99.5%**	-	**99.8%**	**99.8%**	**99.4%**	**99.1%**	-											
Max. TWC effectiveness (pre-post)				**89.6%**	**90.0%**	**92.8%**	**99.2%**	-	-	**69.7%**	**70.9%**	**78.4%**	**94.9%**	-	**99.9%**	**99.9%**	**97.7%**	**99.9%**	-	**100.0%**	**99.9%**	**98.0%**	**99.7%**	-	**99.9%**	**99.8%**	**99.6%**	**99.7%**	-											
Min. TWC effectiveness (pre-post)				**88.4%**	**88.8%**	**91.9%**	**98.2%**	-	-	**62.4%**	**63.3%**	**77.1%**	**91.8%**	-	**99.8%**	**99.8%**	**96.8%**	**99.5%**	-	**99.9%**	**99.9%**	**97.0%**	**99.2%**	-	**99.8%**	**99.8%**	**99.1%**	**98.1%**	-											

Table 10 Emissions and fuel consumption results from the Fiat Tipo 1.4 vehicle over the WLTC cycle for TWC Low S at 100 cycles

BOSMAL

BOSMAL Automotive Research and Development Institute Ltd

Exhaust Emissions Testing Laboratory

WLTP test (Reg 2017/1151) - WLTC driving cycle

VIN: ZFA35600006K20252 **Vehicle model:** **Fiat Tipo 1.4 LPG** **Emission standard: Euro 6**

Tyres: Continental ContiEcoContact 5 225/45 R17 V XL

Inertia [kg]:	1509			Emission WLTC						Emission LOW					Emission MIDDLE					Emission HIGH					Emission Ex-HIGH					CO_2 emission					Fuel consumption					Note 1
Mileage[km]	Date	Chassis dyno F0/F1/F2	Test No.	[mg/km]						[mg/km]					[mg/km]					[mg/km]					[mg/km]					[g/km]					[l/100 km] (2)					
				THC	NMHC	CO	NOx	PM	PN	THC	NMHC	CO	NOx	PN	THC	NMHC	CO	NOx	PN	THC	NMHC	CO	NOx	PN	THC	NMHC	CO	NOx	PN	WLTC	LOW	MIDDLE	HIGH	Ex-HIGH	WLTC	LOW	MIDDLE	HIGH	Ex-HIGH	
Ageing stage: 100 cycles				BAG - MODAL DIL - PRE - POST																																				
4 697	2019-01-03	45.1 -0.87 0.0390	L1-0001	66	61	682	18	0.58	6.26E+11	487	451	3598	108	4.44E+12	1	1	209	6	5.84E+10	1	1	440	5	1.66E+10	1	1	68	3	4.87E+10	152.4	223.0	148.8	130.2	147.1	9.45	14.16	9.17	8.05	9.05	Bags
				70	64	679	18	-	-	511	474	3563	107	-	3	2	210	6	-	2	1	441	5	-	1	1	69	3	-	153.2	223.6	149.2	130.5	148.7	9.50	14.19	9.20	8.07	9.15	Modal Dil
				669	640	8232	2351	-	-	1541	1467	16475	1409	-	743	714	10027	1668	-	539	517	7404	2022	-	411	392	4804	3387	-	140.3	207.3	131.9	117.0	140.3	9.55	14.63	9.22	8.01	9.17	Modal PRE cat
				87	81	772	20	-	-	650	603	4150	123	-	2	1	241	5	-	1	1	458	4	-	1	1	79	2	-	156.3	228.4	152.1	133.1	151.7	9.70	14.57	9.38	8.23	9.34	Modal TP
TWC effectiveness (pre-bag)				90.2%	90.5%	91.7%	99.2%	-	-	68.4%	69.3%	78.2%	92.3%	-	99.8%	99.9%	97.9%	99.6%	-	99.8%	99.8%	94.1%	99.8%	-	99.8%	99.7%	98.6%	99.9%	-											TWC eff
TWC effectiveness (pre-post)				86.9%	87.3%	90.6%	99.2%	-	-	57.9%	58.9%	74.8%	91.3%	-	99.8%	99.8%	97.6%	99.7%	-	99.9%	99.9%	93.8%	99.8%	-	99.8%	99.8%	98.4%	99.9%	-											TWC eff
4 721	2019-01-03	45.1 -0.87 0.0390	L1-0002	70	64	746	21	0.63	6.47E+11	514	469	4454	97	4.44E+12	2	1	372	25	4.91E+10	1	1	157	5	1.62E+10	1	1	66	4	1.00E+11	150.8	219.2	148.8	129.8	144.2	9.36	14.01	9.19	8.00	8.87	Bags
				73	67	745	20	-	-	536	490	4434	92	-	3	2	373	23	-	1	1	159	5	-	1	1	68	4	-	151.5	219.5	149.0	130.2	145.6	9.40	14.02	9.20	8.03	8.96	Modal Dil
				663	631	8707	2336	-	-	1558	1466	19540	1224	-	716	684	10879	1657	-	519	497	6908	2134	-	418	399	4897	3326	-	138.4	200.8	132.1	117.9	136.2	9.48	14.52	9.31	8.02	8.93	Modal PRE cat
				96	88	827	22	-	-	711	654	5060	105	-	1	1	340	26	-	0	1	165	6	-	1	1	76	4	-	154.6	224.3	151.9	132.8	148.6	9.61	14.41	9.38	8.19	9.14	Modal TP
TWC effectiveness (pre-bag)				89.5%	89.9%	91.4%	99.1%	-	-	67.0%	68.0%	77.2%	92.1%	-	99.8%	99.8%	96.6%	98.5%	-	99.9%	99.9%	97.7%	99.8%	-	99.8%	99.8%	98.6%	99.9%	-											TWC eff
TWC effectiveness (pre-post)				85.5%	86.0%	90.5%	99.0%	-	-	54.3%	55.4%	74.1%	91.4%	-	99.8%	99.8%	96.9%	98.4%	-	99.9%	99.9%	97.6%	99.7%	-	99.9%	99.8%	98.5%	99.9%	-											TWC eff
4 744	2019-01-04	45.1 -0.87 0.0390	L1-0004	57	53	550	21	0.78	5.31E+11	424	390	3480	114	3.82E+12	1	1	91	14	4.66E+10	1	1	86	5	8.07E+09	1	1	118	3	3.38E+10	148.6	214.1	144.7	127.5	144.7	9.20	13.58	8.91	7.85	8.91	Bags
				61	55	548	20	-	-	444	408	3458	110	-	3	2	92	14	-	2	1	87	5	-	2	1	119	3	-	149.4	214.6	145.0	127.9	146.3	9.25	13.62	8.93	7.87	9.01	Modal Dil
				658	629	7679	2343	-	-	1521	1445	16764	1317	-	730	703	8900	1657	-	533	513	6111	2125	-	401	382	4926	3313	-	137.4	197.8	129.1	116.3	137.9	9.32	14.07	8.93	7.84	9.03	Modal PRE cat
				76	71	601	22	-	-	570	526	3847	128	-	1	1	95	14	-	0	0	84	4	-	1	1	123	2	-	152.4	219.1	147.8	130.4	149.2	9.45	13.95	9.10	8.03	9.19	Modal TP
TWC effectiveness (pre-bag)				91.3%	91.6%	92.8%	99.1%	-	-	72.1%	73.0%	79.2%	91.4%	-	99.8%	99.9%	99.0%	99.1%	-	99.9%	99.9%	98.6%	99.8%	-	99.8%	99.8%	97.6%	99.9%	-											TWC eff
TWC effectiveness (pre-post)				88.4%	88.8%	92.2%	99.1%	-	-	62.5%	63.6%	77.0%	90.3%	-	99.8%	99.9%	98.9%	99.1%	-	99.9%	99.9%	98.6%	99.8%	-	99.8%	99.8%	97.5%	99.9%	-											TWC eff
Mean values				64	59	659	20	0.66	6.02E+11	475	437	3844	106	4.23E+12	2	1	224	15	5.14E+10	1	1	228	5	1.36E+10	1	1	84	4	6.10E+10	150.6	218.8	147.4	129.2	145.3	9.34	13.91	9.09	7.97	8.94	Bags
				68	62	657	19	-	-	497	457	3819	103	-	3	2	225	15	-	2	1	229	5	-	1	1	85	4	-	151.4	219.2	147.8	129.5	146.9	9.39	13.94	9.11	7.99	9.04	Modal Dil
				663	633	8206	2343	-	-	1540	1459	17593	1316	-	730	700	9935	1661	-	530	509	6808	2094	-	410	391	4876	3342	-	138.7	202.0	131.0	117.1	138.1	9.45	14.41	9.15	7.96	9.04	Modal PRE cat
				87	80	733	21	-	-	644	594	4352	119	-	1	1	225	15	-	0	1	235	5	-	1	1	92	3	-	154.4	223.9	150.6	132.1	149.8	9.59	14.31	9.29	8.15	9.22	Modal TP
Standard deviation				5.3	4.7	81.8	1.3	0.09	5.04E+10	37.6	33.7	434.2	7.1	2.94E+11	0.1	0.2	115.1	7.5	5.08E+09	0.1	0.1	152.6	0.2	3.94E+09	0.1	0.1	23.7	0.7	2.86E+10	1.54	3.68	1.94	1.19	1.26	0.10	0.24	0.13	0.09	0.08	Bags
				5.3	4.9	81.8	0.9	-	-	38.9	35.5	437.5	7.9	-	0.1	0.1	115.1	6.9	-	0.2	0.1	153.0	0.2	-	0.1	0.0	23.8	0.6	-	1.54	3.69	1.94	1.20	1.33	0.10	0.24	0.13	0.08	0.08	Modal Dil
				4.7	4.7	420.4	6.0	-	-	14.9	10.4	1381.5	75.5	-	11.3	12.4	810.7	4.9	-	8.3	8.6	532.6	51.0	-	7.0	7.0	52.2	32.3	-	1.21	3.94	1.38	0.68	1.67	0.10	0.24	0.16	0.08	0.10	Modal PRE cat
				8.0	7.3	96.2	1.3	-	-	57.7	52.3	515.3	9.7	-	0.1	0.1	100.7	8.5	-	0.1	0.1	160.4	0.5	-	0.1	0.1	21.7	0.7	-	1.58	3.78	1.99	1.22	1.35	0.11	0.26	0.13	0.09	0.08	Modal TP
Type A uncertainty				3.0	2.7	47.2	0.7	0.05	2.91E+10	21.7	19.5	250.7	4.1	1.70E+11	0.1	0.1	66.5	4.3	2.93E+09	0.1	0.1	88.1	0.1	2.27E+09	0.0	0.0	13.7	0.4	1.65E+10	0.89	2.13	1.12	0.69	0.73	0.06	0.14	0.07	0.05	0.04	Bags
				3.1	2.9	47.3	0.5	-	-	22.5	20.5	252.6	4.6	-	0.1	0.1	66.5	4.0	-	0.1	0.0	88.3	0.1	-	0.1	0.0	13.7	0.4	-	0.89	2.13	1.12	0.69	0.77	0.06	0.14	0.07	0.05	0.05	Modal Dil
				2.7	2.7	242.7	3.5	-	-	8.6	6.0	797.6	43.6	-	6.6	7.2	468.0	2.8	-	4.8	5.0	307.5	29.4	-	4.1	4.0	30.1	18.6	-	0.70	2.27	0.80	0.39	0.96	0.06	0.14	0.09	0.05	0.06	Modal PRE cat
				4.6	4.2	55.5	0.7	-	-	33.3	30.2	297.5	5.6	-	0.0	0.1	58.1	4.9	-	0.0	0.0	92.6	0.3	-	0.1	0.0	12.5	0.4	-	0.91	2.18	1.15	0.70	0.78	0.06	0.15	0.08	0.05	0.05	Modal TP
Mean TWC effectiveness (pre-bag)				90.3%	90.7%	92.0%	99.1%	-	-	69.2%	70.1%	78.2%	91.9%	-	99.8%	99.8%	97.8%	99.1%	-	99.9%	99.9%	96.8%	99.8%	-	99.8%	99.8%	98.3%	99.9%	-											
Max. TWC effectiveness (pre-bag)				91.3%	91.6%	92.8%	99.2%	-	-	72.1%	73.0%	79.2%	92.3%	-	99.8%	99.9%	99.0%	99.6%	-	99.9%	99.9%	98.6%	99.8%	-	99.8%	99.8%	98.6%	99.9%	-											
Min. TWC effectiveness (pre-bag)				89.5%	89.9%	91.4%	99.1%	-	-	67.0%	68.0%	77.2%	91.4%	-	99.8%	99.8%	96.6%	98.5%	-	99.8%	99.8%	94.1%	99.8%	-	99.8%	99.7%	97.6%	99.9%	-											
Mean TWC effectiveness (pre-post)				86.9%	87.4%	91.1%	99.1%	-	-	58.2%	59.3%	75.3%	91.0%	-	99.8%	99.8%	97.8%	99.1%	-	99.9%	99.9%	96.7%	99.8%	-	99.8%	99.8%	98.1%	99.9%	-											
Max. TWC effectiveness (pre-post)				88.4%	88.8%	92.2%	99.2%	-	-	62.5%	63.6%	77.0%	91.4%	-	99.8%	99.9%	98.9%	99.7%	-	99.9%	99.9%	98.6%	99.8%	-	99.9%	99.8%	98.5%	99.9%	-											
Min. TWC effectiveness (pre-post)				85.5%	86.0%	90.5%	99.0%	-	-	54.3%	55.4%	74.1%	90.3%	-	99.8%	99.8%	96.9%	98.4%	-	99.9%	99.9%	93.8%	99.7%	-	99.8%	99.8%	97.5%	99.9%	-											

Table 11 Emissions and fuel consumption results from the Fiat Tipo 1.4 vehicle over the WLTC cycle for TWC Low S at 175 cycles

BOSMAL Automotive Research and Development Institute Ltd

Exhaust Emissions Testing Laboratory

WLTP test (Reg 2017/1151) - WLTC driving cycle

VIN: ZFA35600006K20252 **Vehicle model:** **Fiat Tipo 1.4 LPG** **Emission standard: Euro 6** Tyres: Continental ContiEcoContact 5 225/45 R17 V XL

Inertia [kg]:	1509			Emission WLTC						Emission LOW					Emission MIDDLE					Emission HIGH					Emission Ex-HIGH					CO_2 emission					Fuel consumption					Note 1
				[mg/km]						[mg/km]					[mg/km]					[mg/km]					[mg/km]					[g/km]					[l/100 km] (2)					
Mileage[km]	Date	Chassis dyno F0/F1/F2	Test No.	THC	NMHC	CO	NOx	PM	PN	THC	NMHC	CO	NOx	PN	THC	NMHC	CO	NOx	PN	THC	NMHC	CO	NOx	PN	THC	NMHC	CO	NOx	PN	WLTC	LOW	MIDDLE	HIGH	Ex-HIGH	WLTC	LOW	MIDDLE	HIGH	Ex-HIGH	
Ageing stage: 175 cycles				BAG - MODAL DIL - PRE - POST																																				
4 814	2019-01-22	45.1	L1-0019	64	59	527	23	0.64	5.04E+11	472	439	3365	116	3.57E+12	1	1	141	11	3.09E+10	1	0	105	11	1.16E+10	1	1	46	5	4.99E+10	147.8	212.7	143.4	127.9	143.2	9.15	13.50	8.84	7.88	8.81	Bags
		-0.87		*68*	*63*	*527*	*23*	-	-	*497*	*462*	*3360*	*116*	-	*3*	*2*	*142*	*11*	-	*1*	*1*	*107*	*10*	-	*2*	*1*	*47*	*5*	-	*148.6*	*213.8*	*143.6*	*128.3*	*144.6*	*9.20*	*13.57*	*8.84*	*7.90*	*8.90*	*Modal Dil*
		0.0390		*666*	*637*	*7831*	*2341*	-	-	*1609*	*1534*	*17344*	*1308*	-	*738*	*710*	*9427*	*1614*	-	*513*	*493*	*6396*	*2108*	-	*401*	*383*	*4574*	*3353*	-	*136.5*	*196.4*	*126.3*	*117.0*	*136.8*	*9.27*	*14.05*	*8.81*	*7.91*	*8.93*	*Modal PRE cat*
				87	*81*	*593*	*26*	-	-	*644*	*600*	*3795*	*135*	-	*2*	*1*	*140*	*8*	-	*1*	*1*	*123*	*14*	-	*1*	*1*	*56*	*4*	-	*151.6*	*218.4*	*146.3*	*130.9*	*147.6*	*9.40*	*13.92*	*9.01*	*8.06*	*9.08*	*Modal TP*
TWC effectiveness (pre-bag)				**90.4%**	**90.7%**	**93.3%**	**99.0%**	-	-	**70.7%**	**71.4%**	**80.6%**	**91.1%**	-	**99.8%**	**99.9%**	**98.5%**	**99.3%**	-	**99.9%**	**99.9%**	**98.4%**	**99.5%**	-	**99.7%**	**99.7%**	**99.0%**	**99.8%**	-											*TWC eff*
TWC effectiveness (pre-post)				**87.0%**	**87.3%**	**92.4%**	**98.9%**	-	-	**60.0%**	**60.9%**	**78.1%**	**89.7%**	-	**99.8%**	**99.8%**	**98.5%**	**99.5%**	-	**99.8%**	**99.8%**	**98.1%**	**99.3%**	-	**99.7%**	**99.7%**	**98.8%**	**99.9%**	-											*TWC eff*
4 837	2019-01-23	45.1	L1-0022	67	62	610	22	0.75	6.56E+11	498	459	3938	120	4.64E+12	2	1	166	13	6.43E+10	1	0	53	7	1.45E+10	1	1	102	4	5.87E+10	147.9	214.5	143.6	126.6	143.9	9.17	13.67	8.85	7.79	8.86	Bags
		-0.87		*71*	*65*	*608*	*22*	-	-	*520*	*480*	*3916*	*120*	-	*3*	*2*	*169*	*13*	-	*1*	*1*	*54*	*7*	-	*1*	*1*	*101*	*4*	-	*148.6*	*215.1*	*144.0*	*127.1*	*145.1*	*9.21*	*13.70*	*8.87*	*7.82*	*8.93*	*Modal Dil*
		0.0390		*609*	*581*	*7231*	*2601*	-	-	*1431*	*1365*	*14399*	*1555*	-	*667*	*639*	*8431*	*2040*	-	*485*	*464*	*5991*	*2404*	-	*374*	*355*	*4928*	*3488*	-	*140.4*	*193.4*	*132.3*	*121.1*	*142.1*	*9.45*	*13.55*	*9.08*	*8.11*	*9.29*	*Modal PRE cat*
				73	*68*	*589*	*24*	-	-	*546*	*503*	*3703*	*131*	-	*2*	*1*	*178*	*14*	-	*1*	*1*	*65*	*8*	-	*1*	*1*	*113*	*4*	-	*152.1*	*209.2*	*148.0*	*132.0*	*150.6*	*9.43*	*13.33*	*9.12*	*8.12*	*9.27*	*Modal TP*
TWC effectiveness (pre-bag)				**89.0%**	**89.4%**	**91.6%**	**99.1%**	-	-	**65.2%**	**66.4%**	**72.7%**	**92.3%**	-	**99.7%**	**99.8%**	**98.0%**	**99.3%**	-	**99.9%**	**99.9%**	**99.1%**	**99.7%**	-	**99.7%**	**99.8%**	**97.9%**	**99.9%**	-											*TWC eff*
TWC effectiveness (pre-post)				**87.9%**	**88.4%**	**91.9%**	**99.1%**	-	-	**61.9%**	**63.2%**	**74.3%**	**91.6%**	-	**99.7%**	**99.8%**	**97.9%**	**99.3%**	-	**99.9%**	**99.9%**	**98.9%**	**99.7%**	-	**99.7%**	**99.7%**	**97.7%**	**99.9%**	-											*TWC eff*
4 837	2019-01-24	45.1	L1-0027	67	61	807	23	0.83	5.97E+11	495	456	4808	121	4.23E+12	2	1	152	13	3.69E+10	1	1	334	7	1.43E+10	1	1	96	6	6.34E+10	146.5	212.5	142.1	125.4	142.6	9.10	13.62	8.76	7.74	8.78	Bags
		-0.87		*71*	*65*	*804*	*23*	-	-	*519*	*478*	*4780*	*122*	-	*3*	*2*	*152*	*13*	-	*1*	*1*	*335*	*7*	-	*2*	*1*	*97*	*6*	-	*147.3*	*213.0*	*142.4*	*125.9*	*144.1*	*9.15*	*13.66*	*8.77*	*7.78*	*8.87*	*Modal Dil*
		0.0390		*631*	*603*	*7720*	*2556*	-	-	*1517*	*1447*	*15587*	*1498*	-	*697*	*668*	*8801*	*2009*	-	*500*	*479*	*7010*	*2240*	-	*375*	*357*	*4761*	*3545*	-	*139.1*	*195.5*	*130.6*	*117.4*	*141.9*	*9.42*	*13.81*	*9.01*	*7.99*	*9.25*	*Modal PRE cat*
				73	*67*	*789*	*25*	-	-	*541*	*496*	*4582*	*131*	-	*2*	*1*	*164*	*14*	-	*1*	*1*	*352*	*7*	-	*1*	*1*	*110*	*7*	-	*151.4*	*212.3*	*147.0*	*129.4*	*150.3*	*9.40*	*13.60*	*9.06*	*7.99*	*9.25*	*Modal TP*
TWC effectiveness (pre-bag)				**89.4%**	**89.8%**	**89.6%**	**99.1%**	-	-	**67.3%**	**68.5%**	**69.2%**	**91.9%**	-	**99.7%**	**99.8%**	**98.3%**	**99.3%**	-	**99.9%**	**99.9%**	**95.2%**	**99.7%**	-	**99.7%**	**99.7%**	**98.0%**	**99.8%**	-											*TWC eff*
TWC effectiveness (pre-post)				**88.4%**	**88.9%**	**89.8%**	**99.0%**	-	-	**64.3%**	**65.7%**	**70.6%**	**91.2%**	-	**99.7%**	**99.8%**	**98.1%**	**99.3%**	-	**99.9%**	**99.9%**	**95.0%**	**99.7%**	-	**99.7%**	**99.7%**	**97.7%**	**99.8%**	-											*TWC eff*
Mean values				66	61	648	23	0.74	5.85E+11	489	451	4037	119	4.15E+12	2	1	153	12	4.41E+10	1	1	164	8	1.35E+10	1	1	81	5	5.74E+10	147.4	213.2	143.1	126.6	143.2	9.14	13.60	8.81	7.80	8.82	Bags
				70	*64*	*646*	*23*	-	-	*512*	*473*	*4019*	*119*	-	*3*	*2*	*154*	*12*	-	*1*	*1*	*165*	*8*	-	*2*	*1*	*82*	*5*	-	*148.2*	*214.0*	*143.3*	*127.1*	*144.6*	*9.19*	*13.64*	*8.83*	*7.83*	*8.90*	*Modal Dil*
				635	*607*	*7594*	*2499*	-	-	*1519*	*1449*	*15776*	*1454*	-	*701*	*672*	*8886*	*1888*	-	*500*	*479*	*6466*	*2251*	-	*384*	*365*	*4754*	*3462*	-	*138.7*	*195.1*	*129.7*	*118.5*	*140.2*	*9.38*	*13.80*	*8.97*	*8.00*	*9.16*	*Modal PRE cat*
				78	*72*	*657*	*25*	-	-	*577*	*533*	*4027*	*132*	-	*2*	*1*	*161*	*12*	-	*1*	*1*	*180*	*10*	-	*1*	*1*	*93*	*5*	-	*151.7*	*213.3*	*147.1*	*130.7*	*149.5*	*9.41*	*13.61*	*9.06*	*8.06*	*9.20*	*Modal TP*
Standard deviation				1.5	1.1	117.4	0.3	0.08	6.26E+10	11.7	8.8	593.0	2.0	4.43E+11	0.4	0.2	10.6	1.1	1.45E+10	0.0	0.1	121.8	1.6	1.34E+09	0.1	0.1	25.0	0.8	5.60E+09	0.65	0.92	0.66	1.03	0.53	0.03	0.07	0.04	0.06	0.03	Bags
				1.3	*1.0*	*116.2*	*0.3*	-	-	*10.9*	*8.1*	*584.5*	*2.5*	-	*0.2*	*0.1*	*11.0*	*1.2*	-	*0.0*	*0.1*	*121.9*	*1.6*	-	*0.1*	*0.1*	*24.6*	*0.8*	-	*0.62*	*0.83*	*0.68*	*0.98*	*0.42*	*0.03*	*0.06*	*0.04*	*0.05*	*0.03*	*Modal Dil*
				23.6	*23.2*	*260.9*	*113.6*	-	-	*72.8*	*68.9*	*1209.7*	*105.8*	-	*29.2*	*29.5*	*410.9*	*193.8*	-	*11.7*	*11.7*	*419.0*	*121.0*	-	*12.7*	*12.8*	*144.7*	*80.5*	-	*1.65*	*1.27*	*2.55*	*1.84*	*2.47*	*0.08*	*0.21*	*0.11*	*0.09*	*0.16*	*Modal PRE cat*
				6.5	*6.5*	*93.7*	*0.6*	-	-	*47.3*	*47.4*	*394.6*	*2.1*	-	*0.2*	*0.1*	*15.6*	*2.6*	-	*0.1*	*0.1*	*123.7*	*3.2*	-	*0.1*	*0.1*	*26.2*	*1.1*	-	*0.30*	*3.82*	*0.67*	*1.03*	*1.35*	*0.01*	*0.24*	*0.04*	*0.05*	*0.09*	*Modal TP*
Type A uncertainty				0.9	0.6	67.8	0.2	0.05	3.62E+10	6.8	5.1	342.4	1.2	2.56E+11	0.2	0.1	6.1	0.7	8.39E+09	0.0	0.0	70.3	0.9	7.72E+08	0.1	0.1	14.4	0.5	3.23E+09	0.37	0.53	0.38	0.60	0.31	0.02	0.04	0.02	0.03	0.02	Bags
				0.8	*0.6*	*67.1*	*0.2*	-	-	*6.3*	*4.7*	*337.5*	*1.4*	-	*0.1*	*0.1*	*6.3*	*0.7*	-	*0.0*	*0.0*	*70.4*	*0.9*	-	*0.1*	*0.1*	*14.2*	*0.5*	-	*0.36*	*0.48*	*0.39*	*0.57*	*0.24*	*0.02*	*0.03*	*0.02*	*0.03*	*0.01*	*Modal Dil*
				13.6	*13.4*	*150.6*	*65.6*	-	-	*42.0*	*39.8*	*698.4*	*61.1*	-	*16.9*	*17.0*	*237.3*	*111.9*	-	*6.7*	*6.7*	*241.9*	*69.9*	-	*7.3*	*7.4*	*83.5*	*46.5*	-	*0.96*	*0.74*	*1.47*	*1.06*	*1.43*	*0.04*	*0.12*	*0.06*	*0.05*	*0.09*	*Modal PRE cat*
				3.7	*3.7*	*54.1*	*0.3*	-	-	*27.3*	*27.4*	*227.8*	*1.2*	-	*0.1*	*0.0*	*9.0*	*1.5*	-	*0.1*	*0.0*	*71.4*	*1.8*	-	*0.1*	*0.0*	*15.1*	*0.7*	-	*0.17*	*2.20*	*0.39*	*0.60*	*0.78*	*0.01*	*0.14*	*0.02*	*0.03*	*0.05*	*Modal TP*
Mean TWC effectiveness (pre-bag)				**89.6%**	**90.0%**	**91.5%**	**99.1%**	-	-	**67.7%**	**68.8%**	**74.1%**	**91.8%**	-	**99.7%**	**99.8%**	**98.3%**	**99.3%**	-	**99.9%**	**99.9%**	**97.6%**	**99.6%**	-	**99.7%**	**99.7%**	**98.3%**	**99.9%**	-											
Max. TWC effectiveness (pre-bag)				**90.4%**	**90.7%**	**93.3%**	**99.1%**	-	-	**70.7%**	**71.4%**	**80.6%**	**92.3%**	-	**99.8%**	**99.9%**	**98.5%**	**99.3%**	-	**99.9%**	**99.9%**	**99.1%**	**99.7%**	-	**99.7%**	**99.8%**	**99.0%**	**99.9%**	-											
Min. TWC effectiveness (pre-bag)				**89.0%**	**89.4%**	**89.6%**	**99.0%**	-	-	**65.2%**	**66.4%**	**69.2%**	**91.1%**	-	**99.7%**	**99.8%**	**98.0%**	**99.3%**	-	**99.9%**	**99.9%**	**95.2%**	**99.5%**	-	**99.7%**	**99.7%**	**97.9%**	**99.8%**	-											
Mean TWC effectiveness (pre-post)				**87.8%**	**88.2%**	**91.4%**	**99.0%**	-	-	**62.1%**	**63.3%**	**74.3%**	**90.8%**	-	**99.7%**	**99.8%**	**98.2%**	**99.4%**	-	**99.9%**	**99.9%**	**97.3%**	**99.6%**	-	**99.7%**	**99.7%**	**98.1%**	**99.9%**	-											
Max. TWC effectiveness (pre-post)				**88.4%**	**88.9%**	**92.4%**	**99.1%**	-	-	**64.3%**	**65.7%**	**78.1%**	**91.6%**	-	**99.8%**	**99.8%**	**98.5%**	**99.5%**	-	**99.9%**	**99.9%**	**98.9%**	**99.7%**	-	**99.7%**	**99.7%**	**98.8%**	**99.9%**	-											
Min. TWC effectiveness (pre-post)				**87.0%**	**87.3%**	**89.8%**	**98.9%**	-	-	**60.0%**	**60.9%**	**70.6%**	**89.7%**	-	**99.7%**	**99.8%**	**97.9%**	**99.3%**	-	**99.8%**	**99.8%**	**95.0%**	**99.3%**	-	**99.7%**	**99.7%**	**97.7%**	**99.8%**	-											

Table 12 Emissions and fuel consumption results from the Fiat Tipo 1.4 vehicle over the WLTC cycle for TWC Low S at 250 cycles

BOSMAL
BOSMAL Automotive Research and Development Institute Ltd
Exhaust Emissions Testing Laboratory

WLTP test (Reg 2017/1151) - WLTC driving cycle

VIN: ZFA35600006K20252 **Vehicle model:** **Fiat Tipo 1.4 LPG** **Emission standard: Euro 6**

Tyres: Continental ContiEcoContact 5 225/45 R17 V XL

Inertia [kg]:	1509			Emission WLTC						Emission LOW					Emission MIDDLE					Emission HIGH					Emission Ex-HIGH					CO_2 emission					Fuel consumption					Note 1
				[mg/km]						[mg/km]					[mg/km]					[mg/km]					[mg/km]					[g/km]					[l/100 km] (2)					
Mileage[km]	Date	Chassis dyno F0/F1/F2	Test No.	THC	NMHC	CO	NOx	PM	PN	THC	NMHC	CO	NOx	PN	THC	NMHC	CO	NOx	PN	THC	NMHC	CO	NOx	PN	THC	NMHC	CO	NOx	PN	WLTC	LOW	MIDDLE	HIGH	Ex-HIGH	WLTC	LOW	MIDDLE	HIGH	Ex-HIGH	
Ageing stage: 250 cycles				**BAG - MODAL DIL - PRE - POST**																																				
5 188	21.03.2019	45.1 -0.87 0.0390	L1-0160	55	50	618	23	0.75	5.05E+11	402	365	3861	131	3.57E+12	2	1	203	10	3.77E+10	1	1	175	6	2.24E+10	2	2	24	6	4.64E+10	149.4	218.1	146.0	128.0	144.3	9.26	13.86	9.00	7.89	8.88	Bags
				58	*52*	*618*	*23*	-	-	*421*	*383*	*3855*	*128*	-	*4*	*2*	*205*	*10*	-	*2*	*1*	*177*	*6*	-	*3*	*2*	*25*	*6*	-	*150.3*	*218.7*	*146.7*	*128.5*	*145.7*	*9.32*	*13.90*	*9.04*	*7.92*	*8.96*	*Modal Dil*
				586	*558*	*7499*	*2344*	-	-	*1337*	*1264*	*15859*	*1313*	-	*651*	*624*	*9409*	*1671*	-	*469*	*449*	*6204*	*2063*	-	*367*	*350*	*4387*	*3363*	-	*139.0*	*202.9*	*131.8*	*116.9*	*138.3*	*9.38*	*14.26*	*9.14*	*7.88*	*9.00*	*Modal PRE cat*
				70	*64*	*687*	*25*	-	-	*519*	*471*	*4348*	*152*	-	*2*	*1*	*218*	*7*	-	*1*	*1*	*178*	*5*	-	*2*	*2*	*27*	*4*	-	*153.3*	*223.3*	*149.6*	*131.1*	*148.6*	*9.51*	*14.25*	*9.22*	*8.08*	*9.14*	*Modal TP*
TWC effectiveness (pre-bag)				**90.6%**	**91.1%**	**91.8%**	**99.0%**	-	-	**69.9%**	**71.1%**	**75.7%**	**90.0%**	-	**99.7%**	**99.8%**	**97.8%**	**99.4%**	-	**99.8%**	**99.8%**	**97.2%**	**99.7%**	-	**99.4%**	**99.5%**	**99.5%**	**99.8%**	-											*TWC eff*
TWC effectiveness (pre-post)				**88.0%**	**88.6%**	**90.8%**	**98.9%**	-	-	**61.2%**	**62.7%**	**72.6%**	**88.4%**	-	**99.7%**	**99.8%**	**97.7%**	**99.6%**	-	**99.9%**	**99.8%**	**97.1%**	**99.8%**	-	**99.4%**	**99.5%**	**99.4%**	**99.9%**	-											*TWC eff*
5 259	23.03.2019	45.1 -0.87 0.0390	L1-0164	66	60	679	21	0.54	5.13E+11	479	438	4594	98	3.64E+12	3	2	199	9	2.50E+10	2	2	61	10	8.17E+09	3	2	24	9	6.08E+10	146.5	214.4	142.8	125.1	141.6	9.08	13.72	8.80	7.70	8.71	Bags
				68	*61*	*680*	*20*	-	-	*496*	*453*	*4593*	*93*	-	*3*	*1*	*201*	*9*	-	*1*	*1*	*63*	*9*	-	*2*	*2*	*24*	*8*	-	*147.3*	*215.3*	*143.0*	*125.7*	*142.9*	*9.13*	*13.77*	*8.82*	*7.74*	*8.79*	*Modal Dil*
				604	*575*	*7530*	*2286*	-	-	*1483*	*1401*	*18221*	*1190*	-	*659*	*631*	*9143*	*1624*	-	*460*	*441*	*5643*	*2075*	-	*368*	*351*	*4229*	*3261*	-	*135.4*	*198.1*	*127.5*	*114.0*	*135.0*	*9.17*	*14.22*	*8.85*	*7.64*	*8.78*	*Modal PRE cat*
				86	*78*	*782*	*20*	-	-	*635*	*582*	*5345*	*106*	-	*2*	*1*	*201*	*7*	-	*1*	*1*	*65*	*7*	-	*2*	*1*	*28*	*7*	-	*150.2*	*220.0*	*145.8*	*128.2*	*145.7*	*9.33*	*14.17*	*8.99*	*7.89*	*8.96*	*Modal TP*
TWC effectiveness (pre-bag)				**89.1%**	**89.6%**	**91.0%**	**99.1%**	-	-	**67.7%**	**68.7%**	**74.8%**	**91.8%**	-	**99.5%**	**99.7%**	**97.8%**	**99.4%**	-	**99.6%**	**99.6%**	**98.9%**	**99.5%**	-	**99.3%**	**99.3%**	**99.4%**	**99.7%**	-											*TWC eff*
TWC effectiveness (pre-post)				**85.8%**	**86.4%**	**89.6%**	**99.1%**	-	-	**57.2%**	**58.5%**	**70.7%**	**91.1%**	-	**99.7%**	**99.8%**	**97.8%**	**99.6%**	-	**99.8%**	**99.9%**	**98.8%**	**99.7%**	-	**99.5%**	**99.6%**	**99.3%**	**99.8%**	-											*TWC eff*
5 326	2019-03-29	45.1 -0.87 0.0390	L1-0178	58	53	720	25	0.48	5.54E+11	429	390	4662	141	3.90E+12	2	1	260	6	5.58E+10	1	1	113	6	2.14E+10	2	1	43	10	5.68E+10	148.0	217.7	145.1	126.0	142.8	9.18	13.92	8.95	7.76	8.79	Bags
				61	*55*	*721*	*23*	-	-	*447*	*406*	*4667*	*127*	-	*3*	*2*	*261*	*6*	-	*1*	*1*	*114*	*6*	-	*2*	*1*	*44*	*9*	-	*136.7*	*202.7*	*130.8*	*114.2*	*134.9*	*9.26*	*14.39*	*9.11*	*7.70*	*8.80*	*Modal Dil*
				594	*565*	*7755*	*2283*	-	-	*1417*	*1341*	*17166*	*1261*	-	*615*	*587*	*9788*	*1625*	-	*463*	*443*	*6128*	*2034*	-	*387*	*370*	*4486*	*3262*	-	*151.7*	*223.4*	*148.4*	*128.8*	*146.9*	*9.43*	*14.38*	*9.15*	*7.93*	*9.04*	*Modal PRE cat*
				76	*69*	*835*	*26*	-	-	*564*	*513*	*5540*	*150*	-	*2*	*1*	*273*	*5*	-	*1*	*1*	*98*	*4*	-	*1*	*1*	*44*	*10*	-	*148.8*	*218.7*	*145.7*	*126.3*	*144.1*	*9.23*	*13.98*	*8.98*	*7.78*	*8.87*	*Modal TP*
TWC effectiveness (pre-bag)				**90.2%**	**90.7%**	**90.7%**	**98.9%**	-	-	**69.7%**	**70.9%**	**72.8%**	**88.9%**	-	**99.6%**	**99.8%**	**97.3%**	**99.6%**	-	**99.8%**	**99.9%**	**98.2%**	**99.7%**	-	**99.6%**	**99.6%**	**99.1%**	**99.7%**	-											*TWC eff*
TWC effectiveness (pre-post)				**87.2%**	**87.8%**	**89.2%**	**98.9%**	-	-	**60.2%**	**61.7%**	**67.7%**	**88.1%**	-	**99.7%**	**99.8%**	**97.2%**	**99.7%**	-	**99.9%**	**99.9%**	**98.4%**	**99.8%**	-	**99.6%**	**99.6%**	**99.0%**	**99.7%**	-											*TWC eff*
Mean values				60	54	672	23	0.59	5.24E+11	437	398	4372	123	3.70E+12	3	2	220	8	3.95E+10	1	1	116	7	1.73E+10	2	2	30	8	5.46E+10	148.0	216.7	144.7	126.4	142.9	9.18	13.83	8.92	7.78	8.79	Bags
				62	*56*	*673*	*22*	-	-	*455*	*414*	*4372*	*116*	-	*3*	*2*	*223*	*8*	-	*2*	*1*	*118*	*7*	-	*2*	*2*	*31*	*8*	-	*144.7*	*212.2*	*140.2*	*122.8*	*141.2*	*9.24*	*14.02*	*8.99*	*7.79*	*8.85*	*Modal Dil*
				594	*566*	*7594*	*2305*	-	-	*1412*	*1335*	*17082*	*1255*	-	*642*	*614*	*9447*	*1640*	-	*464*	*444*	*5991*	*2057*	-	*374*	*357*	*4367*	*3295*	-	*142.0*	*208.2*	*135.9*	*119.9*	*140.1*	*9.32*	*14.29*	*9.05*	*7.82*	*8.94*	*Modal PRE cat*
				77	*70*	*768*	*23*	-	-	*573*	*522*	*5078*	*136*	-	*2*	*1*	*230*	*6*	-	*1*	*1*	*113*	*5*	-	*2*	*2*	*33*	*7*	-	*150.8*	*220.7*	*147.0*	*128.5*	*146.1*	*9.36*	*14.13*	*9.06*	*7.92*	*8.99*	*Modal TP*
Standard deviation				4.6	4.4	42.0	1.7	0.11	2.11E+10	32.0	30.3	362.6	18.3	1.42E+11	0.5	0.4	27.8	1.6	1.26E+10	0.5	0.4	46.8	1.8	6.47E+09	0.4	0.4	8.8	1.6	6.07E+09	1.22	1.66	1.36	1.22	1.09	0.07	0.08	0.08	0.08	0.07	Bags
				4.1	*3.8*	*42.4*	*1.3*	-	-	*30.9*	*29.1*	*366.3*	*16.2*	-	*0.1*	*0.2*	*27.4*	*1.5*	-	*0.1*	*0.2*	*46.8*	*1.7*	-	*0.3*	*0.2*	*8.9*	*1.4*	-	*5.86*	*6.90*	*6.79*	*6.21*	*4.55*	*0.08*	*0.26*	*0.12*	*0.10*	*0.08*	*Modal Dil*
				7.6	*7.2*	*114.2*	*28.0*	-	-	*59.5*	*56.2*	*965.9*	*50.2*	-	*19.1*	*19.2*	*264.5*	*21.9*	-	*3.8*	*3.5*	*248.5*	*17.3*	-	*9.3*	*9.3*	*105.9*	*47.8*	-	*7.02*	*10.97*	*9.02*	*6.40*	*5.04*	*0.11*	*0.07*	*0.14*	*0.13*	*0.11*	*Modal PRE cat*
				6.4	*6.0*	*61.0*	*2.5*	-	-	*48.0*	*45.6*	*521.9*	*21.2*	-	*0.1*	*0.1*	*30.6*	*1.1*	-	*0.1*	*0.1*	*47.3*	*1.1*	-	*0.3*	*0.2*	*7.8*	*2.2*	-	*1.90*	*1.95*	*1.81*	*1.95*	*1.88*	*0.12*	*0.11*	*0.11*	*0.12*	*0.11*	*Modal TP*
Type A uncertainty				2.7	2.5	24.3	1.0	0.07	1.22E+10	18.5	17.5	209.3	10.6	8.18E+10	0.3	0.2	16.0	0.9	7.28E+09	0.3	0.2	27.0	1.1	3.74E+09	0.2	0.2	5.1	0.9	3.51E+09	0.70	0.96	0.79	0.70	0.63	0.04	0.05	0.05	0.05	0.04	Bags
				2.3	*2.2*	*24.5*	*0.8*	-	-	*17.8*	*16.8*	*211.5*	*9.3*	-	*0.1*	*0.1*	*15.8*	*0.9*	-	*0.1*	*0.1*	*27.0*	*1.0*	-	*0.2*	*0.1*	*5.1*	*0.8*	-	*3.38*	*3.99*	*3.92*	*3.58*	*2.63*	*0.04*	*0.15*	*0.07*	*0.06*	*0.05*	*Modal Dil*
				4.4	*4.2*	*65.9*	*16.1*	-	-	*34.3*	*32.4*	*557.7*	*29.0*	-	*11.0*	*11.1*	*152.7*	*12.6*	-	*2.2*	*2.0*	*143.5*	*10.0*	-	*5.4*	*5.4*	*61.2*	*27.6*	-	*4.06*	*6.33*	*5.21*	*3.70*	*2.91*	*0.07*	*0.04*	*0.08*	*0.07*	*0.07*	*Modal PRE cat*
				3.7	*3.5*	*35.2*	*1.4*	-	-	*27.7*	*26.3*	*301.3*	*12.2*	-	*0.1*	*0.1*	*17.7*	*0.7*	-	*0.1*	*0.0*	*27.3*	*0.6*	-	*0.1*	*0.1*	*4.5*	*1.3*	-	*1.10*	*1.13*	*1.04*	*1.13*	*1.08*	*0.07*	*0.06*	*0.06*	*0.07*	*0.07*	*Modal TP*
Mean TWC effectiveness (pre-bag)				**90.0%**	**90.5%**	**91.2%**	**99.0%**	-	-	**69.1%**	**70.3%**	**74.4%**	**90.2%**	-	**99.6%**	**99.7%**	**97.7%**	**99.5%**	-	**99.7%**	**99.8%**	**98.1%**	**99.6%**	-	**99.4%**	**99.5%**	**99.3%**	**99.8%**	-											
Max. TWC effectiveness (pre-bag)				**90.6%**	**91.1%**	**91.8%**	**99.1%**	-	-	**69.9%**	**71.1%**	**75.7%**	**91.8%**	-	**99.7%**	**99.8%**	**97.8%**	**99.6%**	-	**99.8%**	**99.9%**	**98.9%**	**99.7%**	-	**99.6%**	**99.6%**	**99.5%**	**99.8%**	-											
Min. TWC effectiveness (pre-bag)				**89.1%**	**89.6%**	**90.7%**	**98.9%**	-	-	**67.7%**	**68.7%**	**72.8%**	**88.9%**	-	**99.5%**	**99.7%**	**97.3%**	**99.4%**	-	**99.6%**	**99.6%**	**97.2%**	**99.5%**	-	**99.3%**	**99.3%**	**99.1%**	**99.7%**	-											
Mean TWC effectiveness (pre-post)				**87.0%**	**87.6%**	**89.9%**	**99.0%**	-	-	**59.5%**	**61.0%**	**70.3%**	**89.2%**	-	**99.7%**	**99.8%**	**97.6%**	**99.6%**	-	**99.9%**	**99.8%**	**98.1%**	**99.7%**	-	**99.5%**	**99.6%**	**99.2%**	**99.8%**	-											
Max. TWC effectiveness (pre-post)				**88.0%**	**88.6%**	**90.8%**	**99.1%**	-	-	**61.2%**	**62.7%**	**72.6%**	**91.1%**	-	**99.7%**	**99.8%**	**97.8%**	**99.7%**	-	**99.9%**	**99.9%**	**98.8%**	**99.8%**	-	**99.6%**	**99.6%**	**99.4%**	**99.9%**	-											
Min. TWC effectiveness (pre-post)				**85.8%**	**86.4%**	**89.2%**	**98.9%**	-	-	**57.2%**	**58.5%**	**67.7%**	**88.1%**	-	**99.7%**	**99.8%**	**97.2%**	**99.6%**	-	**99.8%**	**99.8%**	**97.1%**	**99.7%**	-	**99.4%**	**99.5%**	**99.0%**	**99.7%**	-											

Table 13 Emissions and fuel consumption results from the Fiat Tipo 1.4 vehicle over the constant speed cycle for TWC Low S

BOSMAL Automotive Research and Development Institute Ltd

Exhaust Emissions Testing Laboratory

Project custom test cycle - Constant speed (VConst)
thermally stabilised driving - 80 km/h in 5th gear

VIN: ZFA35600006K20252 **Vehicle model:** **Fiat Tipo 1.4 LPG**

Tyres: Continental ContiEcoContact 5 225/45 R17 V XL

Inertia [kg]:	1509			Phase 1 - 80 km/h in 5th gear (hot stabilised)						Phase 2 - 80 km/h in 5th gear (hot stabilised)						CO$_2$ emission		Fuel consumption		Note 1
Mileage [km]	Date	Chassis dyno F0/F1/F2	Test No.	[mg/km]						[mg/km]						[g/km]		[l/100 km] $^{(2)}$		
				THC	NMHC	CO	NOx	PM	PN	THC	NMHC	CO	NOx	PM	PN	P1	P2	P1	P2	
Ageing stage: 0 cycles				**BAG - MODAL DIL - PRE - POST**																
4 264	23.10.2018	45.1 -0.87 0.0390	L1-0471	0	0	21	0	0.06	3.88E+08	0	0	27	0	0.14	3.63E+08	103.7	100.5	6.38	6.18	Bags
				0	*0*	*21*	*0*	-	-	*0*	*0*	*27*	*0*	-	-	*103.9*	*100.6*	*6.39*	*6.19*	*Modal Dil*
				304	*289*	*3002*	*2240*	-	-	*293*	*278*	*2963*	*2142*	-	-	*100.3*	*97.1*	*6.52*	*6.31*	*Modal PRE cat*
				0	*0*	*21*	*0*	-	-	*0*	*0*	*27*	*0*	-	-	*105.9*	*102.6*	*6.52*	*6.31*	*Modal TP*
TWC effectiveness per phase				**99.84%**	**99.88%**	**99.31%**	**99.99%**	-	-	**99.86%**	**99.91%**	**99.08%**	**100.00%**	-	-					
Mean TWC effectiveness (mean of both phases)				**99.85%**	**99.89%**	**99.19%**	**99.99%**	-	-	-	-	-	-	-	-					
Max. TWC effectiveness (max. of both phases)				**99.86%**	**99.91%**	**99.31%**	**100.00%**	-	-	-	-	-	-	-	-					
Min. TWC effectiveness (min. of both phases)				**99.84%**	**99.88%**	**99.08%**	**99.99%**	-	-	-	-	-	-	-	-					
Ageing stage: 250 cycles				**BAG - MODAL DIL - PRE - POST**																
5 131	19.03.2019	45.1 -0.87 0.0390	L1-0156	0	0	23	0	0.00	1.68E+08	0	0	21	0	0.02	2.51E+08	102.4	101.7	6.30	6.26	Bags
				1	*0*	*23*	*0*	-	-	*1*	*0*	*21*	*0*	-	-	*98.7*	*98.2*	*6.31*	*6.27*	*Modal Dil*
				272	*259*	*3006*	*2167*	-	-	*275*	*261*	*3001*	*2150*	-	-	*104.6*	*103.9*	*6.41*	*6.38*	*Modal PRE cat*
				0	*0*	*26*	*0*	-	-	*0*	*0*	*24*	*0*	-	-	*102.6*	*101.9*	*6.44*	*6.39*	*Modal TP*
TWC effectiveness per phase				**100.00%**	**99.96%**	**99.13%**	**100.00%**	-	-	**100.00%**	**99.98%**	**99.19%**	**100.00%**	-	-					
Mean TWC effectiveness (mean of both phases)				**100.00%**	**99.97%**	**99.16%**	**100.00%**	-	-	-	-	-	-	-	-					
Max. TWC effectiveness (max. of both phases)				**100.00%**	**99.98%**	**99.19%**	**100.00%**	-	-	-	-	-	-	-	-					
Min. TWC effectiveness (min. of both phases)				**100.00%**	**99.96%**	**99.13%**	**100.00%**	-	-	-	-	-	-	-	-					

Table 14 Emissions and fuel consumption results from the Fiat Tipo 1.4 vehicle over the NEDC cycle for TWC High S

BOSMAL
BOSMAL Automotive R&D Institute Ltd
EXHAUST EMISSIONS LABORAOTRY

NEDC test (UNECE R83) - NEDC driving cycle

VIN: ZFA35600006K20252
Model: **Vehicle model: Fiat Tipo 1.4 LPG**
Emission standard: Euro 6
Tyres: Continental ContiEcoContact 5 225/45 R17 V XL

Inertia [kg] 1360				Emissions in the NEDC test										Emissions in the UDC phase					Emissions in the EUDC phase					CO$_2$ emissions			Fuel consumption			Note 1
				Emissions values with DFs (*)				Emissions measured						Emissions measured					Emissions measured					[g/km]			[l/100 km] (**)			
Mileage [km]	Date	Chassis dyno F0/F1/F2	Test No.	THC	NMHC	CO	NOx	THC	NMHC	CO	NOx	PM	PN	THC	NMHC	CO	NOx	PN	THC	NMHC	CO	NOx	PN	NEDC	UDC	EUDC	NEDC	UDC	EUDC	
				[mg/km]				[mg/km]						[mg/km]					[mg/km]											
Ageing stage: 0 cycles				BAG - MODAL DIL - PRE - POST																										
4 061	27.09.2018	21.0	L1-0435	73	66	846	15	56	51	564	10	0.54	4.32E+11	151	137	1449	22	1.14E+12	0	0	46	2	1.57E+10	161.4	223.1	125.3	9.99	13.89	7.71	Bags
		-1.13						57	52	559	9	-	-	155	140	1433	22	-	0	0	48	2	-	161.9	223.0	126.1	10.02	13.88	7.76	Modal Dil
		0.0401						702	667	7054	2376	-	-	1149	1087	11534	1875	-	441	421	4434	2669	-	153.4	210.4	120.1	10.25	14.27	7.90	Modal PRE cat
								70	63	601	11	-	-	188	169	1528	26	-	0	0	59	2	-	165.1	227.4	128.7	10.22	14.17	7.92	Modal TP
				TWC effectiveness (pre-bag)				92.1%	92.4%	92.0%	99.6%	-	-	86.9%	87.4%	87.4%	98.8%	-	99.9%	99.9%	99.0%	99.9%	-							TWC eff
				TWC effectiveness (pre-post)				90.1%	90.6%	91.5%	99.5%	-	-	83.6%	84.4%	86.8%	98.6%	-	99.9%	99.9%	98.7%	99.9%	-							TWC eff
4 083	03.10.2018	21.0	L1-0437	63	57	634	14	48	44	423	9	0.67	4.34E+11	131	119	1059	18	1.13E+12	0	0	50	3	2.41E+10	161.9	221.9	126.8	10.01	13.77	7.80	Bags
		-1.13						49	45	423	8	-	-	134	122	1056	18	-	0	0	52	3	-	162.4	222.3	127.4	10.04	13.80	7.84	Modal Dil
		0.0401						675	641	7330	2354	-	-	1065	1009	12085	1865	-	446	426	4547	2640	-	153.2	208.4	120.9	10.25	14.18	7.96	Modal PRE cat
								58	53	449	10	-	-	156	142	1110	22	-	0	0	62	3	-	165.6	226.6	129.9	10.24	14.07	8.00	Modal TP
				TWC effectiveness (pre-bag)				92.8%	93.1%	94.2%	99.6%	-	-	87.7%	88.2%	91.2%	99.0%	-	100.0%	100.0%	98.9%	99.9%	-							TWC eff
				TWC effectiveness (pre-post)				91.4%	91.8%	93.9%	99.6%	-	-	85.3%	86.0%	90.8%	98.8%	-	100.0%	99.9%	98.6%	99.9%	-							TWC eff
4 209	16.10.2018	21.0	L1-0450	61	56	522	15	47	43	348	10	0.29	2.93E+11	128	117	858	20	7.67E+11	0	0	52	4	1.95E+10	160.5	223.0	124.3	9.91	13.82	7.65	Bags
		-1.13						48	44	347	10	-	-	129	118	854	20	-	0	0	54	4	-	161.0	223.3	125.0	9.95	13.84	7.70	Modal Dil
		0.0401						648	617	7044	2309	-	-	1058	1005	11622	1767	-	411	393	4396	2623	-	151.9	208.8	119.0	10.14	14.16	7.82	Modal PRE cat
								52	48	353	11	-	-	143	130	854	23	-	0	0	63	4	-	164.1	227.5	127.5	10.14	14.10	7.85	Modal TP
				TWC effectiveness (pre-bag)				92.7%	93.0%	95.1%	99.6%	-	-	87.9%	88.4%	92.6%	98.9%	-	99.9%	99.9%	98.8%	99.9%	-							TWC eff
				TWC effectiveness (pre-post)				91.9%	92.3%	95.0%	99.5%	-	-	86.5%	87.1%	92.7%	98.7%	-	100.0%	99.9%	98.6%	99.9%	-							TWC eff
				Mean values				50	46	445	9	0.50	3.87E+11	136	124	1122	20	1.02E+12	0	0	50	3	1.97E+10	161.3	222.7	125.5	9.97	13.83	7.72	Bags
								52	47	443	9	-	-	139	127	1114	20	-	0	0	51	3	-	161.8	222.9	126.2	10.00	13.84	7.76	Modal Dil
								675	642	7143	2346	-	-	1091	1034	11747	1835	-	433	413	4459	2644	-	152.8	209.2	120.0	10.22	14.20	7.89	Modal PRE cat
								60	54	468	11	-	-	162	147	1164	23	-	0	0	61	3	-	164.9	227.2	128.7	10.20	14.11	7.92	Modal TP
				Standard deviation				3.9	3.4	89.7	0.5	0.16	6.59E+10	10.2	8.9	245.2	1.6	1.76E+11	0.1	0.1	2.5	0.5	3.43E+09	0.58	0.55	1.01	0.04	0.05	0.06	Bags
								4.2	3.6	87.8	0.5	-	-	11.2	9.7	240.0	1.6	-	0.1	0.1	2.4	0.5	-	0.57	0.39	0.95	0.04	0.03	0.06	Modal Dil
								22.2	20.2	132.6	27.8	-	-	41.3	37.5	241.7	48.7	-	15.5	14.5	64.1	19.0	-	0.66	0.86	0.76	0.05	0.05	0.06	Modal PRE cat
								7.2	6.3	102.2	0.5	-	-	19.2	16.7	277.9	1.5	-	0.0	0.0	1.9	0.6	-	0.62	0.37	0.99	0.04	0.04	0.06	Modal TP
				Type A uncertainty				2.2	2.0	51.8	0.3	0.09	3.80E+10	5.9	5.1	141.6	0.9	1.01E+11	0.1	0.1	1.5	0.3	1.98E+09	0.34	0.32	0.58	0.02	0.03	0.04	Bags
								2.5	2.1	50.7	0.3	-	-	6.5	5.6	138.5	0.9	-	0.1	0.1	1.4	0.3	-	0.33	0.23	0.55	0.02	0.02	0.03	Modal Dil
								12.8	11.7	76.5	16.0	-	-	23.9	21.7	139.5	28.1	-	8.9	8.4	37.0	11.0	-	0.38	0.49	0.44	0.03	0.03	0.03	Modal PRE cat
								4.2	3.6	59.0	0.3	-	-	11.1	9.6	160.5	0.9	-	0.0	0.0	1.1	0.3	-	0.36	0.22	0.57	0.03	0.02	0.03	Modal TP
				Mean TWC effectiveness (pre-bag)				92.6%	92.9%	93.8%	99.6%	-	-	87.5%	88.0%	90.4%	98.9%	-	99.9%	99.9%	98.9%	99.9%	-							
				Max. TWC effectiveness (pre-bag)				92.8%	93.1%	95.1%	99.6%	-	-	87.9%	88.4%	92.6%	99.0%	-	100.0%	100.0%	99.0%	99.9%	-							
				Min. TWC effectiveness (pre-bag)				92.1%	92.4%	92.0%	99.6%	-	-	86.9%	87.4%	87.4%	98.8%	-	99.9%	99.9%	98.8%	99.9%	-							
				Mean TWC effectiveness (pre-post)				91.1%	91.6%	93.4%	99.6%	-	-	85.1%	85.8%	90.1%	98.7%	-	100.0%	99.9%	98.6%	99.9%	-							
				Max. TWC effectiveness (pre-post)				91.9%	92.3%	95.0%	99.6%	-	-	86.5%	87.1%	92.7%	98.8%	-	100.0%	99.9%	98.7%	99.9%	-							
				Min. TWC effectiveness (pre-post)				90.1%	90.6%	91.5%	99.5%	-	-	83.6%	84.4%	86.8%	98.6%	-	99.9%	99.9%	98.6%	99.9%	-							
Ageing stage: 250 cycles				BAG - MODAL DIL - PRE - POST																										
5 865	03.01.2020	21.0	L1-0002					47	43	400	18	0.27	2.13E+11	127	115	1029	44	5.76E+11	1	1	34	2	2.00E+09	159.6	220.3	124.2	9.86	13.67	7.64	Bags
		-1.13						49	44	398	18	-	-	130	117	1022	43	-	1	1	35	2	-	160.3	221.6	124.7	9.91	13.75	7.67	Modal Dil
		0.0401						529	501	6813	2360	-	-	819	773	10789	1902	-	359	342	4498	2627	-	153.1	206.7	121.9	10.17	13.91	8.00	Modal PRE cat
								49	44	334	19	-	-	133	119	841	46	-	0	0	38	3	-	163.6	221.2	130.1	10.10	13.71	8.00	Modal TP
				TWC effectiveness (pre-bag)				91.1%	91.5%	94.1%	99.3%	-	-	84.5%	85.2%	90.5%	97.7%	-	99.8%	99.8%	99.3%	99.9%	-							TWC eff
				TWC effectiveness (pre-post)				90.7%	91.2%	95.1%	99.2%	-	-	83.7%	84.6%	92.2%	97.6%	-	99.9%	99.9%	99.1%	99.9%	-							TWC eff
5 877	05.01.2020	21.0	L1-0003					62	55	642	16	0.13	3.32E+11	165	148	1672	39	8.94E+11	1	1	38	2	2.83E+09	155.5	213.6	121.4	9.64	13.33	7.47	Bags
		-1.13						63	56	649	16	-	-	169	152	1688	40	-	1	1	40	2	-	156.2	214.5	121.9	9.68	13.39	7.50	Modal Dil
		0.0401						566	570	7270	2232	-	-	906	911	11927	1775	-	367	370	4541	2500	-	148.0	197.6	119.0	9.91	13.47	7.82	Modal PRE cat
								66	59	609	17	-	-	177	159	1573	42	-	0	0	43	2	-	158.7	212.5	127.2	9.83	13.25	7.83	Modal TP
				TWC effectiveness (pre-bag)				89.1%	90.3%	91.2%	99.3%	-	-	81.8%	83.7%	86.0%	97.8%	-	99.8%	99.8%	99.2%	99.9%	-							TWC eff
				TWC effectiveness (pre-post)				88.4%	89.7%	91.6%	99.2%	-	-	80.5%	82.6%	86.8%	97.6%	-	99.9%	99.9%	99.0%	99.9%	-							TWC eff
5 888	07.01.2020	21.0	L1-0004					87	80	629	16	0.55	3.92E+11	233	215	1629	39	1.05E+12	1	1	41	2	4.20E+09	157.6	218.1	122.1	9.77	13.61	7.51	Bags
		-1.13						89	83	637	15	-	-	240	222	1650	38	-	1	1	42	2	-	158.5	219.4	122.8	9.83	13.70	7.55	Modal Dil
		0.0401						620	590	7520	2144	-	-	1038	985	12821	1658	-	374	358	4410	2430	-	147.2	202.7	114.6	9.90	13.90	7.55	Modal PRE cat
								73	66	586	12	-	-	198	178	1503	29	-	0	0	48	2	-	161.7	223.8	125.3	10.01	13.95	7.71	Modal TP
				TWC effectiveness (pre-bag)				86.0%	86.4%	91.6%	99.3%	-	-	77.6%	78.1%	87.3%	97.6%	-	99.8%	99.8%	99.1%	99.9%	-							TWC eff
				TWC effectiveness (pre-post)				88.2%	88.8%	92.2%	99.4%	-	-	81.0%	82.0%	88.3%	98.3%	-	99.9%	99.9%	98.9%	99.9%	-							TWC eff
				Mean values				65	59	557	16	0.32	3.13E+11	175	160	1444	41	8.41E+11	1	1	38	2	3.01E+09	157.5	217.3	122.6	9.76	13.54	7.54	Bags
								67	61	561	16	-	-	179	163	1453	41	-	1	1	39	2	-	158.3	218.5	123.1	9.80	13.61	7.58	Modal Dil
								572	553	7201	2245	-	-	921	890	11845	1778	-	367	356	4483	2519	-	149.5	202.3	118.5	9.99	13.76	7.79	Modal PRE cat
								63	56	509	16	-	-	169	152	1306	39	-	0	0	43	2	-	161.4	219.2	127.5	9.98	13.64	7.85	Modal TP
				Standard deviation				16.2	15.6	111.1	0.9	0.17	7.43E+10	43.7	41.8	293.5	2.2	1.98E+11	0.0	0.1	3.2	0.1	9.09E+08	1.66	2.79	1.18	0.09	0.15	0.07	Bags
								16.9	16.2	115.4	0.9	-	-	45.5	43.6	305.3	2.1	-	0.0	0.1	3.0	0.2	-	1.71	2.95	1.15	0.10	0.16	0.07	Modal Dil
								37.4	38.1	292.8	88.4	-	-	90.0	87.7	831.5	99.7	-	6.1	11.4	54.7	81.3	-	2.61	3.73	2.99	0.13	0.20	0.19	Modal PRE cat
								10.0	9.1	124.7	2.7	-	-	26.8	24.4	330.1	7.4	-	0.0	0.1	3.8	0.1	-	2.01	4.85	1.98	0.11	0.29	0.12	Modal TP
				Type A uncertainty				9.4	9.0	64.1	0.5	0.10	4.29E+10	25.2	24.2	169.5	1.3	1.15E+11	0.0	0.0	1.8	0.1	5.25E+08	0.96	1.61	0.68	0.05	0.09	0.04	Bags
								9.8	9.4	66.6	0.5	-	-	26.3	25.2	176.3	1.2	-	0.0	0.0	1.7	0.1	-	0.99	1.70	0.66	0.06	0.09	0.04	Modal Dil
								21.6	22.0	169.0	51.1	-	-	52.0	50.6	480.0	57.6	-	3.5	6.6	31.6	46.9	-	1.51	2.15	1.73	0.07	0.12	0.11	Modal PRE cat
								5.8	5.3	72.0	1.6	-	-	15.5	14.1	190.6	4.3	-	0.0	0.0	2.2	0.0	-	1.16	2.80	1.14	0.07	0.17	0.07	Modal TP
				Mean TWC effectiveness (pre-bag)				88.7%	89.4%	92.3%	99.3%	-	-	81.3%	82.3%	87.9%	97.7%	-	99.8%	99.8%	99.2%	99.9%	-							
				Max. TWC effectiveness (pre-bag)				91.1%	91.5%	94.1%	99.3%	-	-	84.5%	85.2%	90.5%	97.8%	-	99.8%	99.8%	99.3%	99.9%	-							
				Min. TWC effectiveness (pre-bag)				86.0%	86.4%	91.2%	99.3%	-	-	77.6%	78.1%	86.0%	97.6%	-	99.8%	99.8%	99.1%	99.9%	-							
				Mean TWC effectiveness (pre-post)				89.1%	89.9%	93.0%	99.3%	-	-	81.7%	83.1%	89.1%	97.8%	-	99.9%	99.9%	99.0%	99.9%	-							
				Max. TWC effectiveness (pre-post)				90.7%	91.2%	95.1%	99.4%	-	-	83.7%	84.6%	92.2%	98.3%	-	99.9%	99.9%	99.1%	99.9%	-							
				Min. TWC effectiveness (pre-post)				88.2%	88.8%	91.6%	99.2%	-	-	80.5%	82.0%	86.8%	97.6%	-	99.9%	99.9%	98.9%	99.9%	-							

	THC	NMHC	CO	NOx
Euro 6 SI limits [mg/km]	100	68	1000	60

(*) - as defined in Regulation (EC) 2007/595, applied only at the 0 cycle ageing stage (for informational purposes)

Table 15 Emissions and fuel consumption results from the Fiat Tipo 1.4 vehicle over the WLTC cycle for TWC High S at 0 cycles

BOSMAL Automotive Research and Development Institute Ltd

Exhaust Emissions Testing Laboratory

WLTP test (Reg 2017/1151) - WLTC driving cycle

VIN: ZFA35600006K20252 **Vehicle model:** **Fiat Tipo 1.4 LPG** **Emission standard: Euro 6** Tyres: Continental ContiEcoContact 5 225/45 R17 V XL

Inertia [kg]:	1509			Emission WLTC						Emission LOW					Emission MIDDLE					Emission HIGH					Emission Ex-HIGH					CO_2 emission					Fuel consumption					Note 1
				[mg/km]						[mg/km]					[mg/km]					[mg/km]					[mg/km]					[g/km]					[l/100 km] (2)					
Mileage[km]	Date	Chassis dyno F0/F1/F2	Test No.	THC	NMHC	CO	NOx	PM	PN	THC	NMHC	CO	NOx	PN	THC	NMHC	CO	NOx	PN	THC	NMHC	CO	NOx	PN	THC	NMHC	CO	NOx	PN	WLTC	LOW	MIDDLE	HIGH	Ex-HIGH	WLTC	LOW	MIDDLE	HIGH	Ex-HIGH	
Ageing stage: 0 cycles				BAG - MODAL DIL - PRE - POST																																				
4 094	2018-10-04	45.1 -0.87 0.0390	L1-0438	57	53	404	26	1.21	6.17E+11	426	394	2229	36	4.19E+12	0	0	181	4	1.37E+11	0	0	128	5	2.82E+10	1	1	90	54	6.54E+10	148.6	215.7	145.1	128.7	142.7	9.19	13.56	8.94	7.93	8.78	Bags
				59	*55*	*400*	*26*	-	-	*442*	*409*	*2198*	*35*	-	*1*	*0*	*181*	*4*	-	*0*	*0*	*128*	*5*	-	*1*	*1*	*89*	*53*	-	*149.1*	*216.3*	*144.9*	*128.6*	*144.1*	*9.22*	*13.60*	*8.93*	*7.92*	*8.87*	*Modal Dil*
				717	*687*	*6992*	*2473*	-	-	*1665*	*1594*	*13826*	*1390*	-	*778*	*748*	*8354*	*1812*	-	*568*	*545*	*5706*	*2272*	-	*458*	*436*	*4769*	*3432*	-	*139.0*	*199.9*	*129.4*	*119.3*	*138.8*	*9.36*	*13.94*	*8.91*	*7.99*	*9.08*	*Modal PRE cat*
				65	*60*	*424*	*27*	-	-	*490*	*451*	*2234*	*42*	-	*0*	*0*	*190*	*5*	-	*0*	*0*	*151*	*4*	-	*0*	*1*	*120*	*54*	-	*152.1*	*220.7*	*147.8*	*131.2*	*147.0*	*9.41*	*13.88*	*9.11*	*8.08*	*9.05*	*Modal TP*
TWC effectiveness (pre-bag)				**92.1%**	**92.3%**	**94.2%**	**98.9%**	-	-	**74.4%**	**75.3%**	**83.9%**	**97.4%**	-	**100.0%**	**100.0%**	**97.8%**	**99.8%**	-	**100.0%**	**100.0%**	**97.8%**	**99.8%**	-	**99.9%**	**99.9%**	**98.1%**	**98.4%**	-											*TWC eff*
TWC effectiveness (pre-post)				**90.9%**	**91.2%**	**93.9%**	**98.9%**	-	-	**70.6%**	**71.7%**	**83.8%**	**97.0%**	-	**100.0%**	**99.9%**	**97.7%**	**99.8%**	-	**100.0%**	**100.0%**	**97.4%**	**99.8%**	-	**99.9%**	**99.9%**	**97.5%**	**98.4%**	-											*TWC eff*
4 117	2018-10-09	45.1 -0.87 0.0390	L1-0441	47	43	515	10	1.02	6.01E+11	353	323	2315	40	4.11E+12	1	0	327	3	4.27E+10	0	0	428	6	8.40E+09	1	1	25	8	1.22E+11	150.1	218.8	146.9	129.1	144.4	9.29	13.75	9.07	7.98	8.88	Bags
				50	*45*	*510*	*10*	-	-	*367*	*336*	*2303*	*36*	-	*1*	*1*	*325*	*3*	-	*1*	*1*	*420*	*6*	-	*1*	*1*	*26*	*7*	-	*150.8*	*219.2*	*146.9*	*129.3*	*146.0*	*9.33*	*13.77*	*9.06*	*7.99*	*8.98*	*Modal Dil*
				700	*669*	*7609*	*2436*	-	-	*1573*	*1499*	*15241*	*1314*	-	*759*	*726*	*9532*	*1836*	-	*584*	*560*	*6597*	*2152*	-	*442*	*421*	*4531*	*3444*	-	*139.7*	*201.4*	*130.6*	*118.2*	*140.4*	*9.46*	*14.15*	*9.10*	*8.02*	*9.16*	*Modal PRE cat*
				56	*51*	*515*	*11*	-	-	*417*	*379*	*2240*	*43*	-	*1*	*1*	*339*	*3*	-	*0*	*0*	*441*	*5*	-	*0*	*1*	*35*	*9*	-	*153.8*	*223.6*	*149.7*	*131.9*	*148.9*	*9.52*	*14.04*	*9.24*	*8.15*	*9.16*	*Modal TP*
TWC effectiveness (pre-bag)				**93.2%**	**93.5%**	**93.2%**	**99.6%**	-	-	**77.5%**	**78.5%**	**84.8%**	**97.0%**	-	**99.9%**	**99.9%**	**96.6%**	**99.9%**	-	**99.9%**	**99.9%**	**93.5%**	**99.7%**	-	**99.9%**	**99.8%**	**99.4%**	**99.8%**	-											*TWC eff*
TWC effectiveness (pre-post)				**92.0%**	**92.4%**	**93.2%**	**99.6%**	-	-	**73.5%**	**74.7%**	**85.3%**	**96.7%**	-	**99.9%**	**99.9%**	**96.4%**	**99.9%**	-	**100.0%**	**99.9%**	**93.3%**	**99.8%**	-	**99.9%**	**99.8%**	**99.2%**	**99.7%**	-											*TWC eff*
4 131	2018-10-18	45.1 -0.87 0.0390	L1-0458	43	39	392	11	0.68	5.32E+11	317	289	2284	49	3.65E+12	1	0	189	10	5.47E+10	0	0	109	4	1.51E+10	1	1	46	3	8.98E+10	151.7	222.6	147.3	130.5	146.3	9.38	13.97	9.07	8.04	9.00	Bags
				44	*40*	*393*	*10*	-	-	*330*	*300*	*2287*	*46*	-	*1*	*1*	*191*	*10*	-	*1*	*0*	*111*	*4*	-	*1*	*0*	*46*	*3*	-	*152.5*	*224.1*	*147.2*	*130.9*	*147.6*	*9.43*	*14.07*	*9.07*	*8.06*	*9.08*	*Modal Dil*
				592	*563*	*6830*	*2534*	-	-	*1318*	*1249*	*13600*	*1457*	-	*613*	*585*	*7620*	*1911*	-	*468*	*446*	*5676*	*2317*	-	*417*	*396*	*4848*	*3483*	-	*144.2*	*211.1*	*135.0*	*122.7*	*143.0*	*9.64*	*14.54*	*9.15*	*8.18*	*9.34*	*Modal PRE cat*
				49	*45*	*400*	*11*	-	-	*371*	*336*	*2285*	*52*	-	*0*	*0*	*206*	*10*	-	*0*	*0*	*112*	*4*	-	*0*	*0*	*57*	*4*	-	*155.5*	*228.5*	*150.0*	*133.4*	*150.6*	*9.61*	*14.34*	*9.24*	*8.22*	*9.27*	*Modal TP*
TWC effectiveness (pre-bag)				**92.8%**	**93.1%**	**94.3%**	**99.6%**	-	-	**75.9%**	**76.9%**	**83.2%**	**96.6%**	-	**99.9%**	**99.9%**	**97.5%**	**99.5%**	-	**99.9%**	**99.9%**	**98.1%**	**99.8%**	-	**99.9%**	**99.9%**	**99.1%**	**99.9%**	-											*TWC eff*
TWC effectiveness (pre-post)				**91.7%**	**92.0%**	**94.1%**	**99.5%**	-	-	**71.9%**	**73.1%**	**83.2%**	**96.4%**	-	**99.9%**	**99.9%**	**97.3%**	**99.5%**	-	**100.0%**	**99.9%**	**98.0%**	**99.8%**	-	**100.0%**	**99.9%**	**98.8%**	**99.9%**	-											*TWC eff*
Mean values				49	45	437	16	0.97	5.83E+11	366	335	2276	42	3.99E+12	1	0	232	6	7.82E+10	0	0	222	5	1.72E+10	1	1	54	22	9.24E+10	150.1	219.0	146.4	129.4	144.4	9.28	13.76	9.03	7.98	8.89	Bags
				51	*47*	*434*	*15*	-	-	*380*	*348*	*2263*	*39*	-	*1*	*1*	*232*	*6*	-	*1*	*0*	*220*	*5*	-	*1*	*1*	*54*	*21*	-	*150.8*	*219.9*	*146.3*	*129.6*	*145.9*	*9.32*	*13.81*	*9.02*	*7.99*	*8.98*	*Modal Dil*
				670	*640*	*7144*	*2481*	-	-	*1519*	*1447*	*14222*	*1387*	-	*717*	*686*	*8502*	*1853*	-	*540*	*517*	*5993*	*2247*	-	*439*	*418*	*4716*	*3453*	-	*140.9*	*204.1*	*131.7*	*120.1*	*140.7*	*9.48*	*14.21*	*9.05*	*8.06*	*9.19*	*Modal PRE cat*
				57	*52*	*446*	*16*	-	-	*426*	*389*	*2253*	*46*	-	*0*	*0*	*245*	*6*	-	*0*	*0*	*235*	*4*	-	*0*	*1*	*70*	*22*	-	*153.8*	*224.3*	*149.2*	*132.2*	*148.8*	*9.51*	*14.09*	*9.20*	*8.15*	*9.16*	*Modal TP*
Standard deviation				5.9	5.8	55.3	7.4	0.22	3.68E+10	44.9	43.7	35.4	5.4	2.40E+11	0.2	0.1	67.2	3.3	4.21E+10	0.1	0.1	145.9	0.7	8.21E+09	0.0	0.0	27.0	23.0	2.32E+10	1.30	2.80	0.94	0.78	1.48	0.08	0.17	0.06	0.04	0.09	Bags
				6.1	*6.1*	*53.8*	*7.4*	-	-	*46.5*	*45.4*	*46.4*	*5.0*	-	*0.2*	*0.1*	*65.8*	*3.1*	-	*0.1*	*0.2*	*141.5*	*0.7*	-	*0.0*	*0.1*	*26.4*	*22.7*	-	*1.40*	*3.20*	*1.00*	*0.93*	*1.45*	*0.08*	*0.19*	*0.06*	*0.06*	*0.09*	*Modal Dil*
				55.5	*54.6*	*335.6*	*40.5*	-	-	*146.8*	*145.8*	*726.5*	*58.6*	-	*73.9*	*72.2*	*787.7*	*42.1*	-	*51.3*	*50.6*	*427.2*	*69.3*	-	*16.9*	*16.4*	*134.9*	*22.0*	-	*2.29*	*4.95*	*2.40*	*1.93*	*1.72*	*0.12*	*0.25*	*0.10*	*0.09*	*0.11*	*Modal PRE cat*
				6.5	*6.3*	*49.4*	*7.4*	-	-	*49.1*	*47.2*	*22.9*	*4.3*	-	*0.2*	*0.1*	*67.0*	*3.0*	-	*0.1*	*0.1*	*146.8*	*0.6*	-	*0.1*	*0.1*	*36.0*	*22.3*	-	*1.39*	*3.22*	*1.00*	*0.92*	*1.45*	*0.08*	*0.19*	*0.06*	*0.05*	*0.09*	*Modal TP*
Type A uncertainty				3.4	3.4	31.9	4.3	0.13	2.13E+10	25.9	25.3	20.5	3.1	1.38E+11	0.1	0.0	38.8	1.9	2.43E+10	0.1	0.1	84.3	0.4	4.74E+09	0.0	0.0	15.6	13.3	1.34E+10	0.75	1.62	0.55	0.45	0.85	0.05	0.10	0.04	0.03	0.05	Bags
				3.5	*3.5*	*31.1*	*4.3*	-	-	*26.8*	*26.2*	*26.8*	*2.9*	-	*0.1*	*0.0*	*38.0*	*1.8*	-	*0.1*	*0.1*	*81.7*	*0.4*	-	*0.0*	*0.1*	*15.2*	*13.1*	-	*0.81*	*1.85*	*0.58*	*0.54*	*0.83*	*0.05*	*0.11*	*0.04*	*0.03*	*0.05*	*Modal Dil*
				32.0	*31.5*	*193.8*	*23.4*	-	-	*84.8*	*84.2*	*419.4*	*33.8*	-	*42.6*	*41.7*	*454.8*	*24.3*	-	*29.6*	*29.2*	*246.6*	*40.0*	-	*9.7*	*9.5*	*77.9*	*12.7*	-	*1.32*	*2.86*	*1.38*	*1.12*	*0.99*	*0.07*	*0.14*	*0.06*	*0.05*	*0.06*	*Modal PRE cat*
				3.8	*3.6*	*28.5*	*4.3*	-	-	*28.4*	*27.3*	*13.2*	*2.5*	-	*0.1*	*0.0*	*38.7*	*1.8*	-	*0.1*	*0.1*	*84.8*	*0.4*	-	*0.1*	*0.1*	*20.8*	*12.9*	-	*0.80*	*1.86*	*0.58*	*0.53*	*0.83*	*0.05*	*0.11*	*0.04*	*0.03*	*0.05*	*Modal TP*
Mean TWC effectiveness (pre-bag)				**92.7%**	**93.0%**	**93.9%**	**99.4%**	-	-	**76.0%**	**76.9%**	**84.0%**	**97.0%**	-	**99.9%**	**99.9%**	**97.3%**	**99.7%**	-	**99.9%**	**99.9%**	**96.5%**	**99.8%**	-	**99.9%**	**99.9%**	**98.9%**	**99.4%**	-											
Max. TWC effectiveness (pre-bag)				**93.2%**	**93.5%**	**94.3%**	**99.6%**	-	-	**77.5%**	**78.5%**	**84.8%**	**97.4%**	-	**100.0%**	**100.0%**	**97.8%**	**99.9%**	-	**100.0%**	**100.0%**	**98.1%**	**99.8%**	-	**99.9%**	**99.9%**	**99.4%**	**99.9%**	-											
Min. TWC effectiveness (pre-bag)				**92.1%**	**92.3%**	**93.2%**	**98.9%**	-	-	**74.4%**	**75.3%**	**83.2%**	**96.6%**	-	**99.9%**	**99.9%**	**96.6%**	**99.5%**	-	**99.9%**	**99.9%**	**93.5%**	**99.7%**	-	**99.9%**	**99.8%**	**98.1%**	**98.4%**	-											
Mean TWC effectiveness (pre-post)				**91.5%**	**91.9%**	**93.8%**	**99.3%**	-	-	**72.0%**	**73.2%**	**84.1%**	**96.7%**	-	**99.9%**	**99.9%**	**97.2%**	**99.7%**	-	**100.0%**	**99.9%**	**96.2%**	**99.8%**	-	**99.9%**	**99.9%**	**98.5%**	**99.4%**	-											
Max. TWC effectiveness (pre-post)				**92.0%**	**92.4%**	**94.1%**	**99.6%**	-	-	**73.5%**	**74.7%**	**85.3%**	**97.0%**	-	**100.0%**	**99.9%**	**97.7%**	**99.9%**	-	**100.0%**	**100.0%**	**98.0%**	**99.8%**	-	**100.0%**	**99.9%**	**99.2%**	**99.9%**	-											
Min. TWC effectiveness (pre-post)				**90.9%**	**91.2%**	**93.2%**	**98.9%**	-	-	**70.6%**	**71.7%**	**83.2%**	**96.4%**	-	**99.9%**	**99.9%**	**96.4%**	**99.5%**	-	**100.0%**	**99.9%**	**93.3%**	**99.8%**	-	**99.9%**	**99.8%**	**97.5%**	**98.4%**	-											

Table 16 Emissions and fuel consumption results from the Fiat Tipo 1.4 vehicle over the WLTC cycle for TWC High S at 50 cycles

BOSMAL
BOSMAL Automotive Research and Development Institute Ltd
Exhaust Emissions Testing Laboratory

WLTP test (Reg 2017/1151) - WLTC driving cycle

VIN: ZFA35600006K20252 | **Vehicle model:** **Fiat Tipo 1.4 LPG** | **Emission standard: Euro 6** | Tyres: Continental ContiEcoContact 5 225/45 R17 V XL

Inertia [kg]:	1509			Emission WLTC						Emission LOW					Emission MIDDLE					Emission HIGH					Emission Ex-HIGH					CO$_2$ emission					Fuel consumption					Note 1
				[mg/km]						[mg/km]					[mg/km]					[mg/km]					[mg/km]					[g/km]					[l/100 km] $^{(2)}$					
Mileage[km]	Date	Chassis dyno F0/F1/F2	Test No.	THC	NMHC	CO	NOx	PM	PN	THC	NMHC	CO	NOx	PN	THC	NMHC	CO	NOx	PN	THC	NMHC	CO	NOx	PN	THC	NMHC	CO	NOx	PN	WLTC	LOW	MIDDLE	HIGH	Ex-HIGH	WLTC	LOW	MIDDLE	HIGH	Ex-HIGH	
Ageing stage: 50 cycles				BAG - MODAL DIL - PRE - POST																																				
5 373	11.06.2019	45.1 -0.87 0.0390	L1-0291	62	57	692	14	0.50	5.30E+11	463	425	3677	84	3.76E+12	1	1	223	6	3.49E+10	0	0	438	3	9.77E+09	1	1	67	3	6.17E+10	147.0	215.9	142.4	124.8	143.1	9.12	13.72	8.78	7.72	8.81	Bags
				65	60	695	13	-	-	483	445	3680	78	-	2	1	226	6	-	1	1	441	3	-	1	1	69	3	-	147.5	216.4	142.5	125.0	144.0	9.15	13.76	8.79	7.73	8.87	Modal Dil
				648	619	8118	2252	-	-	1548	1470	17843	1171	-	675	647	9512	1569	-	520	499	7026	1895	-	407	389	4627	3360	-	134.5	197.0	126.2	111.5	136.0	9.18	14.12	8.81	7.63	8.88	Modal PRE cat
				77	71	769	14	-	-	575	528	4090	89	-	1	1	257	5	-	0	1	477	2	-	1	1	76	2	-	150.5	221.0	145.3	127.5	147.0	9.34	14.09	8.96	7.89	9.05	Modal TP
TWC effectiveness (pre-bag)				90.4%	90.8%	91.5%	99.4%	-	-	70.1%	71.1%	79.4%	92.8%	-	99.8%	99.9%	97.7%	99.6%	-	99.9%	99.9%	93.8%	99.9%	-	99.8%	99.8%	98.5%	99.9%	-											TWC eff
TWC effectiveness (pre-post)				88.1%	88.6%	90.5%	99.4%	-	-	62.9%	64.1%	77.1%	92.4%	-	99.8%	99.8%	97.3%	99.7%	-	99.9%	99.9%	93.2%	99.9%	-	99.8%	99.8%	98.4%	99.9%	-											TWC eff
5 397	12.06.2019	45.1 -0.87 0.0390	L2-0294	57	52	506	14	0.56	5.20E+11	425	389	3267	82	3.51E+12	1	1	109	6	4.54E+10	0	0	109	2	2.04E+10	1	1	51	3	1.12E+11	147.3	214.8	144.4	126.6	141.8	9.12	13.61	8.89	7.80	8.72	Bags
				59	54	509	13	-	-	443	406	3275	80	-	2	1	111	6	-	1	0	110	2	-	1	1	53	3	-	148.2	215.8	145.2	127.3	142.9	9.18	13.67	8.94	7.84	8.80	Modal Dil
				628	600	7573	2333	-	-	1425	1350	16771	1315	-	678	651	8846	1664	-	511	491	6353	2046	-	403	385	4469	3346	-	135.8	198.0	129.6	114.8	134.5	9.20	14.07	8.95	7.77	8.78	Modal PRE cat
				73	67	565	15	-	-	550	505	3716	93	-	1	1	112	5	-	0	0	99	2	-	1	1	57	2	-	151.2	220.3	148.0	129.8	145.9	9.37	14.01	9.11	7.99	8.98	Modal TP
TWC effectiveness (pre-bag)				91.0%	91.3%	93.3%	99.4%	-	-	70.2%	71.2%	80.5%	93.7%	-	99.9%	99.9%	98.8%	99.7%	-	99.9%	99.9%	98.3%	99.9%	-	99.8%	99.8%	98.8%	99.9%	-											TWC eff
TWC effectiveness (pre-post)				88.3%	88.8%	92.5%	99.4%	-	-	61.4%	62.6%	77.8%	93.0%	-	99.9%	99.9%	98.7%	99.7%	-	99.9%	99.9%	98.4%	99.9%	-	99.8%	99.8%	98.7%	99.9%	-											TWC eff
5 443	13.06.2019	45.1 -0.87 0.0390	L1-0299	52	48	494	14	0.50	5.63E+11	392	358	2955	86	3.98E+12	1	1	249	3	4.27E+10	0	0	127	3	2.22E+10	1	1	32	3	5.47E+10	147.9	218.0	145.3	126.6	141.6	9.15	13.77	8.96	7.80	8.71	Bags
				55	50	493	14	-	-	408	373	2942	83	-	2	1	250	3	-	1	1	130	3	-	1	1	33	3	-	148.6	218.8	145.9	126.8	142.8	9.20	13.82	9.00	7.81	8.78	Modal Dil
				600	572	7695	2315	-	-	1384	1311	16529	1278	-	644	615	9650	1603	-	469	448	6388	2086	-	396	379	4397	3311	-	136.6	201.4	129.9	115.3	134.6	9.25	14.24	9.04	7.79	8.78	Modal PRE cat
				71	65	561	14	-	-	533	489	3382	91	-	1	1	274	3	-	0	0	138	2	-	0	1	37	3	-	151.6	223.3	148.7	129.4	145.7	9.39	14.16	9.17	7.97	8.96	Modal TP
TWC effectiveness (pre-bag)				91.3%	91.6%	93.6%	99.4%	-	-	71.7%	72.7%	82.1%	93.3%	-	99.9%	99.9%	97.4%	99.8%	-	99.9%	99.9%	98.0%	99.9%	-	99.9%	99.8%	99.3%	99.9%	-											TWC eff
TWC effectiveness (pre-post)				88.1%	88.6%	92.7%	99.4%	-	-	61.5%	62.7%	79.5%	92.9%	-	99.9%	99.9%	97.2%	99.8%	-	99.9%	99.9%	97.8%	99.9%	-	99.9%	99.8%	99.2%	99.9%	-											TWC eff
Mean values				57	52	564	14	0.52	5.38E+11	426	391	3300	84	3.75E+12	1	1	193	5	4.10E+10	0	0	225	3	1.75E+10	1	1	50	3	7.62E+10	147.4	216.3	144.0	126.0	142.1	9.13	13.70	8.88	7.77	8.75	Bags
				60	55	566	13	-	-	445	408	3299	81	-	2	1	195	5	-	1	1	227	3	-	1	1	52	3	-	148.1	217.0	144.5	126.4	143.2	9.17	13.75	8.91	7.79	8.82	Modal Dil
				625	597	7795	2300	-	-	1452	1377	17048	1255	-	666	638	9336	1612	-	500	479	6589	2009	-	402	384	4498	3339	-	135.6	198.8	128.6	113.9	135.0	9.21	14.14	8.93	7.73	8.81	Modal PRE cat
				74	68	632	14	-	-	553	507	3729	91	-	1	1	214	4	-	0	1	238	2	-	1	1	57	3	-	151.1	221.5	147.3	128.9	146.2	9.37	14.09	9.08	7.95	9.00	Modal TP
Standard deviation				3.9	3.7	90.7	0.2	0.03	1.84E+10	29.1	27.5	295.9	1.4	1.92E+11	0.1	0.0	60.9	1.3	4.46E+09	0.1	0.1	151.0	0.2	5.48E+09	0.1	0.1	14.4	0.2	2.57E+10	0.39	1.34	1.23	0.86	0.65	0.02	0.07	0.08	0.04	0.04	Bags
				4.1	3.9	91.5	0.2	-	-	30.9	29.5	302.0	2.2	-	0.2	0.2	60.8	1.2	-	0.2	0.2	151.4	0.2	-	0.1	0.0	14.6	0.3	-	0.46	1.28	1.45	0.99	0.56	0.02	0.06	0.09	0.05	0.04	Modal Dil
				19.5	19.2	233.7	34.6	-	-	69.9	68.0	570.8	60.8	-	15.2	16.0	351.1	39.3	-	22.4	22.2	309.0	82.6	-	4.4	4.1	96.2	20.5	-	0.84	1.89	1.66	1.68	0.65	0.03	0.07	0.10	0.07	0.05	Modal PRE cat
				2.4	2.2	97.2	0.2	-	-	17.3	16.1	289.1	1.6	-	0.2	0.1	72.8	1.0	-	0.0	0.1	169.7	0.1	-	0.1	0.1	16.1	0.4	-	0.46	1.28	1.46	1.00	0.59	0.02	0.06	0.09	0.04	0.04	Modal TP
Type A uncertainty				2.3	2.1	52.4	0.1	0.02	1.06E+10	16.8	15.9	170.8	0.8	1.11E+11	0.1	0.0	35.1	0.7	2.57E+09	0.0	0.0	87.2	0.1	3.16E+09	0.0	0.0	8.3	0.1	1.48E+10	0.22	0.77	0.71	0.50	0.38	0.01	0.04	0.04	0.02	0.02	Bags
				2.3	2.2	52.8	0.1	-	-	17.8	17.0	174.4	1.3	-	0.1	0.1	35.1	0.7	-	0.1	0.1	87.4	0.1	-	0.0	0.0	8.4	0.2	-	0.27	0.74	0.84	0.57	0.33	0.01	0.03	0.05	0.03	0.02	Modal Dil
				11.3	11.1	134.9	20.0	-	-	40.3	39.2	329.5	35.1	-	8.8	9.3	202.7	22.7	-	12.9	12.8	178.4	47.7	-	2.5	2.3	55.6	11.8	-	0.49	1.09	0.96	0.97	0.38	0.02	0.04	0.06	0.04	0.03	Modal PRE cat
				1.4	1.3	56.1	0.1	-	-	10.0	9.3	166.9	0.9	-	0.1	0.1	42.0	0.6	-	0.0	0.0	98.0	0.1	-	0.1	0.1	9.3	0.2	-	0.26	0.74	0.84	0.57	0.34	0.01	0.04	0.05	0.03	0.02	Modal TP
Mean TWC effectiveness (pre-bag)				90.9%	91.2%	92.8%	99.4%	-	-	70.7%	71.6%	80.7%	93.3%	-	99.9%	99.9%	97.9%	99.7%	-	99.9%	99.9%	96.7%	99.9%	-	99.8%	99.8%	98.9%	99.9%	-											
Max. TWC effectiveness (pre-bag)				91.3%	91.6%	93.6%	99.4%	-	-	71.7%	72.7%	82.1%	93.7%	-	99.9%	99.9%	98.8%	99.8%	-	99.9%	99.9%	98.3%	99.9%	-	99.9%	99.8%	99.3%	99.9%	-											
Min. TWC effectiveness (pre-bag)				90.4%	90.8%	91.5%	99.4%	-	-	70.1%	71.1%	79.4%	92.8%	-	99.8%	99.9%	97.4%	99.6%	-	99.9%	99.9%	93.8%	99.9%	-	99.8%	99.8%	98.5%	99.9%	-											
Mean TWC effectiveness (pre-post)				88.2%	88.6%	91.9%	99.4%	-	-	61.9%	63.1%	78.2%	92.8%	-	99.8%	99.9%	97.7%	99.7%	-	99.9%	99.9%	96.5%	99.9%	-	99.8%	99.8%	98.7%	99.9%	-											
Max. TWC effectiveness (pre-post)				88.3%	88.8%	92.7%	99.4%	-	-	62.9%	64.1%	79.5%	93.0%	-	99.9%	99.9%	98.7%	99.8%	-	99.9%	99.9%	98.4%	99.9%	-	99.9%	99.8%	99.2%	99.9%	-											
Min. TWC effectiveness (pre-post)				88.1%	88.6%	90.5%	99.4%	-	-	61.4%	62.6%	77.1%	92.4%	-	99.8%	99.8%	97.2%	99.7%	-	99.9%	99.9%	93.2%	99.9%	-	99.8%	99.8%	98.4%	99.9%	-											

Table 17 Emissions and fuel consumption results from the Fiat Tipo 1.4 vehicle over the WLTC cycle for TWC High S at 100 cycles

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BOSMAL Automotive Research and Development Institute Ltd

Exhaust Emissions Testing Laboratory

WLTP test (Reg 2017/1151) - WLTC driving cycle

VIN: ZFA35600006K20252 **Vehicle model:** **Fiat Tipo 1.4 LPG** **Emission standard: Euro 6**

Tyres: Continental ContiEcoContact 5 225/45 R17 V XL

Inertia [kg]:	1509			Emission WLTC						Emission LOW					Emission MIDDLE				
Mileage[km]	Date	Chassis dyno F0/F1/F2	Test No.	[mg/km]						[mg/km]					[mg/km]				
				THC	NMHC	CO	NOx	PM	PN	THC	NMHC	CO	NOx	PN	THC	NMHC	CO	NOx	PN
Ageing stage: 100 cycles				BAG - MODAL DIL - PRE - POST															
5 514	24.06.2019	45.1 -0.87 0.0390	L1-0338	54	50	471	27	0.41	4.17E+11	401	371	3176	110	3.00E+12	1	1	112	41	1.62E+10
				56	52	471	26	-	-	415	383	3167	107	-	2	1	113	40	-
				581	555	7215	2283	-	-	1366	1300	16547	1222	-	616	591	8520	1604	-
				68	63	503	28	-	-	509	471	3385	123	-	1	1	113	40	-
TWC effectiveness (pre-bag)				90.7%	91.0%	93.5%	98.8%	-	-	70.6%	71.5%	80.8%	91.0%	-	99.8%	99.8%	98.7%	97.5%	-
TWC effectiveness (pre-post)				88.3%	88.6%	93.0%	98.8%	-	-	62.7%	63.8%	79.5%	89.9%	-	99.8%	99.8%	98.7%	97.5%	-
5 537	25.06.2019	45.1 -0.87 0.0390	L1-0344	66	61	524	19	0.62	5.63E+11	490	454	3441	101	4.02E+12	2	1	165	4	3.24E+10
				69	64	524	19	-	-	511	475	3430	100	-	2	1	167	4	-
				628	600	7399	2342	-	-	1523	1449	16936	1275	-	690	664	8989	1616	-
				86	80	582	21	-	-	637	591	3836	113	-	1	1	181	4	-
TWC effectiveness (pre-bag)				89.4%	89.8%	92.9%	99.2%	-	-	67.8%	68.6%	79.7%	92.1%	-	99.7%	99.8%	98.2%	99.7%	-
TWC effectiveness (pre-post)				86.3%	86.7%	92.1%	99.1%	-	-	58.2%	59.2%	77.3%	91.1%	-	99.8%	99.8%	98.0%	99.8%	-
5 560	26.06.2019	45.1 -0.87 0.0390	L1-0345	55	50	465	21	0.61	5.14E+11	407	374	3140	102	3.72E+12	1	1	107	23	2.52E+10
				58	53	464	19	-	-	425	390	3120	92	-	2	1	109	21	-
				587	560	7139	2278	-	-	1406	1332	16382	1249	-	608	583	8325	1627	-
				69	63	516	21	-	-	510	469	3508	107	-	1	1	105	22	-
TWC effectiveness (pre-bag)				90.6%	91.0%	93.5%	99.1%	-	-	71.1%	71.9%	80.8%	91.8%	-	99.8%	99.9%	98.7%	98.6%	-
TWC effectiveness (pre-post)				88.3%	88.7%	92.8%	99.1%	-	-	63.7%	64.8%	78.6%	91.4%	-	99.8%	99.8%	98.7%	98.6%	-
Mean values				58	54	487	22	0.55	4.98E+11	433	400	3252	104	3.58E+12	1	1	128	23	2.46E+10
				61	56	486	21	-	-	450	416	3239	100	-	2	1	130	22	-
				599	572	7251	2301	-	-	1432	1360	16622	1249	-	638	613	8611	1616	-
				74	69	534	23	-	-	552	510	3577	114	-	1	1	133	22	-
Standard deviation				5.6	5.3	26.5	3.2	0.10	6.07E+10	40.8	38.7	134.3	3.9	4.28E+11	0.3	0.2	26.4	14.8	6.61E+09
				5.9	5.7	26.8	3.4	-	-	43.2	41.5	136.2	6.4	-	0.1	0.1	26.6	14.6	-
				20.7	20.1	109.3	29.0	-	-	66.6	64.1	231.9	21.5	-	36.9	36.3	278.6	9.2	-
				8.1	7.7	34.7	3.0	-	-	60.0	57.0	190.3	6.7	-	0.1	0.0	34.1	14.8	-
Type A uncertainty				3.3	3.1	15.3	1.8	0.06	3.50E+10	23.6	22.4	77.5	2.3	2.47E+11	0.2	0.1	15.2	8.6	3.82E+09
				3.4	3.3	15.5	1.9	-	-	24.9	24.0	78.7	3.7	-	0.0	0.0	15.3	8.4	-
				11.9	11.6	63.1	16.8	-	-	38.4	37.0	133.9	12.4	-	21.3	21.0	160.9	5.3	-
				4.7	4.5	20.0	1.7	-	-	34.6	32.9	109.9	3.9	-	0.0	0.0	19.7	8.6	-
Mean TWC effectiveness (pre-bag)				90.3%	90.6%	93.3%	99.0%	-	-	69.8%	70.7%	80.4%	91.6%	-	99.8%	99.8%	98.5%	98.6%	-
Max. TWC effectiveness (pre-bag)				90.7%	91.0%	93.5%	99.2%	-	-	71.1%	71.9%	80.8%	92.1%	-	99.8%	99.9%	98.7%	99.7%	-
Min. TWC effectiveness (pre-bag)				89.4%	89.8%	92.9%	98.8%	-	-	67.8%	68.6%	79.7%	91.0%	-	99.7%	99.8%	98.2%	97.5%	-
Mean TWC effectiveness (pre-post)				87.6%	88.0%	92.6%	99.0%	-	-	61.5%	62.6%	78.5%	90.8%	-	99.8%	99.8%	98.5%	98.6%	-
Max. TWC effectiveness (pre-post)				88.3%	88.7%	93.0%	99.1%	-	-	63.7%	64.8%	79.5%	91.4%	-	99.8%	99.8%	98.7%	99.8%	-
Min. TWC effectiveness (pre-post)				86.3%	86.7%	92.1%	98.8%	-	-	58.2%	59.2%	77.3%	89.9%	-	99.8%	99.8%	98.0%	97.5%	-

Mileage[km]	Test No.	Emission HIGH					Emission Ex-HIGH					CO$_2$ emission					Fuel consumption					Note 1
		[mg/km]					[mg/km]					[g/km]					[l/100 km] (2)					
		THC	NMHC	CO	NOx	PN	THC	NMHC	CO	NOx	PN	WLTC	LOW	MIDDLE	HIGH	Ex-HIGH	WLTC	LOW	MIDDLE	HIGH	Ex-HIGH	
Ageing stage: 100 cycles																						
5 514	L1-0338	1	1	68	8	9.76E+09	1	1	19	4	3.71E+10	146.6	216.5	142.3	125.0	141.6	9.07	13.69	8.76	7.69	8.71	Bags
		1	1	69	8	-	1	1	19	4	-	147.1	217.0	142.5	125.3	142.6	9.10	13.73	8.78	7.71	8.77	Modal Dil
		450	431	5633	2022	-	381	364	4353	3296	-	135.3	199.8	127.1	114.1	134.4	9.13	14.14	8.75	7.64	8.76	Modal PRE cat
		0	1	74	6	-	1	1	23	3	-	150.1	221.6	145.3	127.7	145.5	9.29	14.05	8.95	7.86	8.95	Modal TP
TWC effectiveness (pre-bag)		99.9%	99.9%	98.8%	99.6%	-	99.7%	99.7%	99.6%	99.9%	-											TWC eff
TWC effectiveness (pre-post)		99.9%	99.9%	98.7%	99.7%	-	99.8%	99.7%	99.5%	99.9%	-											TWC eff
5 537	L1-0344	1	1	81	3	8.53E+09	1	1	17	11	4.93E+10	146.6	216.0	142.2	124.4	142.2	9.08	13.71	8.76	7.66	8.75	Bags
		1	1	83	3	-	1	1	18	10	-	147.3	216.4	142.8	124.7	143.4	9.12	13.74	8.80	7.68	8.82	Modal Dil
		479	459	5824	2068	-	384	366	4260	3400	-	135.2	197.9	126.7	113.2	135.5	9.15	14.09	8.79	7.61	8.82	Modal PRE cat
		0	1	81	2	-	1	1	23	14	-	150.4	221.2	145.7	127.2	146.4	9.32	14.09	8.98	7.83	9.01	Modal TP
TWC effectiveness (pre-bag)		99.8%	99.9%	98.6%	99.9%	-	99.7%	99.7%	99.6%	99.7%	-											TWC eff
TWC effectiveness (pre-post)		99.9%	99.9%	98.6%	99.9%	-	99.8%	99.7%	99.5%	99.6%	-											TWC eff
5 560	L1-0345	0	0	58	5	1.43E+10	1	1	17	4	1.97E+10	145.9	215.3	141.9	124.4	140.6	9.03	13.62	8.74	7.66	8.65	Bags
		1	1	61	4	-	1	1	17	4	-	146.5	216.0	142.0	124.8	141.8	9.07	13.67	8.74	7.68	8.72	Modal Dil
		462	444	5604	2002	-	375	358	4303	3280	-	134.5	198.4	126.9	112.8	133.6	9.07	14.05	8.72	7.57	8.70	Modal PRE cat
		0	1	59	4	-	1	1	22	3	-	149.5	220.6	144.8	127.3	144.7	9.26	14.00	8.91	7.84	8.90	Modal TP
TWC effectiveness (pre-bag)		99.9%	99.9%	99.0%	99.8%	-	99.8%	99.8%	99.6%	99.9%	-											TWC eff
TWC effectiveness (pre-post)		99.9%	99.9%	98.9%	99.8%	-	99.8%	99.7%	99.5%	99.9%	-											TWC eff
Mean values		1	1	69	5	1.09E+10	1	1	18	6	3.54E+10	146.3	215.9	142.1	124.6	141.4	9.06	13.67	8.75	7.67	8.70	Bags
		1	1	71	5	-	1	1	18	6	-	147.0	216.5	142.4	124.9	142.6	9.10	13.71	8.77	7.69	8.77	Modal Dil
		464	445	5687	2030	-	380	363	4305	3325	-	135.0	198.7	126.9	113.4	134.5	9.11	14.09	8.76	7.61	8.76	Modal PRE cat
		0	1	71	4	-	1	1	23	7	-	150.0	221.1	145.3	127.4	145.5	9.29	14.05	8.95	7.84	8.95	Modal TP
Standard deviation		0.2	0.1	9.4	2.1	2.50E+09	0.2	0.1	0.9	3.3	1.21E+10	0.33	0.47	0.17	0.30	0.67	0.02	0.04	0.01	0.02	0.04	Bags
		0.0	0.1	9.1	2.1	-	0.1	0.1	0.9	3.2	-	0.33	0.42	0.34	0.24	0.67	0.02	0.03	0.02	0.01	0.04	Modal Dil
		11.8	11.4	97.7	27.6	-	3.9	3.6	38.2	53.0	-	0.37	0.81	0.14	0.52	0.79	0.03	0.04	0.03	0.03	0.05	Modal PRE cat
		0.0	0.0	9.3	1.5	-	0.1	0.0	0.3	4.9	-	0.36	0.41	0.38	0.22	0.72	0.03	0.04	0.03	0.01	0.04	Modal TP
Type A uncertainty		0.1	0.1	5.4	1.2	1.44E+09	0.1	0.1	0.5	1.9	7.01E+09	0.19	0.27	0.10	0.17	0.38	0.01	0.02	0.01	0.01	0.02	Bags
		0.0	0.1	5.2	1.2	-	0.0	0.0	0.5	1.8	-	0.19	0.24	0.20	0.14	0.39	0.01	0.02	0.01	0.01	0.02	Modal Dil
		6.8	6.6	56.4	16.0	-	2.2	2.1	22.0	30.6	-	0.21	0.47	0.08	0.30	0.45	0.02	0.02	0.02	0.02	0.03	Modal PRE cat
		0.0	0.0	5.4	0.9	-	0.1	0.0	0.1	2.8	-	0.21	0.23	0.22	0.12	0.41	0.01	0.02	0.02	0.01	0.03	Modal TP
Mean TWC effectiveness (pre-bag)		99.9%	99.9%	98.8%	99.7%	-	99.8%	99.8%	99.6%	99.8%	-											
Max. TWC effectiveness (pre-bag)		99.9%	99.9%	99.0%	99.9%	-	99.8%	99.8%	99.6%	99.9%	-											
Min. TWC effectiveness (pre-bag)		99.8%	99.9%	98.6%	99.6%	-	99.7%	99.7%	99.6%	99.7%	-											
Mean TWC effectiveness (pre-post)		99.9%	99.9%	98.7%	99.8%	-	99.8%	99.7%	99.5%	99.8%	-											
Max. TWC effectiveness (pre-post)		99.9%	99.9%	98.9%	99.9%	-	99.8%	99.7%	99.5%	99.9%	-											
Min. TWC effectiveness (pre-post)		99.9%	99.9%	98.6%	99.7%	-	99.8%	99.7%	99.5%	99.6%	-											

Table 18 Emissions and fuel consumption results from the Fiat Tipo 1.4 vehicle over the WLTC cycle for TWC High S at 175 cycles

BOSMAL
BOSMAL Automotive Research and Development Institute Ltd
Exhaust Emissions Testing Laboratory

WLTP test (Reg 2017/1151) - WLTC driving cycle

VIN: ZFA35600006K20252
Vehicle model: **Fiat Tipo 1.4 LPG**
Emission standard: Euro 6
Tyres: Continental ContiEcoContact 5 225/45 R17 V XL

Inertia [kg]:	1509			Emission WLTC						Emission LOW					Emission MIDDLE					Emission HIGH					Emission Ex-HIGH					CO$_2$ emission					Fuel consumption					Note 1
				[mg/km]						[mg/km]					[mg/km]					[mg/km]					[mg/km]					[g/km]					[l/100 km] [(2)]					
Mileage[km]	Date	Chassis dyno F0/F1/F2	Test No.	THC	NMHC	CO	NOx	PM	PN	THC	NMHC	CO	NOx	PN	THC	NMHC	CO	NOx	PN	THC	NMHC	CO	NOx	PN	THC	NMHC	CO	NOx	PN	WLTC	LOW	MIDDLE	HIGH	Ex-HIGH	WLTC	LOW	MIDDLE	HIGH	Ex-HIGH	
Ageing stage: 175 cycles				BAG - MODAL DIL - PRE - POST																																				
5 654	07.08.2019	45.1 -0.87 0.0390	L1-0395	55	49	645	17	0.60	5.05E+11	412	369	4260	112	3.61E+12	1	1	206	4	3.43E+10	0	0	104	3	1.99E+10	0	0	25	3	4.23E+10	145.4	215.5	142.2	123.9	140.0	9.02	13.74	8.77	7.63	8.61	Bags
				57	*51*	*649*	*17*	-	-	*429*	*385*	*4285*	*105*	-	*2*	*1*	*209*	*4*	-	*1*	*0*	*106*	*3*	-	*1*	*0*	*26*	*3*	-	*146.4*	*216.4*	*142.9*	*124.6*	*141.4*	*9.08*	*13.81*	*8.81*	*7.67*	*8.70*	*Modal Dil*
				578	*550*	*7696*	*2253*	-	-	*1336*	*1254*	*17946*	*1211*	-	*609*	*582*	*9149*	*1610*	-	*462*	*443*	*6054*	*2005*	-	*380*	*363*	*4484*	*3226*	-	*134.5*	*199.5*	*128.3*	*112.9*	*132.8*	*9.12*	*14.25*	*8.89*	*7.62*	*8.67*	*Modal PRE cat*
				74	*67*	*734*	*19*	-	-	*555*	*501*	*4927*	*124*	-	*1*	*1*	*216*	*3*	-	*0*	*1*	*100*	*3*	-	*1*	*1*	*28*	*3*	-	*149.4*	*221.2*	*145.7*	*127.1*	*144.3*	*9.27*	*14.18*	*8.98*	*7.83*	*8.88*	*Modal TP*
TWC effectiveness (pre-bag)				**90.5%**	**91.1%**	**91.6%**	**99.2%**	-	-	**69.2%**	**70.6%**	**76.3%**	**90.7%**	-	**99.8%**	**99.9%**	**97.7%**	**99.8%**	-	**100.0%**	**100.0%**	**98.3%**	**99.9%**	-	**99.9%**	**99.9%**	**99.4%**	**99.9%**	-											*TWC eff*
TWC effectiveness (pre-post)				**87.2%**	**87.9%**	**90.5%**	**99.2%**	-	-	**58.5%**	**60.1%**	**72.5%**	**89.7%**	-	**99.8%**	**99.8%**	**97.6%**	**99.8%**	-	**99.9%**	**99.9%**	**98.3%**	**99.9%**	-	**99.8%**	**99.8%**	**99.4%**	**99.9%**	-											*TWC eff*
5 677	08.08.2019	45.1 -0.87 0.0390	L1-0398	56	51	531	14	0.31	4.42E+11	415	380	3308	91	3.17E+12	2	1	212	3	2.34E+10	0	0	124	2	1.35E+10	1	1	34	3	3.93E+10	146.5	219.6	143.4	124.4	140.3	9.07	13.90	8.84	7.66	8.63	Bags
				59	*53*	*532*	*14*	-	-	*434*	*398*	*3303*	*89*	-	*2*	*1*	*213*	*3*	-	*1*	*0*	*126*	*2*	-	*1*	*1*	*34*	*3*	-	*147.3*	*220.4*	*143.8*	*125.0*	*141.6*	*9.12*	*13.96*	*8.86*	*7.70*	*8.71*	*Modal Dil*
				592	*565*	*7565*	*2258*	-	-	*1390*	*1319*	*16602*	*1289*	-	*617*	*590*	*9543*	*1581*	-	*475*	*455*	*6047*	*1997*	-	*382*	*365*	*4377*	*3236*	-	*134.7*	*203.4*	*127.4*	*112.9*	*132.3*	*9.13*	*14.37*	*8.87*	*7.62*	*8.63*	*Modal PRE cat*
				69	*63*	*592*	*16*	-	-	*516*	*474*	*3722*	*101*	-	*2*	*1*	*226*	*3*	-	*0*	*1*	*129*	*2*	-	*1*	*1*	*37*	*3*	-	*150.3*	*225.1*	*146.5*	*127.4*	*144.5*	*9.31*	*14.30*	*9.03*	*7.85*	*8.89*	*Modal TP*
TWC effectiveness (pre-bag)				**90.6%**	**91.0%**	**93.0%**	**99.4%**	-	-	**70.2%**	**71.2%**	**80.1%**	**92.9%**	-	**99.8%**	**99.9%**	**97.8%**	**99.8%**	-	**99.9%**	**99.9%**	**97.9%**	**99.9%**	-	**99.8%**	**99.9%**	**99.2%**	**99.9%**	-											*TWC eff*
TWC effectiveness (pre-post)				**88.3%**	**88.8%**	**92.2%**	**99.3%**	-	-	**62.9%**	**64.1%**	**77.6%**	**92.2%**	-	**99.7%**	**99.8%**	**97.6%**	**99.8%**	-	**99.9%**	**99.9%**	**97.9%**	**99.9%**	-	**99.8%**	**99.8%**	**99.1%**	**99.9%**	-											*TWC eff*
5 701	09.08.2019	45.1 -0.87 0.0390	L1-0402	47	42	512	15	0.45	4.33E+11	351	316	3429	100	3.11E+12	1	1	142	2	2.78E+10	0	0	81	2	4.51E+09	1	0	13	2	4.07E+10	145.2	217.2	141.9	123.3	139.3	8.99	13.75	8.74	7.59	8.57	Bags
				49	*44*	*513*	*15*	-	-	*365*	*329*	*3430*	*97*	-	*2*	*1*	*144*	*2*	-	*1*	*0*	*83*	*2*	-	*1*	*1*	*13*	*3*	-	*146.0*	*218.0*	*142.3*	*123.8*	*140.6*	*9.04*	*13.80*	*8.77*	*7.62*	*8.65*	*Modal Dil*
				564	*536*	*7307*	*2238*	-	-	*1311*	*1238*	*16414*	*1285*	-	*604*	*577*	*8782*	*1590*	-	*437*	*418*	*5827*	*2001*	-	*372*	*354*	*4353*	*3172*	-	*134.8*	*200.8*	*127.8*	*113.4*	*132.8*	*9.10*	*14.18*	*8.82*	*7.62*	*8.65*	*Modal PRE cat*
				61	*55*	*564*	*17*	-	-	*458*	*414*	*3793*	*113*	-	*1*	*1*	*153*	*2*	-	*0*	*1*	*82*	*2*	-	*1*	*1*	*17*	*3*	-	*148.9*	*222.5*	*145.0*	*126.2*	*143.4*	*9.22*	*14.13*	*8.93*	*7.77*	*8.82*	*Modal TP*
TWC effectiveness (pre-bag)				**91.7%**	**92.1%**	**93.0%**	**99.3%**	-	-	**73.2%**	**74.5%**	**79.1%**	**92.2%**	-	**99.8%**	**99.9%**	**98.4%**	**99.9%**	-	**99.9%**	**100.0%**	**98.6%**	**99.9%**	-	**99.8%**	**99.9%**	**99.7%**	**99.9%**	-											*TWC eff*
TWC effectiveness (pre-post)				**89.1%**	**89.7%**	**92.3%**	**99.2%**	-	-	**65.1%**	**66.6%**	**76.9%**	**91.2%**	-	**99.8%**	**99.8%**	**98.3%**	**99.9%**	-	**99.9%**	**99.9%**	**98.6%**	**99.9%**	-	**99.7%**	**99.8%**	**99.6%**	**99.9%**	-											*TWC eff*
Mean values				52	47	563	16	0.45	4.60E+11	393	355	3666	101	3.30E+12	1	1	187	3	2.85E+10	0	0	103	2	1.26E+10	1	0	24	3	4.08E+10	145.7	217.4	142.5	123.9	139.9	9.03	13.80	8.78	7.63	8.61	Bags
				55	*49*	*565*	*15*	-	-	*409*	*371*	*3673*	*97*	-	*2*	*1*	*189*	*3*	-	*1*	*0*	*105*	*3*	-	*1*	*0*	*24*	*3*	-	*146.6*	*218.3*	*143.0*	*124.5*	*141.2*	*9.08*	*13.86*	*8.81*	*7.67*	*8.69*	*Modal Dil*
				578	*550*	*7523*	*2250*	-	-	*1346*	*1270*	*16987*	*1261*	-	*610*	*583*	*9158*	*1594*	-	*458*	*438*	*5976*	*2001*	-	*378*	*361*	*4404*	*3211*	-	*134.7*	*201.2*	*127.8*	*113.1*	*132.6*	*9.12*	*14.27*	*8.86*	*7.62*	*8.65*	*Modal PRE cat*
				68	*62*	*630*	*17*	-	-	*510*	*463*	*4147*	*113*	-	*2*	*1*	*198*	*3*	-	*0*	*1*	*104*	*2*	-	*1*	*1*	*27*	*3*	-	*149.5*	*222.9*	*145.7*	*126.9*	*144.0*	*9.27*	*14.20*	*8.98*	*7.81*	*8.86*	*Modal TP*
Standard deviation				3.9	3.7	58.4	1.3	0.12	3.18E+10	29.5	28.1	423.3	8.5	2.25E+11	0.1	0.1	31.7	0.7	4.48E+09	0.1	0.1	17.5	0.3	6.30E+09	0.1	0.1	8.5	0.2	1.20E+09	0.58	1.68	0.65	0.44	0.41	0.04	0.07	0.04	0.03	0.03	Bags
				4.2	*4.0*	*60.2*	*1.0*	-	-	*31.4*	*30.0*	*435.9*	*6.5*	-	*0.2*	*0.1*	*31.5*	*0.7*	-	*0.1*	*0.1*	*17.6*	*0.4*	-	*0.1*	*0.1*	*8.6*	*0.2*	-	*0.57*	*1.64*	*0.61*	*0.47*	*0.45*	*0.04*	*0.07*	*0.04*	*0.03*	*0.03*	*Modal Dil*
				11.6	*11.6*	*161.4*	*8.6*	-	-	*33.2*	*34.9*	*682.4*	*35.7*	-	*5.5*	*5.2*	*310.4*	*12.2*	-	*15.5*	*15.6*	*105.5*	*3.5*	-	*4.4*	*4.5*	*56.9*	*28.3*	-	*0.10*	*1.61*	*0.37*	*0.21*	*0.24*	*0.01*	*0.08*	*0.03*	*0.00*	*0.02*	*Modal PRE cat*
				5.2	*4.7*	*74.4*	*1.3*	-	-	*40.0*	*36.2*	*552.0*	*9.6*	-	*0.1*	*0.1*	*32.3*	*0.5*	-	*0.0*	*0.0*	*19.2*	*0.3*	-	*0.1*	*0.0*	*8.5*	*0.2*	-	*0.59*	*1.61*	*0.63*	*0.50*	*0.47*	*0.04*	*0.07*	*0.04*	*0.03*	*0.03*	*Modal TP*
Type A uncertainty				2.2	2.1	33.7	0.7	0.07	1.83E+10	17.0	16.2	244.4	4.9	1.30E+11	0.1	0.1	18.3	0.4	2.59E+09	0.1	0.0	10.1	0.2	3.64E+09	0.1	0.1	4.9	0.1	6.95E+08	0.34	0.97	0.38	0.26	0.23	0.02	0.04	0.02	0.02	0.01	Bags
				2.4	*2.3*	*34.7*	*0.6*	-	-	*18.2*	*17.3*	*251.7*	*3.8*	-	*0.1*	*0.1*	*18.2*	*0.4*	-	*0.1*	*0.0*	*10.2*	*0.2*	-	*0.1*	*0.1*	*5.0*	*0.1*	-	*0.33*	*0.95*	*0.35*	*0.27*	*0.26*	*0.02*	*0.04*	*0.02*	*0.02*	*0.02*	*Modal Dil*
				6.7	*6.7*	*93.2*	*5.0*	-	-	*19.1*	*20.1*	*394.0*	*20.6*	-	*3.2*	*3.0*	*179.2*	*7.1*	-	*8.9*	*9.0*	*60.9*	*2.0*	-	*2.6*	*2.6*	*32.9*	*16.4*	-	*0.06*	*0.93*	*0.21*	*0.12*	*0.14*	*0.01*	*0.05*	*0.02*	*0.00*	*0.01*	*Modal PRE cat*
				3.0	*2.7*	*43.0*	*0.8*	-	-	*23.1*	*20.9*	*318.7*	*5.5*	-	*0.1*	*0.0*	*18.6*	*0.3*	-	*0.0*	*0.0*	*11.1*	*0.2*	-	*0.0*	*0.0*	*4.9*	*0.1*	-	*0.34*	*0.93*	*0.36*	*0.29*	*0.27*	*0.02*	*0.04*	*0.02*	*0.02*	*0.02*	*Modal TP*
Mean TWC effectiveness (pre-bag)				**90.9%**	**91.4%**	**92.5%**	**99.3%**	-	-	**70.8%**	**72.1%**	**78.5%**	**92.0%**	-	**99.8%**	**99.9%**	**98.0%**	**99.8%**	-	**99.9%**	**100.0%**	**98.3%**	**99.9%**	-	**99.8%**	**99.9%**	**99.5%**	**99.9%**	-											
Max. TWC effectiveness (pre-bag)				**91.7%**	**92.1%**	**93.0%**	**99.4%**	-	-	**73.2%**	**74.5%**	**80.1%**	**92.9%**	-	**99.8%**	**99.9%**	**98.4%**	**99.9%**	-	**100.0%**	**100.0%**	**98.6%**	**99.9%**	-	**99.9%**	**99.9%**	**99.7%**	**99.9%**	-											
Min. TWC effectiveness (pre-bag)				**90.5%**	**91.0%**	**91.6%**	**99.2%**	-	-	**69.2%**	**70.6%**	**76.3%**	**90.7%**	-	**99.8%**	**99.9%**	**97.7%**	**99.8%**	-	**99.9%**	**99.9%**	**97.9%**	**99.9%**	-	**99.8%**	**99.9%**	**99.2%**	**99.9%**	-											
Mean TWC effectiveness (pre-post)				**88.2%**	**88.8%**	**91.6%**	**99.2%**	-	-	**62.1%**	**63.6%**	**75.7%**	**91.0%**	-	**99.8%**	**99.8%**	**97.8%**	**99.8%**	-	**99.9%**	**99.9%**	**98.3%**	**99.9%**	-	**99.8%**	**99.8%**	**99.4%**	**99.9%**	-											
Max. TWC effectiveness (pre-post)				**89.1%**	**89.7%**	**92.3%**	**99.3%**	-	-	**65.1%**	**66.6%**	**77.6%**	**92.2%**	-	**99.8%**	**99.8%**	**98.3%**	**99.9%**	-	**99.9%**	**99.9%**	**98.6%**	**99.9%**	-	**99.8%**	**99.8%**	**99.6%**	**99.9%**	-											
Min. TWC effectiveness (pre-post)				**87.2%**	**87.9%**	**90.5%**	**99.2%**	-	-	**58.5%**	**60.1%**	**72.5%**	**89.7%**	-	**99.7%**	**99.8%**	**97.6%**	**99.8%**	-	**99.9%**	**99.9%**	**97.9%**	**99.9%**	-	**99.7%**	**99.8%**	**99.1%**	**99.9%**	-											

Table 19 Emissions and fuel consumption results from the Fiat Tipo 1.4 vehicle over the WLTC cycle for TWC High S at 250 cycles

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BOSMAL Automotive Research and Development Institute Ltd
Exhaust Emissions Testing Laboratory

WLTP test (Reg 2017/1151) - WLTC driving cycle

VIN: ZFA35600006K20252 **Vehicle model:** **Fiat Tipo 1.4 LPG** **Emission standard: Euro 6**

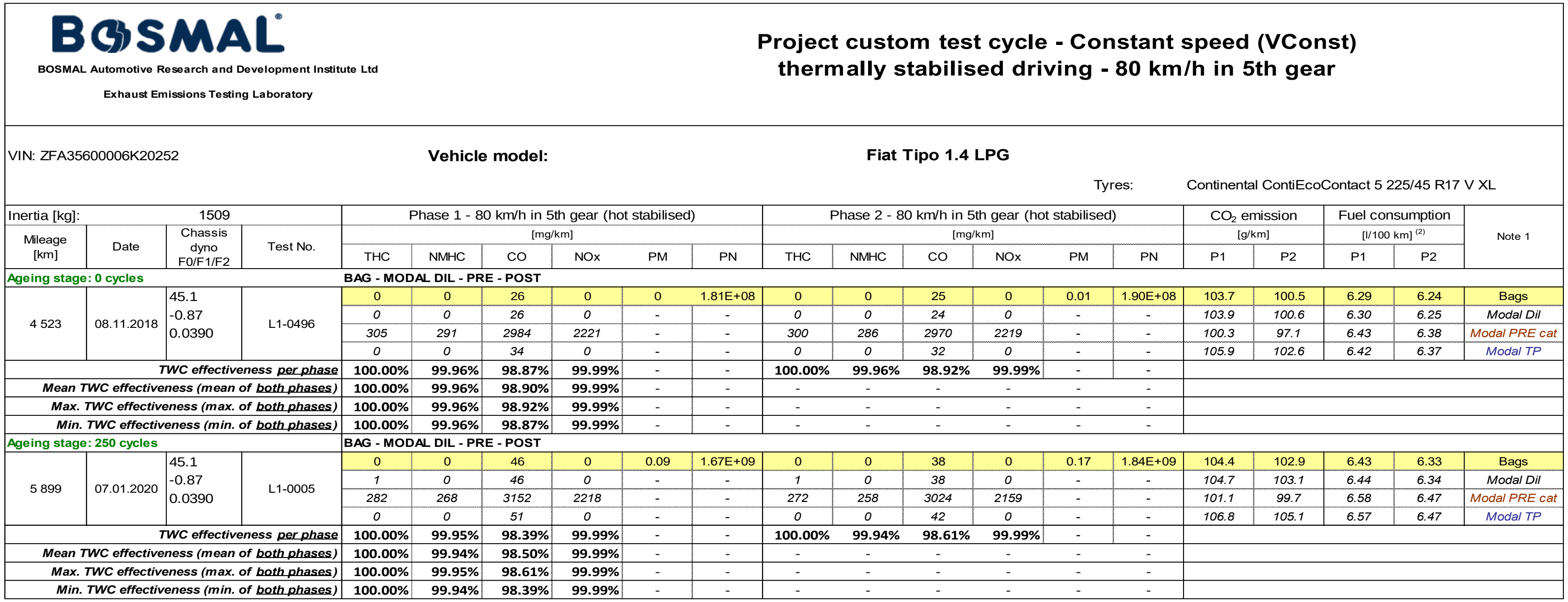
Tyres: Continental ContiEcoContact 5 225/45 R17 V XL

Inertia [kg]:	1509			Emission WLTC						Emission LOW				
				[mg/km]						[mg/km]				
Mileage[km]	Date	Chassis dyno F0/F1/F2	Test No.	THC	NMHC	CO	NOx	PM	PN	THC	NMHC	CO	NOx	PN
Ageing stage: 250 cycles				BAG - MODAL DIL - PRE - POST										
5 749	19.12.2019	45.1 -0.87 0.0390	L1-0709	65	60	461	19	0.74	4.77E+11	479	445	3125	119	3.43E+12
				68	63	466	18	-	-	504	470	3156	112	-
				554	528	6444	2599	-	-	1362	1303	12408	1621	-
				71	66	446	21	-	-	526	488	2963	129	-
TWC effectiveness (pre-bag)				88.3%	88.7%	92.8%	99.3%	-	-	64.8%	65.8%	74.8%	92.7%	-
TWC effectiveness (pre-post)				87.2%	87.6%	93.1%	99.2%	-	-	61.4%	62.6%	76.1%	92.1%	-
5 772	20.12.2019	45.1 -0.87 0.0390	L1-0712	70	65	613	16	0.69	5.03E+11	520	480	3868	98	3.61E+12
				74	68	617	16	-	-	547	507	3891	96	-
				543	516	6862	2587	-	-	1347	1285	13188	1578	-
				77	71	606	17	-	-	575	531	3765	110	-
TWC effectiveness (pre-bag)				87.1%	87.5%	91.1%	99.4%	-	-	61.4%	62.6%	70.7%	93.8%	-
TWC effectiveness (pre-post)				85.8%	86.2%	91.2%	99.3%	-	-	57.3%	58.7%	71.4%	93.0%	-
5 795	30.12.2019	45.1 -0.87 0.0390	L1-0716	65	59	778	17	1.01	5.07E+11	478	434	4811	107	3.62E+12
				69	62	784	17	-	-	506	461	4849	106	-
				571	541	7595	2223	-	-	1291	1213	17144	1112	-
				79	71	916	14	-	-	586	526	5675	93	-
TWC effectiveness (pre-bag)				88.7%	89.2%	89.8%	99.2%	-	-	62.9%	64.2%	71.9%	90.4%	-
TWC effectiveness (pre-post)				86.1%	86.9%	87.9%	99.4%	-	-	54.6%	56.6%	66.9%	91.6%	-
Mean values				66	61	618	17	0.81	4.96E+11	492	453	3935	108	3.55E+12
				70	65	622	17	-	-	519	480	3965	105	-
				556	529	6967	2470	-	-	1334	1267	14247	1437	-
				76	69	656	18	-	-	562	515	4134	111	-
Standard deviation				2.5	2.6	129.3	1.4	0.14	1.32E+10	19.4	19.7	689.8	8.5	8.47E+10
				2.5	2.5	129.6	1.0	-	-	19.7	19.8	692.8	6.5	-
				11.6	10.2	475.5	174.8	-	-	30.5	38.8	2073.6	230.3	-
				3.5	2.5	195.2	2.6	-	-	26.0	19.1	1137.3	14.6	-
Type A uncertainty				1.5	1.5	74.6	0.8	0.08	7.59E+09	11.2	11.4	398.2	4.9	4.89E+10
				1.4	1.5	74.8	0.6	-	-	11.4	11.4	400.0	3.7	-
				6.7	5.9	274.6	100.9	-	-	17.6	22.4	1197.2	132.9	-
				2.0	1.5	112.7	1.5	-	-	15.0	11.0	656.6	8.4	-
Mean TWC effectiveness (pre-bag)				88.0%	88.4%	91.2%	99.3%	-	-	63.1%	64.2%	72.5%	92.3%	-
Max. TWC effectiveness (pre-bag)				88.7%	89.2%	92.8%	99.4%	-	-	64.8%	65.8%	74.8%	93.8%	-
Min. TWC effectiveness (pre-bag)				87.1%	87.5%	89.8%	99.2%	-	-	61.4%	62.6%	70.7%	90.4%	-
Mean TWC effectiveness (pre-post)				86.4%	86.9%	90.7%	99.3%	-	-	57.8%	59.3%	71.5%	92.2%	-
Max. TWC effectiveness (pre-post)				87.2%	87.6%	93.1%	99.4%	-	-	61.4%	62.6%	76.1%	93.0%	-
Min. TWC effectiveness (pre-post)				85.8%	86.2%	87.9%	99.2%	-	-	54.6%	56.6%	66.9%	91.6%	-

Inertia [kg]:	1509			Emission MIDDLE					Emission HIGH					Emission Ex-HIGH				
				[mg/km]					[mg/km]					[mg/km]				
Mileage[km]	Date	Chassis dyno F0/F1/F2	Test No.	THC	NMHC	CO	NOx	PN	THC	NMHC	CO	NOx	PN	THC	NMHC	CO	NOx	PN
Ageing stage: 250 cycles																		
5 749	19.12.2019	45.1 -0.87 0.0390	L1-0709	2	1	114	5	2.43E+10	1	1	39	4	6.68E+09	1	1	31	3	4.07E+10
				2	1	115	5	-	1	1	41	4	-	2	1	32	3	-
				559	534	7347	2037	-	432	412	5465	2426	-	354	336	4542	3439	-
				2	1	123	6	-	1	1	46	4	-	1	1	36	3	-
TWC effectiveness (pre-bag)				99.7%	99.8%	98.4%	99.8%	-	99.8%	99.8%	99.3%	99.8%	-	99.6%	99.7%	99.3%	99.9%	-
TWC effectiveness (pre-post)				99.7%	99.8%	98.3%	99.7%	-	99.9%	99.8%	99.2%	99.8%	-	99.6%	99.6%	99.2%	99.9%	-
5 772	20.12.2019	45.1 -0.87 0.0390	L1-0712	2	1	238	4	3.89E+10	1	1	121	3	5.75E+09	1	1	40	3	4.11E+10
				2	1	238	4	-	1	1	122	4	-	1	1	40	3	-
				545	517	8482	2019	-	424	405	5672	2373	-	344	326	4599	3478	-
				1	1	249	4	-	0	1	129	3	-	1	1	44	3	-
TWC effectiveness (pre-bag)				99.7%	99.8%	97.2%	99.8%	-	99.8%	99.8%	97.9%	99.9%	-	99.6%	99.7%	99.1%	99.9%	-
TWC effectiveness (pre-post)				99.7%	99.8%	97.1%	99.8%	-	99.9%	99.9%	97.7%	99.9%	-	99.6%	99.7%	99.0%	99.9%	-
5 795	30.12.2019	45.1 -0.87 0.0390	L1-0716	2	1	320	2	2.36E+10	1	1	178	3	6.39E+09	1	1	48	4	5.09E+10
				2	1	318	2	-	1	1	180	3	-	2	1	48	4	-
				571	539	8536	1496	-	458	437	6292	1997	-	399	381	4597	3253	-
				2	1	408	1	-	0	1	186	2	-	1	1	54	3	-
TWC effectiveness (pre-bag)				99.7%	99.8%	96.3%	99.9%	-	99.9%	99.9%	97.2%	99.8%	-	99.7%	99.8%	99.0%	99.9%	-
TWC effectiveness (pre-post)				99.6%	99.8%	95.2%	99.9%	-	99.9%	99.9%	97.0%	99.9%	-	99.6%	99.7%	98.8%	99.9%	-
Mean values				2	1	224	3	2.89E+10	1	1	113	4	6.27E+09	1	1	40	3	4.42E+10
				2	1	224	3	-	1	1	115	4	-	2	1	40	3	-
				558	530	8121	1851	-	438	418	5810	2266	-	366	348	4579	3390	-
				2	1	260	4	-	0	1	120	3	-	1	1	45	3	-
Standard deviation				0.1	0.1	84.5	1.4	7.07E+09	0.1	0.0	57.0	0.4	3.89E+08	0.0	0.0	6.7	0.2	4.72E+09
				0.2	0.1	83.8	1.3	-	0.1	0.0	57.2	0.4	-	0.1	0.0	6.7	0.2	-
				10.5	9.5	548.1	250.7	-	14.4	13.8	351.4	190.8	-	23.9	24.0	26.3	98.0	-
				0.3	0.1	116.8	2.1	-	0.1	0.0	57.5	0.7	-	0.1	0.1	7.2	0.0	-
Type A uncertainty				0.1	0.1	48.8	0.8	4.08E+09	0.0	0.0	32.9	0.2	2.25E+08	0.0	0.0	3.9	0.1	2.72E+09
				0.1	0.0	48.4	0.8	-	0.0	0.0	33.0	0.2	-	0.1	0.0	3.9	0.1	-
				6.1	5.5	316.4	144.8	-	8.3	8.0	202.9	110.2	-	13.8	13.8	15.2	56.6	-
				0.2	0.1	67.4	1.2	-	0.0	0.0	33.2	0.4	-	0.0	0.0	4.1	0.0	-
Mean TWC effectiveness (pre-bag)				99.7%	99.8%	97.3%	99.8%	-	99.8%	99.8%	98.1%	99.8%	-	99.6%	99.7%	99.1%	99.9%	-
Max. TWC effectiveness (pre-bag)				99.7%	99.8%	98.4%	99.9%	-	99.9%	99.9%	99.3%	99.9%	-	99.7%	99.8%	99.3%	99.9%	-
Min. TWC effectiveness (pre-bag)				99.7%	99.8%	96.3%	99.8%	-	99.8%	99.8%	97.2%	99.8%	-	99.6%	99.7%	99.0%	99.9%	-
Mean TWC effectiveness (pre-post)				99.7%	99.8%	96.9%	99.8%	-	99.9%	99.9%	98.0%	99.9%	-	99.6%	99.7%	99.0%	99.9%	-
Max. TWC effectiveness (pre-post)				99.7%	99.8%	98.3%	99.9%	-	99.9%	99.9%	99.2%	99.9%	-	99.6%	99.7%	99.2%	99.9%	-
Min. TWC effectiveness (pre-post)				99.6%	99.8%	95.2%	99.7%	-	99.9%	99.8%	97.0%	99.8%	-	99.6%	99.6%	98.8%	99.9%	-

Inertia [kg]:	1509			CO$_2$ emission					Fuel consumption					Note 1
				[g/km]					[l/100 km] $^{(2)}$					
Mileage[km]	Date	Chassis dyno F0/F1/F2	Test No.	WLTC	LOW	MIDDLE	HIGH	Ex-HIGH	WLTC	LOW	MIDDLE	HIGH	Ex-HIGH	
Ageing stage: 250 cycles														
5 749	19.12.2019	45.1 -0.87 0.0390	L1-0709	146.2	212.7	141.2	124.6	143.1	9.05	13.47	8.69	7.67	8.80	Bags
				147.5	214.4	142.1	125.5	144.8	9.13	13.58	8.75	7.72	8.91	Modal Dil
				141.9	199.4	134.3	123.0	141.2	9.45	13.72	9.07	8.17	9.19	Modal PRE cat
				152.3	213.3	147.5	132.7	149.3	9.42	13.50	9.08	8.16	9.19	Modal TP
TWC effectiveness (pre-bag)														TWC eff
TWC effectiveness (pre-post)														TWC eff
5 772	20.12.2019	45.1 -0.87 0.0390	L1-0712	146.2	212.7	142.0	124.9	142.3	9.06	13.55	8.76	7.69	8.76	Bags
				147.4	213.8	142.8	125.9	143.8	9.14	13.63	8.81	7.76	8.85	Modal Dil
				140.8	197.4	133.1	122.4	140.0	9.42	13.66	9.10	8.15	9.12	Modal PRE cat
				151.2	210.7	146.8	132.1	148.0	9.37	13.43	9.05	8.14	9.11	Modal TP
TWC effectiveness (pre-bag)														TWC eff
TWC effectiveness (pre-post)														TWC eff
5 795	30.12.2019	45.1 -0.87 0.0390	L1-0716	147.4	214.0	142.3	127.1	143.0	9.15	13.72	8.78	7.83	8.80	Bags
				148.6	215.7	143.3	127.5	144.7	9.23	13.83	8.84	7.86	8.91	Modal Dil
				135.8	198.3	130.1	114.3	134.3	9.19	14.09	8.93	7.73	8.78	Modal PRE cat
				151.6	220.5	146.1	130.0	147.5	9.43	14.22	9.03	8.01	9.08	Modal TP
TWC effectiveness (pre-bag)														TWC eff
TWC effectiveness (pre-post)														TWC eff
Mean values				146.6	213.1	141.8	125.5	142.8	9.09	13.58	8.74	7.73	8.79	Bags
				147.8	214.6	142.7	126.3	144.4	9.17	13.68	8.80	7.78	8.89	Modal Dil
				139.5	198.4	132.5	119.9	138.5	9.36	13.83	9.04	8.02	9.03	Modal PRE cat
				151.7	214.8	146.8	131.6	148.3	9.41	13.72	9.05	8.10	9.12	Modal TP
Standard deviation				0.56	0.63	0.47	1.11	0.33	0.05	0.10	0.04	0.07	0.02	Bags
				0.53	0.78	0.48	0.84	0.45	0.04	0.11	0.04	0.06	0.03	Modal Dil
				2.64	0.84	1.76	3.94	3.00	0.12	0.19	0.07	0.21	0.18	Modal PRE cat
				0.47	4.14	0.54	1.14	0.77	0.03	0.36	0.02	0.07	0.05	Modal TP
Type A uncertainty				0.32	0.36	0.27	0.64	0.19	0.03	0.06	0.02	0.04	0.01	Bags
				0.30	0.45	0.28	0.48	0.26	0.02	0.06	0.02	0.03	0.02	Modal Dil
				1.52	0.48	1.02	2.28	1.73	0.07	0.11	0.04	0.12	0.10	Modal PRE cat
				0.27	2.39	0.31	0.66	0.44	0.01	0.21	0.01	0.04	0.03	Modal TP

Table 20 Emissions and fuel consumption results from the Fiat Tipo 1.4 vehicle over the constant speed cycle for TWC High S



BOSMAL Automotive Research and Development Institute Ltd

Exhaust Emissions Testing Laboratory

Project custom test cycle - Constant speed (VConst)
thermally stabilised driving - 80 km/h in 5th gear

VIN: ZFA35600006K20252 **Vehicle model:** **Fiat Tipo 1.4 LPG**

Tyres: Continental ContiEcoContact 5 225/45 R17 V XL

Inertia [kg]:	1509			Phase 1 - 80 km/h in 5th gear (hot stabilised)						Phase 2 - 80 km/h in 5th gear (hot stabilised)						CO$_2$ emission		Fuel consumption		Note 1
Mileage [km]	Date	Chassis dyno F0/F1/F2	Test No.	[mg/km]						[mg/km]						[g/km]		[l/100 km] $^{(2)}$		
				THC	NMHC	CO	NOx	PM	PN	THC	NMHC	CO	NOx	PM	PN	P1	P2	P1	P2	
Ageing stage: 0 cycles				**BAG - MODAL DIL - PRE - POST**																
4 523	08.11.2018	45.1 -0.87 0.0390	L1-0496	0	0	26	0	0	1.81E+08	0	0	25	0	0.01	1.90E+08	103.7	100.5	6.29	6.24	Bags
				0	*0*	*26*	*0*	-	-	*0*	*0*	*24*	*0*	-	-	*103.9*	*100.6*	*6.30*	*6.25*	*Modal Dil*
				305	*291*	*2984*	*2221*	-	-	*300*	*286*	*2970*	*2219*	-	-	*100.3*	*97.1*	*6.43*	*6.38*	*Modal PRE cat*
				0	*0*	*34*	*0*	-	-	*0*	*0*	*32*	*0*	-	-	*105.9*	*102.6*	*6.42*	*6.37*	*Modal TP*
TWC effectiveness per phase				**100.00%**	**99.96%**	**98.87%**	**99.99%**	-	-	**100.00%**	**99.96%**	**98.92%**	**99.99%**	-	-					
Mean TWC effectiveness (mean of both phases)				**100.00%**	**99.96%**	**98.90%**	**99.99%**	-	-	-	-	-	-	-	-					
Max. TWC effectiveness (max. of both phases)				**100.00%**	**99.96%**	**98.92%**	**99.99%**	-	-	-	-	-	-	-	-					
Min. TWC effectiveness (min. of both phases)				**100.00%**	**99.96%**	**98.87%**	**99.99%**	-	-	-	-	-	-	-	-					
Ageing stage: 250 cycles				**BAG - MODAL DIL - PRE - POST**																
5 899	07.01.2020	45.1 -0.87 0.0390	L1-0005	0	0	46	0	0.09	1.67E+09	0	0	38	0	0.17	1.84E+09	104.4	102.9	6.43	6.33	Bags
				1	*0*	*46*	*0*	-	-	*1*	*0*	*38*	*0*	-	-	*104.7*	*103.1*	*6.44*	*6.34*	*Modal Dil*
				282	*268*	*3152*	*2218*	-	-	*272*	*258*	*3024*	*2159*	-	-	*101.1*	*99.7*	*6.58*	*6.47*	*Modal PRE cat*
				0	*0*	*51*	*0*	-	-	*0*	*0*	*42*	*0*	-	-	*106.8*	*105.1*	*6.57*	*6.47*	*Modal TP*
TWC effectiveness per phase				**100.00%**	**99.95%**	**98.39%**	**99.99%**	-	-	**100.00%**	**99.94%**	**98.61%**	**99.99%**	-	-					
Mean TWC effectiveness (mean of both phases)				**100.00%**	**99.94%**	**98.50%**	**99.99%**	-	-	-	-	-	-	-	-					
Max. TWC effectiveness (max. of both phases)				**100.00%**	**99.95%**	**98.61%**	**99.99%**	-	-	-	-	-	-	-	-					
Min. TWC effectiveness (min. of both phases)				**100.00%**	**99.94%**	**98.39%**	**99.99%**	-	-	-	-	-	-	-	-					

APPENDIX – FUEL CERTIFICATES

Appendix 1:

Results of analysis (PP3/2326/2018)

No	Parameter	Test standard	Unit	Result	Requirements for comparison
1	Sulphur content	ASTM D 6667-14 (A)	mg/kg	8.2	
2	Density at 15 °C	PN-EN ISO 8973:2000	km/m^3	549.2	-
3	Absolute vapor pressure at temperature 20 °C	PN-EN ISO 8973:2000 PN-EN 589 + A1:2012 app. C	kPa	514	-
4	Hydrocarbon composition	PN-EN 27941:2015-12 (A)	% mol % (m/m)		-
	methane			< 0.1 < 0.1	-
	ethane			0.6 0.3	-
	ethene			< 0.1 < 0.1	-
	propane			44.6 38.1	-
	propene			< 0.1 < 0.1	-
	isobutane			9.9 11.1	-
	cyclopropane			< 0.1 < 0.1	-
	n-butane			44.6 50.2	-
	propadiene			< 0.1 < 0.1	-
	1-butene			0.2 0.2	-
	isobutene			< 0.1 < 0.1	-
	2-transbutene			< 0.1 < 0.1	-
	isopentane			0.1 0.1	-
	2-cisbutene			< 0.1 < 0.1	-
	propene			< 0.1 < 0.1	-
	n-pentane			< 0.1 < 0.1	-
	3-methylbutene-1			< 0.1 < 0.1	-
	1,3-butadiene			< 0.1 < 0.1	-
	1,2-butadiene			< 0.1 < 0.1	-
	above C_5			< 0.1 < 0.1	-

Continued on next page

5	Odour	PN-EN 589 + A1:2012 p. 6.3 app. A (A)	Dimensionless quantity	imperceptible	-
6	Water content test	PN-C-96008:1998 p. 4.4.5 (A)	Dimensionless quantity	not detected	-

Appendix 2:

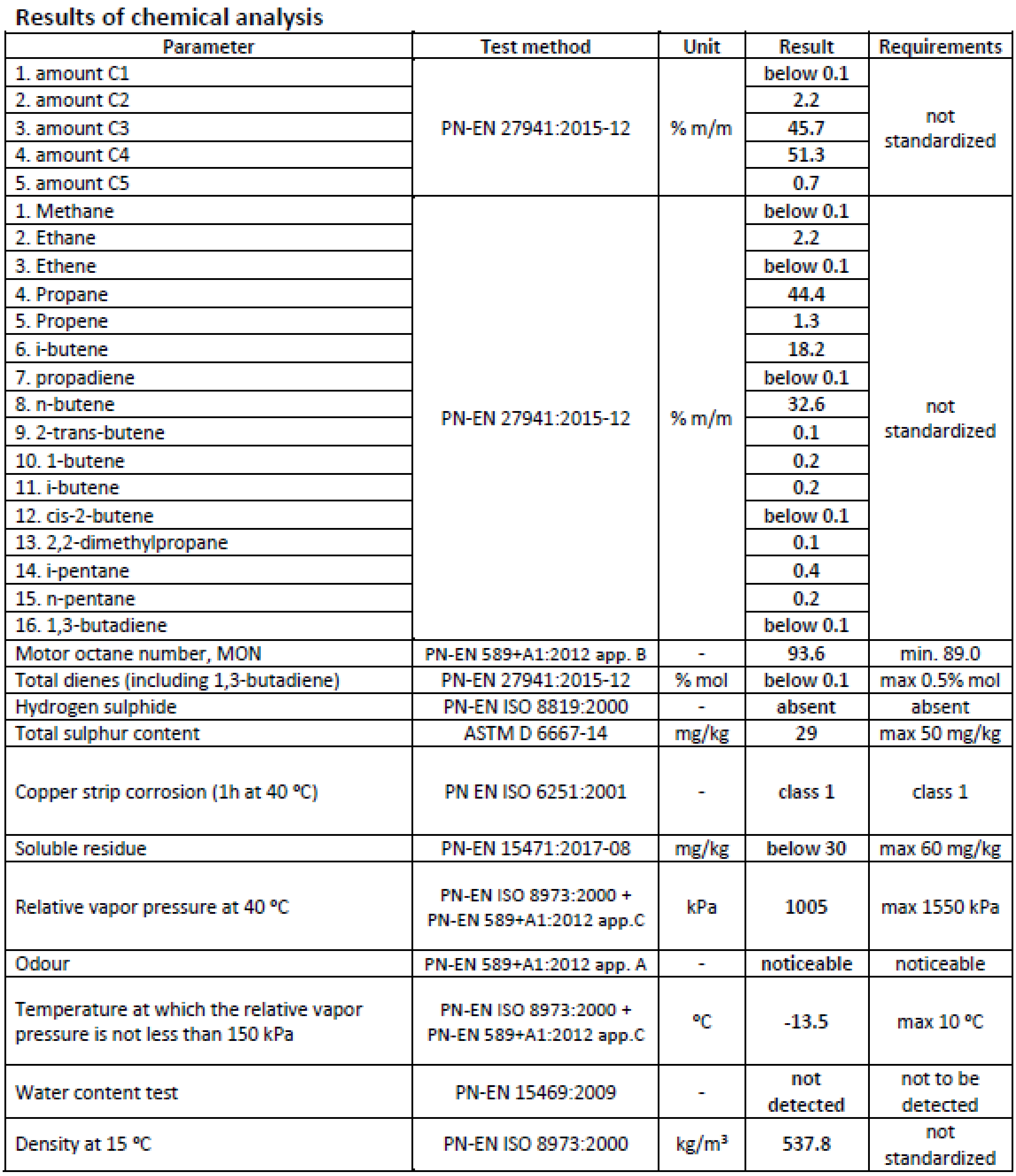
Results of analysis (PP3/61/2019)

No	Parameter	Test standard	Unit	Result	Requirements for comparison
1	Sulphur content	ASTM D 6667-14 (A)	mg/kg	8.2	
2	Density at 15 °C	PN-EN ISO 8973:2000	km/m^3	541.7	-
3	Absolute vapor pressure at temperature 20 °C	PN-EN ISO 8973:2000 PN-EN 589 + A1:2012 app. C	kPa	593	-
4	Hydrocarbon composition	PN-EN 27941:2015-12 (A)	% mol % (m/m)		-
	methane			< 0.1 < 0.1	-
	ethane			1.3 0.8	-
	ethene			< 0.1 < 0.1	-
	propane			53.9 47.3	-
	propene			< 0.1 < 0.1	-
	isobutane			5.4 6.2	-
	cyclopropane			< 0.1 < 0.1	-
	n-butane			39.2 45.4	-
	propadiene			< 0.1 < 0.1	-
	1-butene			0.2 0.3	-
	isobutene			< 0.1 < 0.1	-
	2-transbutene			< 0.1 < 0.1	-
	isopentane			< 0.1 < 0.1	-
	2-cisbutene			< 0.1 < 0.1	-
	propene			< 0.1 < 0.1	-
	n-pentane			< 0.1 < 0.1	-
	3-methylbutene-1			< 0.1 < 0.1	-
	1,3-butadiene			< 0.1 < 0.1	-
	1,2-butadiene			< 0.1 < 0.1	-
	above C_5			< 0.1 < 0.1	-

Continued on next page

5	Odour	PN-EN 589 + A1:2012 p. 6.3 app. A (A)	Dimensionless quantity	imperceptible	-
6	Water content test	PN-C-96008:1998 p. 4.4.5 (A)	Dimensionless quantity	not detected	-

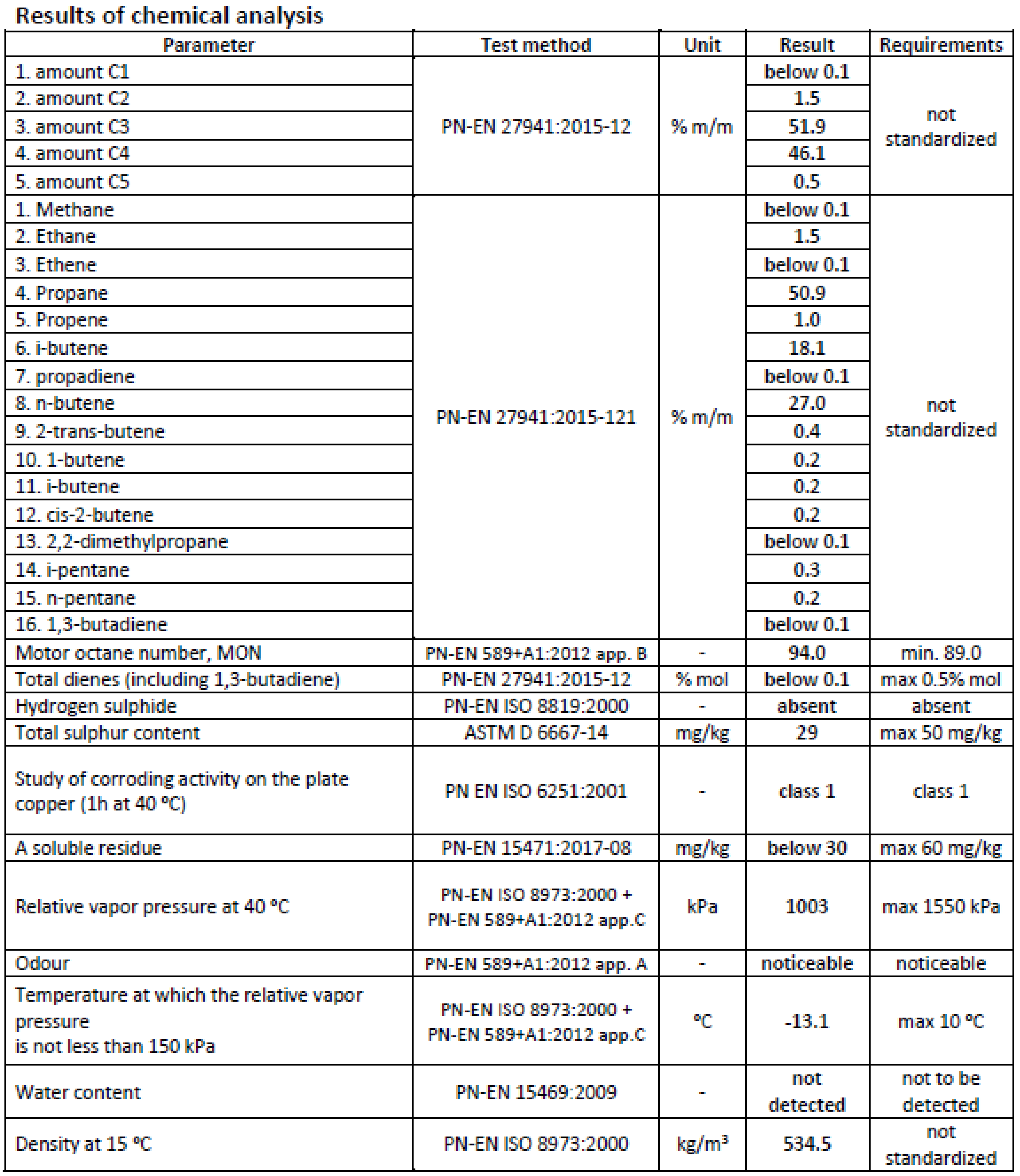
Appendix 3:



Results of chemical analysis

Parameter	Test method	Unit	Result	Requirements
1. amount C1	PN-EN 27941:2015-12	% m/m	below 0.1	not standardized
2. amount C2			2.2	
3. amount C3			45.7	
4. amount C4			51.3	
5. amount C5			0.7	
1. Methane	PN-EN 27941:2015-12	% m/m	below 0.1	not standardized
2. Ethane			2.2	
3. Ethene			below 0.1	
4. Propane			44.4	
5. Propene			1.3	
6. i-butene			18.2	
7. propadiene			below 0.1	
8. n-butene			32.6	
9. 2-trans-butene			0.1	
10. 1-butene			0.2	
11. i-butene			0.2	
12. cis-2-butene			below 0.1	
13. 2,2-dimethylpropane			0.1	
14. i-pentane			0.4	
15. n-pentane			0.2	
16. 1,3-butadiene			below 0.1	
Motor octane number, MON	PN-EN 589+A1:2012 app. B	-	93.6	min. 89.0
Total dienes (including 1,3-butadiene)	PN-EN 27941:2015-12	% mol	below 0.1	max 0.5% mol
Hydrogen sulphide	PN-EN ISO 8819:2000	-	absent	absent
Total sulphur content	ASTM D 6667-14	mg/kg	29	max 50 mg/kg
Copper strip corrosion (1h at 40 °C)	PN EN ISO 6251:2001	-	class 1	class 1
Soluble residue	PN-EN 15471:2017-08	mg/kg	below 30	max 60 mg/kg
Relative vapor pressure at 40 °C	PN-EN ISO 8973:2000 + PN-EN 589+A1:2012 app.C	kPa	1005	max 1550 kPa
Odour	PN-EN 589+A1:2012 app. A	-	noticeable	noticeable
Temperature at which the relative vapor pressure is not less than 150 kPa	PN-EN ISO 8973:2000 + PN-EN 589+A1:2012 app.C	°C	-13.5	max 10 °C
Water content test	PN-EN 15469:2009	-	not detected	not to be detected
Density at 15 °C	PN-EN ISO 8973:2000	kg/m³	537.8	not standardized

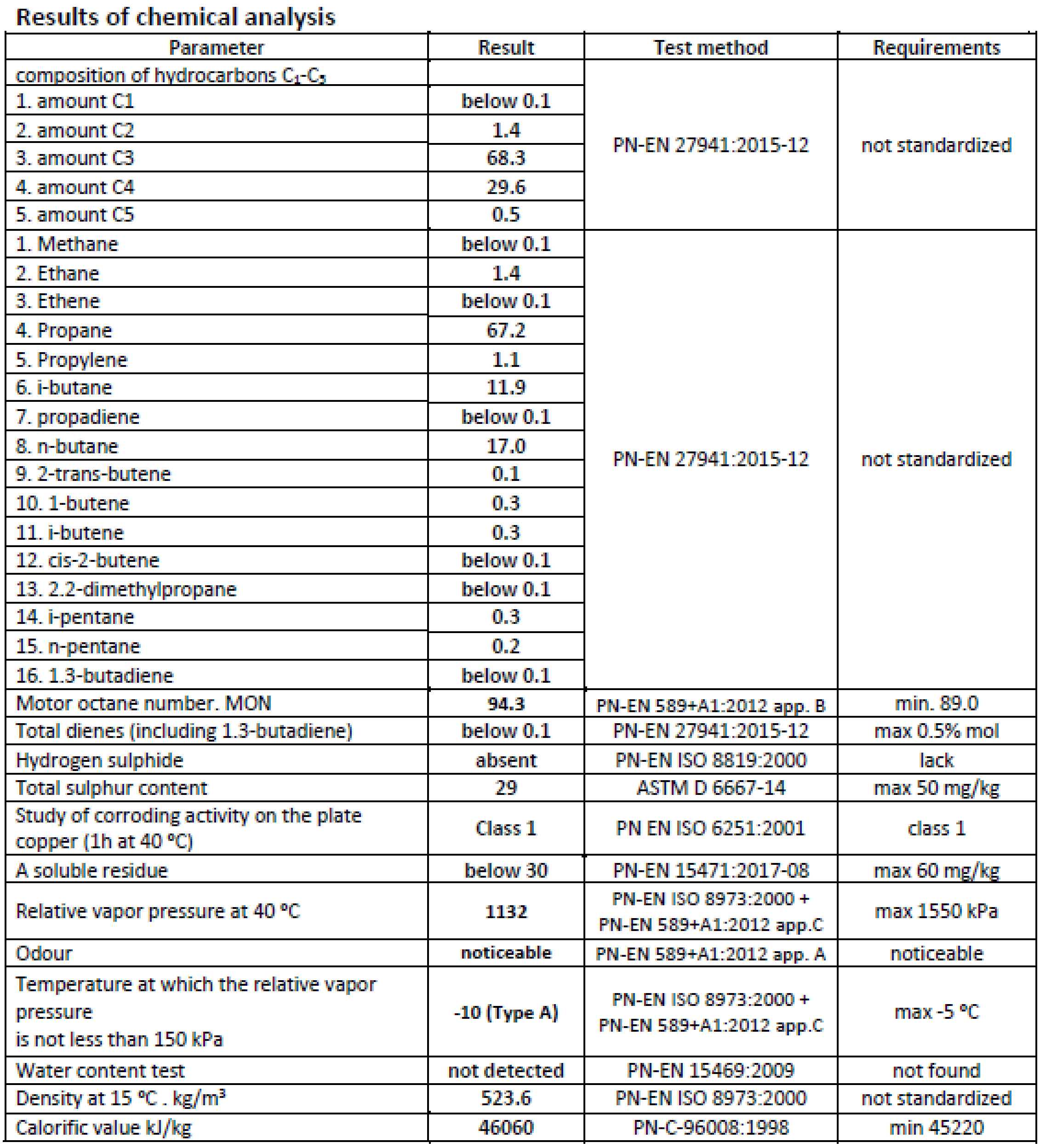
Appendix 4:



Results of chemical analysis

Parameter	Test method	Unit	Result	Requirements
1. amount C1	PN-EN 27941:2015-12	% m/m	below 0.1	not standardized
2. amount C2			1.5	
3. amount C3			51.9	
4. amount C4			46.1	
5. amount C5			0.5	
1. Methane	PN-EN 27941:2015-121	% m/m	below 0.1	not standardized
2. Ethane			1.5	
3. Ethene			below 0.1	
4. Propane			50.9	
5. Propene			1.0	
6. i-butene			18.1	
7. propadiene			below 0.1	
8. n-butene			27.0	
9. 2-trans-butene			0.4	
10. 1-butene			0.2	
11. i-butene			0.2	
12. cis-2-butene			0.2	
13. 2,2-dimethylpropane			below 0.1	
14. i-pentane			0.3	
15. n-pentane			0.2	
16. 1,3-butadiene			below 0.1	
Motor octane number, MON	PN-EN 589+A1:2012 app. B	-	94.0	min. 89.0
Total dienes (including 1,3-butadiene)	PN-EN 27941:2015-12	% mol	below 0.1	max 0.5% mol
Hydrogen sulphide	PN-EN ISO 8819:2000	-	absent	absent
Total sulphur content	ASTM D 6667-14	mg/kg	29	max 50 mg/kg
Study of corroding activity on the plate copper (1h at 40 °C)	PN EN ISO 6251:2001	-	class 1	class 1
A soluble residue	PN-EN 15471:2017-08	mg/kg	below 30	max 60 mg/kg
Relative vapor pressure at 40 °C	PN-EN ISO 8973:2000 + PN-EN 589+A1:2012 app.C	kPa	1003	max 1550 kPa
Odour	PN-EN 589+A1:2012 app. A	-	noticeable	noticeable
Temperature at which the relative vapor pressure is not less than 150 kPa	PN-EN ISO 8973:2000 + PN-EN 589+A1:2012 app.C	°C	-13.1	max 10 °C
Water content	PN-EN 15469:2009	-	not detected	not to be detected
Density at 15 °C	PN-EN ISO 8973:2000	kg/m³	534.5	not standardized

Appendix 5:



Results of chemical analysis

Parameter	Result	Test method	Requirements
composition of hydrocarbons C_1-C_5		PN-EN 27941:2015-12	not standardized
1. amount C1	below 0.1		
2. amount C2	1.4		
3. amount C3	68.3		
4. amount C4	29.6		
5. amount C5	0.5		
1. Methane	below 0.1	PN-EN 27941:2015-12	not standardized
2. Ethane	1.4		
3. Ethene	below 0.1		
4. Propane	67.2		
5. Propylene	1.1		
6. i-butane	11.9		
7. propadiene	below 0.1		
8. n-butane	17.0		
9. 2-trans-butene	0.1		
10. 1-butene	0.3		
11. i-butene	0.3		
12. cis-2-butene	below 0.1		
13. 2.2-dimethylpropane	below 0.1		
14. i-pentane	0.3		
15. n-pentane	0.2		
16. 1.3-butadiene	below 0.1		
Motor octane number. MON	94.3	PN-EN 589+A1:2012 app. B	min. 89.0
Total dienes (including 1.3-butadiene)	below 0.1	PN-EN 27941:2015-12	max 0.5% mol
Hydrogen sulphide	absent	PN-EN ISO 8819:2000	lack
Total sulphur content	29	ASTM D 6667-14	max 50 mg/kg
Study of corroding activity on the plate copper (1h at 40 °C)	Class 1	PN EN ISO 6251:2001	class 1
A soluble residue	below 30	PN-EN 15471:2017-08	max 60 mg/kg
Relative vapor pressure at 40 °C	1132	PN-EN ISO 8973:2000 + PN-EN 589+A1:2012 app.C	max 1550 kPa
Odour	noticeable	PN-EN 589+A1:2012 app. A	noticeable
Temperature at which the relative vapor pressure is not less than 150 kPa	-10 (Type A)	PN-EN ISO 8973:2000 + PN-EN 589+A1:2012 app.C	max -5 °C
Water content test	not detected	PN-EN 15469:2009	not found
Density at 15 °C . kg/m³	523.6	PN-EN ISO 8973:2000	not standardized
Calorific value kJ/kg	46060	PN-C-96008:1998	min 45220

Appendix 6:

Results of chemical analysis

Parameter	Test method	Unit	Result	Requirements
Total sulphur content	ASTM D 6667-14	mg/kg	29	max 50 mg/kg
Copper strip corrosion (1h at 40 °C)	PN EN ISO 6251:2001	-	class 1	class 1

Appendix 7:

Making our world more productive

Page 1 of 1

LINDE GAZ POLSKA SP.ZO.O.

ul. prof. Michala Zyczkowskieg
P-31-864 KRAKOW

Order number: 103000572211/1
Cylinder number: 2727603
Cylinder owner: Linde cylinder
Cylinder volume [l]: 50,00

ISO 9001
ISO 14001
ISO 22000
SCC**

CERTIFICATE Class 1
DIN EN ISO 6141

Components	Nominal value	Actual value	rel. uncertainty in % [1]
propane	30,0 %	30,5 %	± 2
butane	Balance		

Indications in percent and ppm are to be interpreted as ideal parts per volume. All indications of volume are related to STP (1013 mbar; 273,15 K)
The results are certified on the basis of analytics

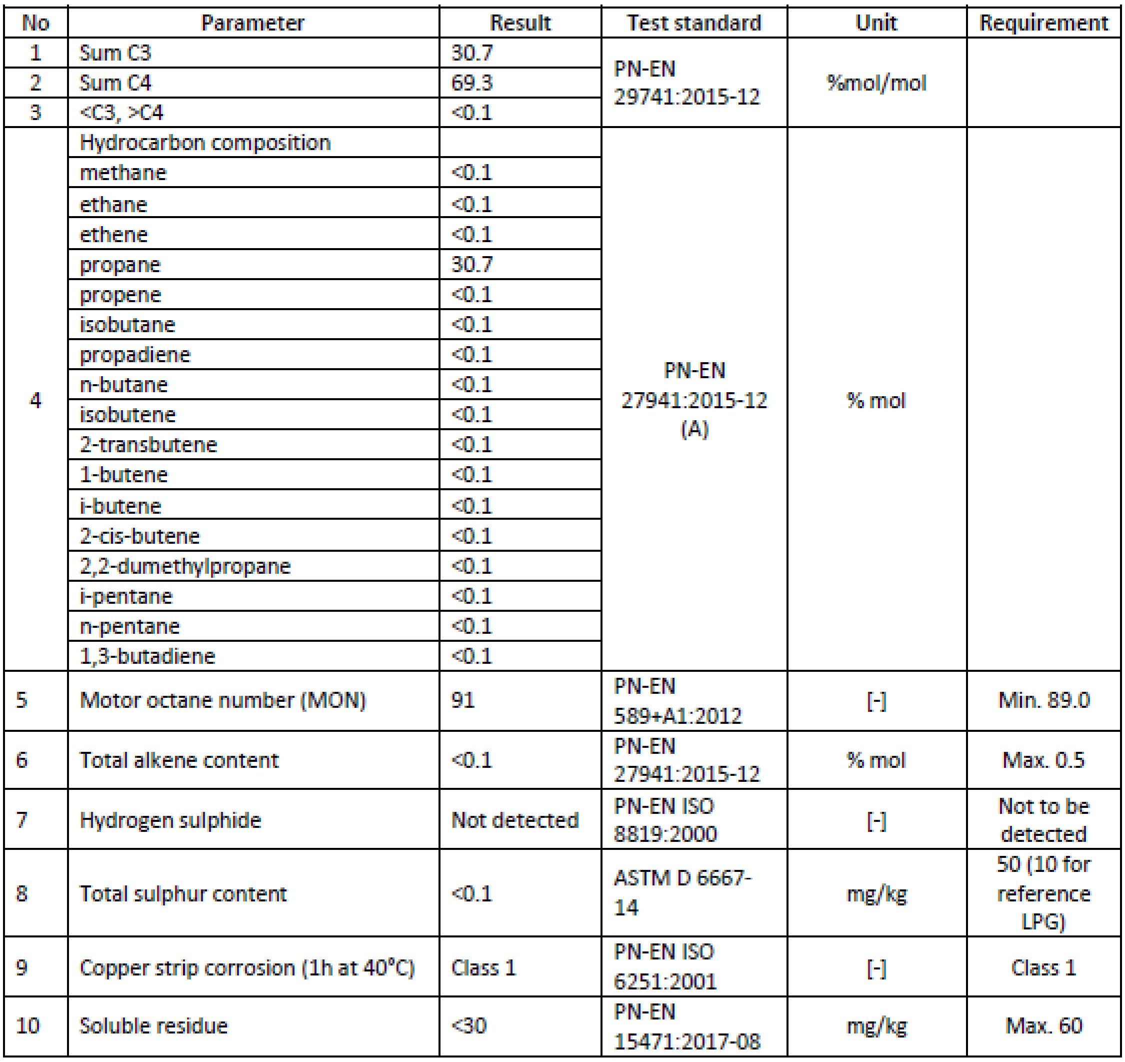
[1] expressed as the expanded measurement uncertainty (coverage factor *k* = 2)

Pressure [15° C]:		Min. storage temperature:	Not applicable
Contents:	21,002 kg	Min. pressure of utilization:	
Stability:	12 months	Rec. usage temperature:	10 °C - 30 °C
Valve outlet:	01 DV-TR	Net weight [Kg]:	21,002
Order:	315790914 / 000020		
Your Order:	PL1-12469		

Cylinder with dip tube and double valve.
Helium headpressure 15 bar

Appendix 8:

Translation of: REPORT NO. 33/TCH/2018-1



No	Parameter	Result	Test standard	Unit	Requirement
1	Sum C3	30.7	PN-EN 29741:2015-12	%mol/mol	
2	Sum C4	69.3			
3	<C3, >C4	<0.1			
4	Hydrocarbon composition		PN-EN 27941:2015-12 (A)	% mol	
	methane	<0.1			
	ethane	<0.1			
	ethene	<0.1			
	propane	30.7			
	propene	<0.1			
	isobutane	<0.1			
	propadiene	<0.1			
	n-butane	<0.1			
	isobutene	<0.1			
	2-transbutene	<0.1			
	1-butene	<0.1			
	i-butene	<0.1			
	2-cis-butene	<0.1			
	2,2-dumethylpropane	<0.1			
	i-pentane	<0.1			
	n-pentane	<0.1			
	1,3-butadiene	<0.1			
5	Motor octane number (MON)	91	PN-EN 589+A1:2012	[-]	Min. 89.0
6	Total alkene content	<0.1	PN-EN 27941:2015-12	% mol	Max. 0.5
7	Hydrogen sulphide	Not detected	PN-EN ISO 8819:2000	[-]	Not to be detected
8	Total sulphur content	<0.1	ASTM D 6667-14	mg/kg	50 (10 for reference LPG)
9	Copper strip corrosion (1h at 40°C)	Class 1	PN-EN ISO 6251:2001	[-]	Class 1
10	Soluble residue	<30	PN-EN 15471:2017-08	mg/kg	Max. 60

APPENDIX – COMPLEMENTARY STUDY: CHEMICAL ANALYSES OF THE AGED TWCS

0. ABSTRACT

Aged three-way catalytic converters (TWCs) were subjected to chemical analyses using advanced laboratory methods. The aim was to quantify quantitative and qualitative differences in the samples, which had been exposed to exhaust gas generated by light duty engines running on two fuel types (CNG, LPG) and with two different sulphur levels (Low, High). Vehicle tests showed that the CNG TWC conversion efficiency was sensitive to sulphur content, while this was not the case for the LPG TWC. At the end of the vehicle tests, it was assumed that this was due to a better desulphation process in the LPG TWC, due to differences in equivalence ratio at high load between the two powertrain types (lean burn with CNG and rich mixture with LPG). The purpose of this study was to check and provide evidence for this assumption. Significant differences between the TWCs' inlet and outlet faces were quantified, as well as differences between the edges of the monolith channels and the channels themselves. The TWCs dedicated to the CNG engine had significantly higher sulphur content than their LPG counterparts; however, no positive correlation between fuel sulphur level and TWC sulphur abundance was evidenced by the results. The different measured sulphur levels between the CNG and LPG TWCs are likely to support the fact that the desulphation process occurs more in LPG operating conditions than in CNG operating conditions. However, the fact that the high-sulphur CNG and the low-sulphur CNG TWCs show the same level of sulphur, whereas the high-sulphur CNG TWC lost much more conversion efficiency shows a non-systematic relationship between the sulphur content of the analysed TWCs and their conversion efficiency. Because of the fact that empirical findings did not directly link the TWCs' sulphur content with their conversion efficiency, the analysis remains inconclusive regarding its initial assumption of a better desulphation process occurring in the LPG TWC.

1. DESCRIPTION AND IDENTIFICATION OF THE OBJECTS TESTED

The objects of the tests were four original aftertreatment systems (three-way catalysts, TWCs) two of which were dedicated to the Lancia Y 0.9 Twin Air CNG application and two of which were dedicated to the Fiat Tipo 1.4 T-Jet LPG application. Within each sub-group, one TWC was denoted as 'Low S', and 'High S'. The four test objects are identified in Table 1.

Table 1 Data of the test objects

Parameter	CNG Low S	CNG High S	TWC Low S	TWC High S
Exhaust aftertreatment system type	Close-coupled three-way catalytic converter		Close-coupled three-way catalytic converter	
Approx. monolith volume [dm^3]	1.0		1.4	
Total PGM content [g/ft^3]; [g/dm^3]	200; 7.063		150; 5.30	
PGM content (Pt:Pd:Rh)	0/192/8 (0:24:1)		0:145:5 (0:29:1)	
Intended application	Aftertreatment system for Lancia Ypsilon (Y) 0.9 Twin Air CNG		Aftertreatment system for Fiat Tipo 1.4 T-Jet LPG	

Prior to their use in this study, the four test objects had previously been the subject of two experimental programmes had been carried out to assess the impact of fuel sulphur level on TWC emissions performance (conversion efficiency) [1], [2].

2. INTRODUCTION; OBJECTIVE OF THE TESTS

Physicochemical characterisations of aged aftertreatment for spark ignition engines (three-way catalysts – TWCs) were carried out in order to assess the impact of variable ageing conditions on the TWCs themselves. Results were obtained in order to provide further insight into the conversion efficiency of the TWCs, which had been previously assessed in separate studies. Two samples were taken from each test object (TWC), one representing the TWC inlet (upstream face) and the other representing the TWC outlet (downstream face). Each sample was analysed using the following combinations of techniques:

- SEM/EDS (Scanning Electron Microscopy with Energy Dispersive Spectroscopy)
- WD-XRF (Wavelength Dispersive X-ray Fluorescence) and ICP-OES (Inductively coupled plasma - optical emission spectrometry).

As mentioned previously, two experimental programmes had been carried out to assess the impact of fuel sulphur level on the performance of the TWCs identified in Table 1 in eliminating regulated emissions. Overall, the results showed variable impacts of fuel sulphur on the test objects [1], [2]. The first study (on CNG fuel – [1]) focused on TWCs for a light-duty nominally stoichiometric CNG engine and showed a relatively clear, noteworthy deterioration in TWC conversion efficiency (i.e. an increase in regulated exhaust emissions) following ageing on CNG fuel of higher sulphur content. In the case of CNG, it was concluded that significant sulphur-driven deactivation (chemical poisoning) took place. Despite the relatively high temperatures and non-static exhaust gas conditions encountered during the highly intensive ageing procedure conducted on the CNG engine, it was adjudged that the TWC was not effectively purged of sulphur, or at least at a rate well below the rate at which sulphur accumulated. Differences in emissions performance (comparing low sulphur fuel to high sulphur fuel) increased over time. The second study (on LPG fuel – [2]) was conceptually very similar to the first, but performed on TWCs for a light-duty, nominally stoichiometric LPG application. That study showed a markedly different trend, namely that TWC performance showed essentially no significant response to LPG fuel sulphur level, even following extensive ageing. In the case of LPG, it was adjudged that the combination of high temperature and exhaust gas of highly variable composition originating from the engine used for ageing – from well below stoichiometry (i.e. $\lambda<1$) at full load to fuel cut-off (i.e. $\lambda>>1$) – enabled passive regeneration of the TWC in the form of sulphur purging.

In order to test these hypotheses and further examine the implications, chemical characterisations were undertaken to investigate differences between the four test objects: CNG-dedicated TWC aged on low-sulphur fuel, CNG-dedicated TWC aged on high-sulphur fuel, LPG-dedicated TWC aged on low-sulphur fuel and LPG-dedicated TWC aged on high-sulphur fuel. Differences were examined according to three distinct (but related) comparison criteria, as shown in Table 2.

Table 2 Comparison matrix for the four test objects

Impact of fuel sulphur level	CNG low S vs CNG high S		LPG low S vs LPG high S	
Intra-TWC differences	CNG low S: inlet vs outlet	CNG high S: inlet vs outlet	LPG low S: inlet vs outlet	LPG high S: inlet vs outlet
Impact of TWC specification and application/fuel-specific ageing	CNG (both TWCs) vs LPG (both TWCs)			

3. SCOPE AND METHODS OF THE TESTS

3.1 Preliminary sample preparation

All test objects (TWCs) had been stored, in their “as found” state (following ageing) at room temperature for at least 12 months. During that time, the TWCs’ inlets and outlets were unobstructed, meaning that the monoliths were exposed to indoor ambient air, but with no direct exposure to exhaust gas.

The monoliths were removed from the aftertreatment system canning by carefully cutting open the metal casing. The monoliths were handled with care and stored in a clean environment.

Next, a section of each of the test objects was taken, corresponding to the upstream and downstream faces (inlet and outlet). A precision saw was used to cut perpendicular to the edge of the monolith, thus creating a narrow disk of approximate thickness 10 mm. This sample was cut in half: half was ground into a fine powder for use in the analyses focusing on the overall chemical composition (WD-XRF and ICP-OES), while the other half was further divided in order to expose the channels running through the sample (i.e. parallel to the direction of flow of the exhaust gas), thus enabling examination of those areas via scanning electron microscopy (SEM).

3.2 Sample **preparation for WD-XRF and ICP-OES analysis**

The samples mentioned in point 3.1 were thoroughly ground in a ceramic mortar then pressed in a manual press in order to convert them to a form suitable for use in the analytical equipment employed (and in accordance with BOSMAL/I-7-43/06).

4. DESCRIPTION AND RESULTS OF THE TESTS

4.1 Measuring equipment

The specifications of the measuring equipment are shown in Table 3.

Table 3 Data of measuring devices

Device Name	Type	Identifying No.	Applicable BOSMAL test instruction
Analytical balance	Radwag	B/5341/BMC	-
ICP-OES spectrometer	Optima 8300	X/5407/BMC	BOSMAL/I-7-43/06
WD-XRF spectrometer	Rigaku ZSX Primus II	X/5403/BMC	BOSMAL/I-7-90/02

Note: see [1] and [2] for detailed descriptions of all equipment and measuring devices used in the ageing and emissions testing of the test objects carried out prior to this study.

4.2. Test results

4.2.1 WD-XRF and ICP-OES results for CNG TWCs

Results are shown in tabulated form below. The platinum group metals (PGM; Pt Pd and Rh) are shown in pure elemental form, while results base metals and other elements are shown on the basis of the element existing in the oxide form dominant at room temperature – i.e. Mg is shown as MgO; Al is shown as Al_2O_3, etc.

Table 4 Quantitative results from WD-XRF and ICP-OES for CNG TWCs

Element	TWC 1 CNG LOW S IN	TWC 1 CNG LOW S OUT	TWC 2 CNG HIGH S IN	TWC 2 CNG HIGH S OUT
	Test results [%] (1)			
Pt	0.013	0.010	0.017	0.012
Pd	1.2	1.0	0.89	0.79
Rh	0.027	0.025	0.028	0.026
Compound	Test results [%] (2)			
Na_2O	< 0.02 (3)	< 0.02 (3)	0.14	0.10
MgO	7.5	6.1	5.4	7.7
Al_2O_3	38.0	43.8	40.3	43.1
SiO_2	23.5	19.2	17.6	23.6
P_2O_5	1.3	0.16	1.7	0.43
SO_3	0.37	0.26	0.38	0.17
K_2O	0.028	0.025	0.024	0.029
CaO	0.48	0.13	0.63	0.38
TiO_2	0.55	0.57	0.51	0.51
Mn_2O_3	< 0.02 (3)	< 0.02 (3)	< 0.02 (3)	< 0.02 (3)
Fe_2O_3	0.64	0.52	0.59	0.56
NiO	0.092	0.028	0.080	0.042
CuO	< 0.02 (3)	< 0.02 (3)	0.042	< 0.02 (3)
ZnO	< 0.02 (3)	< 0.02 (3)	1.6	0.22
SrO	< 0.02 (3)	< 0.02 (3)	< 0.02 (3)	< 0.02 (3)
Y_2O_3	< 0.02 (3)	< 0.02 (3)	< 0.02 (3)	< 0.02 (3)
ZrO_2	11.6	13.3	13.7	10.3
BaO	2.3	2.0	2.4	2.1
La_2O_3	1.3	1.3	1.5	1.1
CeO_2	7.9	9.5	10.0	7.0
Pr_6O_{11}	0.95	1.1	0.94	0.66
Eu_2O_3	< 0.02 (3)	< 0.02 (3)	< 0.02 (3)	< 0.02 (3)
HfO_2	0.47	0.54	0.57	0.35
Nd_2O_3	< 0.02 (3)	< 0.02 (3)	< 0.02 (3)	< 0.02 (3)

(1) mean result from WD-XRF and ICP-OES method
(2) results from WD-XRF method
(3) result under method limit of quantification

As the results relate to measurements made from directly comparable samples, comparisons within and between the test of object for a given fuel type can be made. The results of a numerical comparison of this type are shown in Tables 5 and 6.

Table 5 Comparison of quantitative PGM results from WD-XRF and ICP-OES for CNG TWCs.

Element	Relative comparison of PGM abundances measured from CNG test objects (0%=numerically identical)			
	Inlet vs Inlet	Outlet vs Outlet	Low In vs Out	High In vs Out
Pt	27%	18%	26%	29%
Pd	30%	23%	18%	11%
Rh	4%	4%	8%	7%

Table 6 Comparison of quantitative elemental results from WD-XRF for CNG TWCs

Compound	Relative comparison of PGM abundances measured from CNG test objects (0%=numerically identical)			
	Inlet vs Inlet	Outlet vs Outlet	Low: Inlet vs Outlet	High: Inlet vs Outlet
Na_2O	N/D	N/D	N/D	29%
MgO	33%	23%	21%	43%
Al_2O_3	6%	2%	14%	7%
SiO_2	29%	21%	20%	34%
P_2O_5	27%	92%	156%	75%
SO_3	3%	42%	35%	55%
K_2O	15%	15%	11%	21%
CaO	27%	98%	115%	40%
TiO_2	8%	11%	4%	0%
Mn_2O_3	N/D	N/D	N/D	N/D
Fe_2O_3	8%	7%	21%	5%
NiO	14%	40%	107%	48%
CuO	N/D	N/D	N/D	N/D
ZnO	N/D	N/D	N/D	86%
SrO	N/D	N/D	N/D	N/D
Y_2O_3	N/D	N/D	N/D	N/D
ZrO_2	17%	25%	14%	25%
BaO	4%	5%	14%	13%
La_2O_3	14%	17%	0%	27%
CeO_2	23%	30%	18%	30%
Pr_6O_{11}	1%	50%	15%	30%
Eu_2O_3	N/D	N/D	N/D	N/D
HfO_2	19%	43%	14%	39%
Nd_2O_3	N/D	N/D	N/D	N/D

Generally speaking, the CNG test objects showed relatively high differences between the inlet and outlet PGM levels. However, the absolute levels for Pt are very low, meaning very small absolute differences equate to large relative differences. Comparisons for other compounds showed variable trends, with large relative differences observed in some cases (notably for phosphorous). The main assumed source of phosphorous is lubricating oil (and possibly fuel contaminants), yet the same oil type meeting the ACEA A3 standard was used for ageing (and indeed testing) of the test objects. However, the low absolutely abundances of many of the compounds quantified should be borne in mind when considering results of this type. Certain compounds with higher abundances showed relatively modest differences for both intra- and inter-sample comparisons, including the most abundant compound, Al_2O_3. Lacking a control (i.e. an unaged TWC of identical type), it was not possible to determine to what extent the observed differences resulted from inherent differences between the TWCs (and indeed their inlet and outlet faces), as opposed to fuel-specific ageing effects. In this context, and in light of the CNG emissions trends presented in [1], the lack of an overall positive correlation between CNG sulphur level and the measured abundance of sulphur in the samples would appear to be a potentially significant finding warranting further investigation.

4.2.2 WD-XRF and ICP-OES results for LPG TWCs

Results are shown in tabulated form below. As mentioned in the previous section, PGM are shown in pure elemental form, while results base metals and other elements are shown as oxides.

Table 7 Quantitative results from WD-XRF and ICP-OES for LPG TWCs

Element	TWC 3 LPG LOW S IN	TWC 3 LPG LOW S OUT	TWC 4 LPG HIGH S IN	TWC 4 LPG HIGH S OUT
	Test results [%] (1)			
Pt	0.017	0.017	0.017	0.016
Pd	0.67	0.56	0.67	0.61
Rh	0.021	0.015	0.016	0.015
Compound	Test results [%] (2)			
Na_2O	0.22	0.080	< 0.02 (3)	< 0.02 (3)
MgO	2.8	4.4	3.7	3.9
Al_2O_3	51.5	52.8	52.1	54.7
SiO_2	9.3	14.5	11.5	12.3
P_2O_5	2.5	0.20	2.0	0.070
SO_3	0.14	0.063	< 0.02 (3)	0.058
K_2O	2.2	0.16	0.088	0.045
CaO	0.35	0.075	0.15	0.050
TiO_2	0.27	0.36	0.27	0.34
Mn_2O_3	< 0.02 (3)	< 0.02 (3)	< 0.02 (3)	< 0.02 (3)
Fe_2O_3	0.82	0.72	0.80	0.70
NiO	0.031	0.030	0.036	0.033
CuO	0.10	< 0.02 (3)	0.082	< 0.02 (3)
ZnO	1.4	0.27	< 0.02 (3)	0.091
SrO	0.066	0.075	0.10	0.080
Y_2O_3	< 0.02 (3)	< 0.02 (3)	0.017	0.016
ZrO_2	10.6	10.2	11.0	10.7
BaO	3.1	3.2	3.4	2.9
La_2O_3	0.65	0.60	0.69	0.56
CeO_2	10.7	9.5	10.7	10.3
Pr_6O_{11}	< 0.02 (3)	< 0.02 (3)	< 0.02 (3)	< 0.02 (3)
Eu_2O_3	< 0.02 (3)	< 0.02 (3)	< 0.02 (3)	< 0.02 (3)
HfO_2	0.48	0.48	0.50	0.48
Nd_2O_3	1.2	1.1	1.2	1.1

(1) mean result from WD-XRF and ICP-OES method
(2) results from WD-XRF method
(3) result under method limit of quantification

Numerical comparisons of the results are shown in Tables 8 and 9.

Table 8 Comparison of quantitative PGM results from WD-XRF and ICP-OES for LPG TWCs.

Element	Relative comparison of PGM abundances measured from LPG test objects (0%=numerically identical)			
	Inlet vs Inlet	Outlet vs Outlet	Low In vs Out	High In vs Out
Pt	0%	6%	0%	6%
Pd	0%	9%	18%	9%
Rh	27%	0%	33%	6%

Table 9 Comparison of quantitative elemental results from WD-XRF for LPG TWCs.

Compound	Relative comparison of PGM abundances measured from LPG test objects (0%=numerically identical)			
	Inlet vs Inlet	Outlet vs Outlet	Low: Inlet vs Outlet	High: Inlet vs Outlet
Na_2O	N/D	N/D	93%	N/D
MgO	28%	12%	44%	5%
Al_2O_3	1%	4%	2%	5%
SiO_2	21%	16%	44%	7%
P_2O_5	22%	96%	170%	97%
SO_3	N/D	8%	76%	N/D
K_2O	185%	112%	173%	49%
CaO	80%	40%	129%	67%
TiO_2	0%	6%	29%	26%
Mn_2O_3	N/D	N/D	N/D	N/D
Fe_2O_3	2%	3%	13%	13%
NiO	15%	10%	3%	8%
CuO	20%	N/D	N/D	N/D
ZnO	N/D	99%	135%	N/D
SrO	41%	6%	13%	20%
Y_2O_3	N/D	N/D	N/D	6%
ZrO_2	4%	5%	4%	3%
BaO	9%	10%	3%	15%
La_2O_3	6%	7%	8%	19%
CeO_2	0%	8%	12%	4%
Pr_6O_{11}	N/D	N/D	N/D	N/D
Eu_2O_3	N/D	N/D	N/D	N/D
HfO_2	4%	0%	0%	4%
Nd_2O_3	0%	0%	9%	8%

Overall, the LPG test objects showed somewhat better agreement in terms of PGM levels compared to the CNG test objects, as regards both intra- and inter-TWC comparisons. As with the CNG test objects, comparisons for other compounds showed variable trends, with large relative differences observed in some cases (phosphorous, potassium, calcium and zinc). As in the case of the CNG test objects, the same oil type, which met the ACEA A3 standard, was used for ageing (and indeed testing) of the test objects. However, the low absolute abundances of many of the compounds quantified should be borne in mind when considering results of this type. As expected, compounds with higher abundances showed smaller differences in intra- and inter-sample comparisons. Due to the lack of control measurements, no concrete conclusions can be drawn on the causes and origins of the observed differences in abundance. However, the lack of an overall positive correlation between fuel sulphur level and observed sample sulphur abundance is a finding of potential significance.

4.2.3 SEM results for CNG TWCs

SEM analyses were carried out on samples from the inlet and outlet faces, with sample preparation as described in section 3.1, with the obvious exclusion of the grinding and homogenisation step, since the samples were analysed from the structural point of view, with a clear distinction made between the monolith channels themselves and the intersection where the channel was bounded by the channel walls. The aforementioned location types are hereafter referred to as ‘Channel’ and ‘Edge’, respectively.

SEM images of the CNG test objects are shown in Annex 1. To serve as a guide, a sample result set is shown in Figure 1.

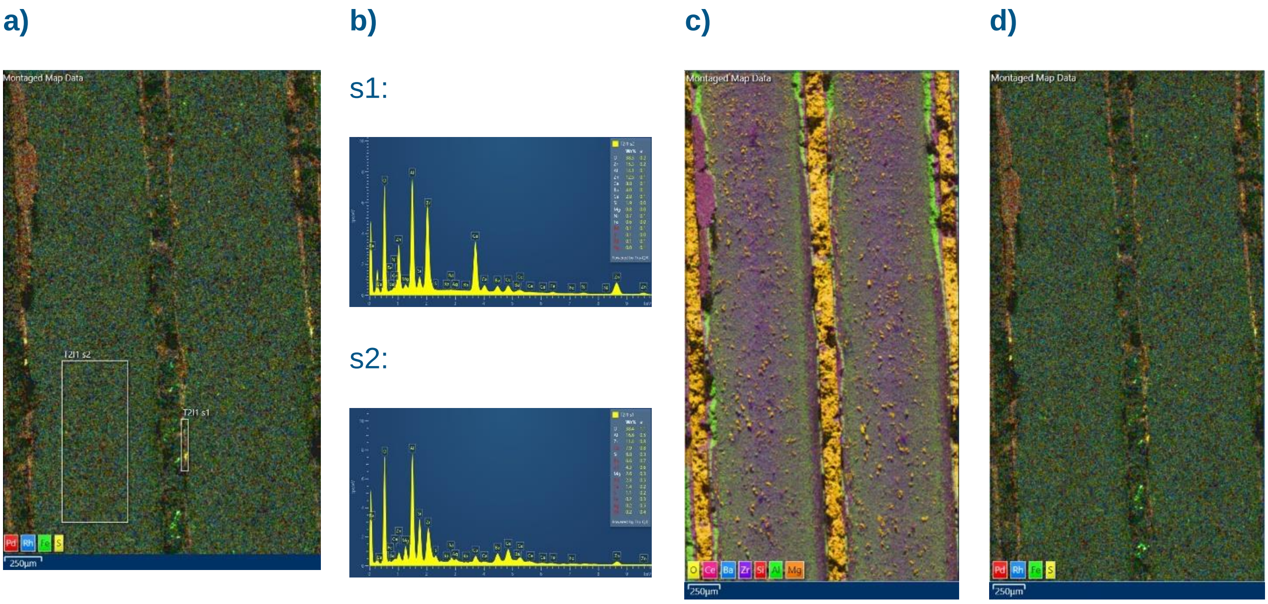


Figure 1 Sample SEM result set for a single location. a) map showing the location of indicated areas 1 and 2 (s1, s2); b) spectrograms for areas s1, s2; c) intensity-based map; d) map showing four chosen elements (Pd, Rh, S, Fe).

Each sample (inlet or outlet) was mapped 5 times; each map (panel a) in the figure above) contained a minimum of 2 indicated areas (s1, s2), in some cases supplemented by examination of a further area (s3) at the SEM operator's discretion. Thus, each sample was subject to a minimum of 10 measurements. The sites at the 5 locations (s1, s2) represented the edges and channels, with those two sites differentiated by eye, making use of the characteristic form of the wall and the elements associated with its core and boundaries to identify edges (refer to the intensity-based map - Figure 1, panel c)); the channel was simply the area between two edges, i.e. within the walls.

Panel b) presents the quantitative spectrograms for s1, s2. In panel c), the intensity-based map shows the distribution of elements with the highest abundances, which are dominated by base metals and oxygen. For that reason, panel d) shows the same map showing the four selected elements of primary interest in the context of this study: Pd and Rh, being the PGM species present in the test objects according to the manufacturer's specification; S, as the focus on the investigations and the independent variable in the ageing studies; and Fe as a tracer species for potential contamination introduced by material originating from engine wear and/or steel saw blades used in sample preparation. Regarding the final point, it can be stated that no direct evidence of any ferrous contamination was observed in any of the samples; however, exhaustive investigation of this aspect would require a control in the form of a sample which had not been exposed to neither engine ageing, nor to ferrous saw-blades.

4.2.4 SEM results for LPG TWCs

SEM analyses were carried out in an identical fashion to those performed on the CNG samples, as described in the previous section.

SEM images of the LPG test objects are shown in Annex 2. As with the CNG samples, it can be stated that no direct evidence of any ferrous contamination was observed.

5 GRAPHICAL COMPARISONS OF WD-XRF RESULTS; FURTHER DISCUSSION

The following figures present comparisons of the results presented in Tables 4 and 7, together with brief discussions of key observations. Results for compounds for which the measured value was below the limit of quantification are not shown in the figures.

As the desired functionality of a TWC is provided – above all – by PGM, the measured abundances of PGM from the test objects can be considered among their most fundamental characteristics. Results of that type are shown graphically in Figures 2 and 3 for the CNG test objects.

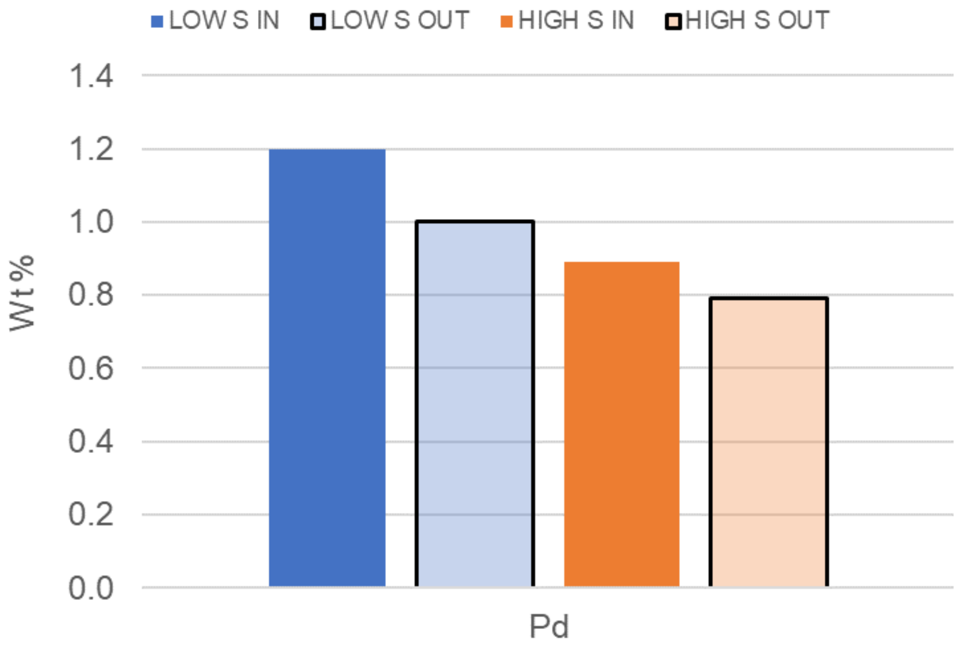


Figure 2 Pd abundance in the CNG test objects, measured by WD-XRF.

Figure 3 Rh abundance in the CNG test objects, measured by WD-XRF.

Figures 4 and 5 show equivalent results for the LPG test objects.

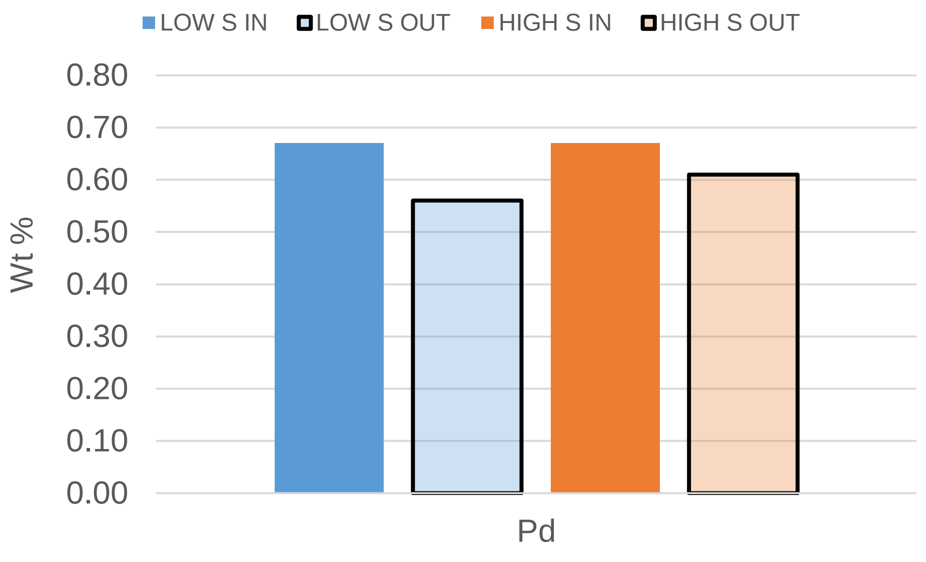


Figure 4 Pd abundance in the LPG test objects, measured by WD-XRF.

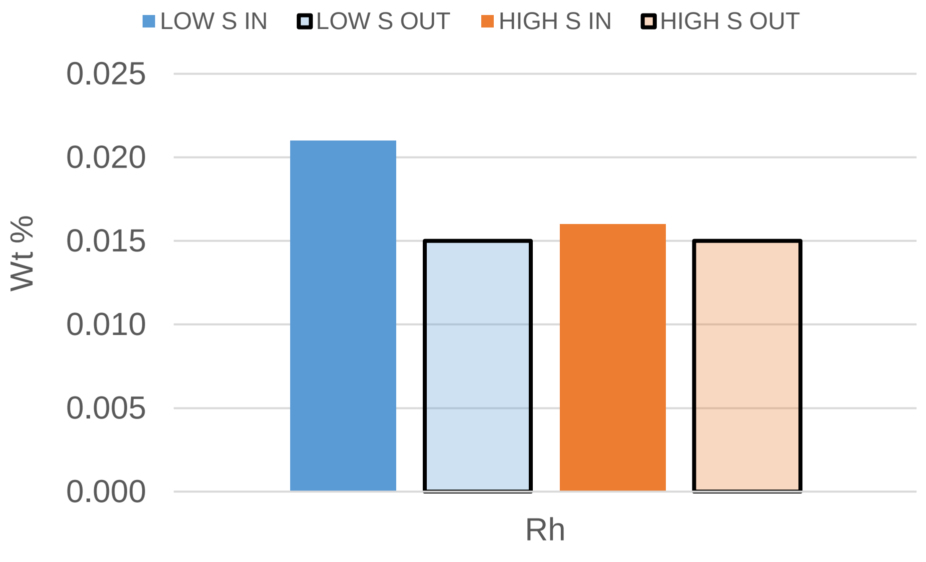


Figure 5 Rh abundance in the LPG test objects, measured by WD-XRF.

As the figures above show, a general trend could be observed for higher Pd and Rh abundances at the inlet than out the outlet of a given test object. However, the results suggest that in some cases differences in abundance were present between test objects of the same type. For example, the Pd abundances in the CNG test objects were measured as being lower in the case of the High unit (Figure 2). The same can be said for the case of Rh for the inlet sample of the LPG units (Figure 5). These measured differences, while rather large in relative terms, are relatively modest in absolute terms and may not necessarily be fully representative of the composition of the test objects.

Base metals including Al, Ce, La, Ba and Zr also play important roles in co-catalysis, oxygen storage, general promotion, structural support and overall stabilisation [3]; results for those five elements, plus Si and Mg are shown in the figures below; Al is shown separately due to its high abundance. Results of that type are shown graphically in Figures 6 and 7 for the CNG test objects.

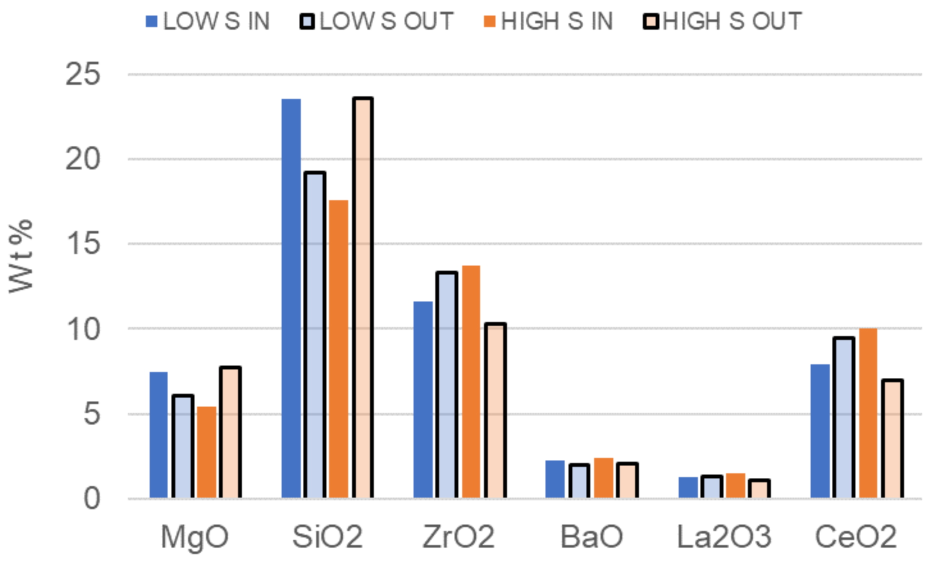


Figure 6 Abundances of selected compounds in the CNG test objects, measured by WD-XRF.

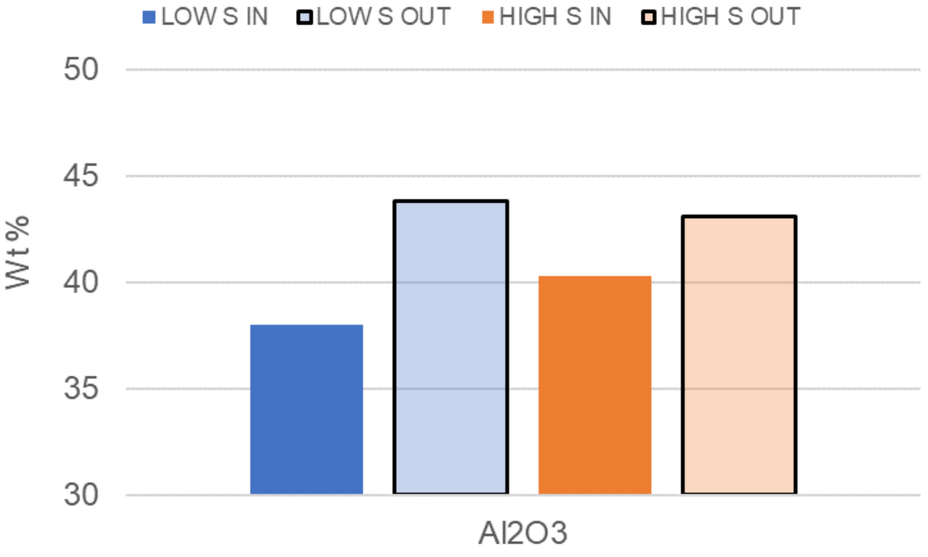


Figure 7 Abundance of Al_2O_3 in the CNG test objects, measured by WD-XRF.

Figures 8 and 9 show the same results for the LPG test objects.

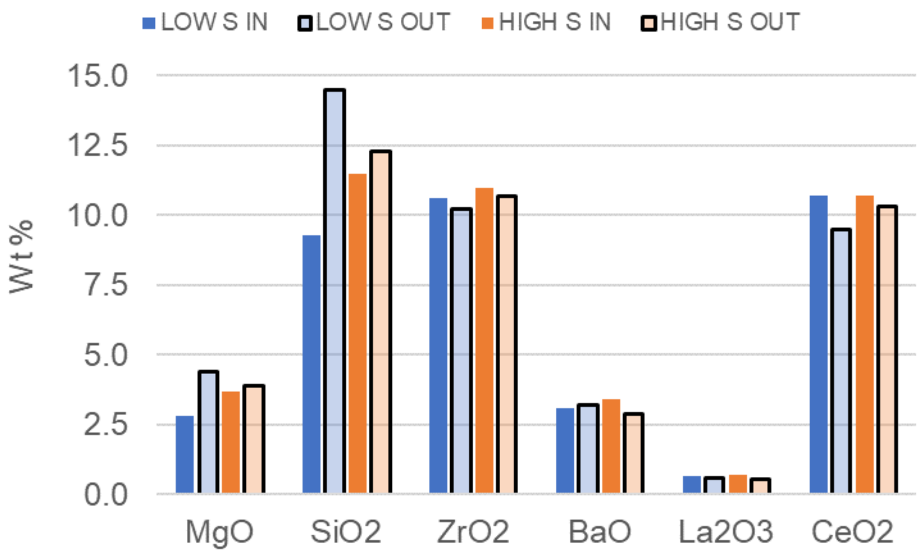


Figure 8 Abundances of selected compounds in the LPG test objects, measured by WD-XRF.

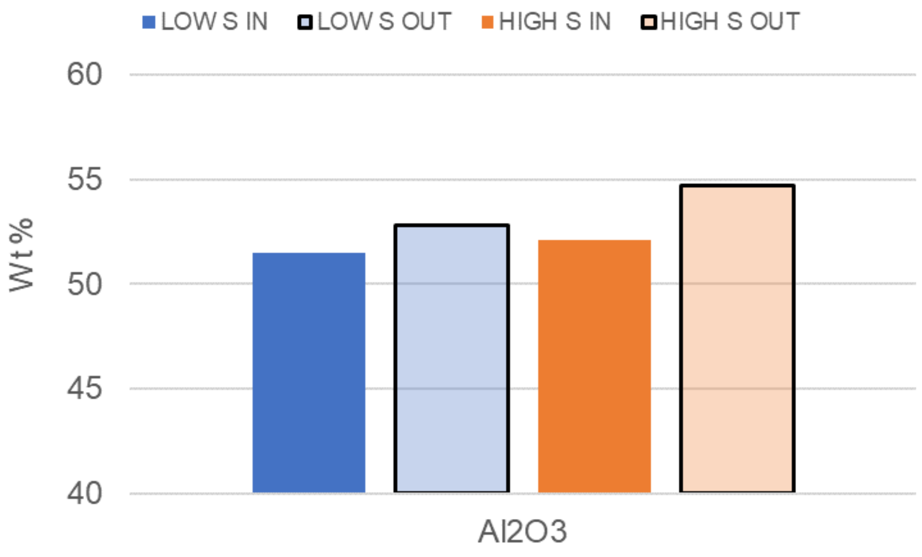


Figure 9 Abundance of Al_2O_3 in the LPG test objects, measured by WD-XRF.

As the independent variable in the TWC ageing studies ([1], [2]) was fuel sulphur content, and as both PGM and base metals present in TWCs are well-known to suffer adverse impacts to their functionality caused by sulfation [3], the measured abundance of sulphur in the test objects was a key point of interest in this study. Results of that type are shown graphically in Figure 10. As with the distribution of PGM, it should be recalled that the measured abundances from the inlet and outlet face samples are not necessarily representative of the holistic value applicable to the entire monolith.

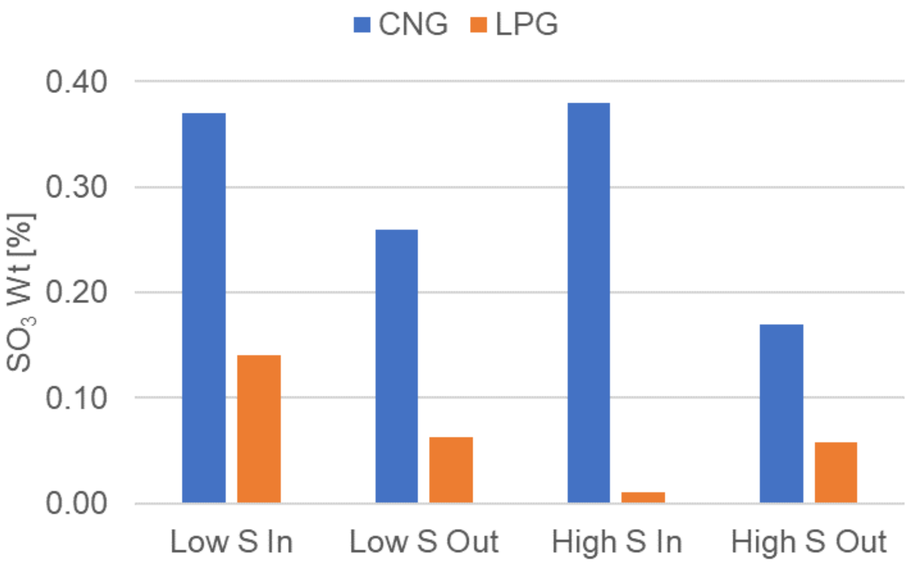


Figure 10 Sulphur abundance in all samples from all test objects, measured by WD-XRF.

As Figure 10 clearly shows, the CNG test objects' sulphur abundance was much higher than that of the LPG test objects, with differences being 264-412% for direct comparisons of all samples except for CNG/LPG High S Inlet, for which the measured difference was an extreme outlier (38-fold). With the exception of the aforementioned outlying result, a finding of this type was broadly expected, due to the test objects' emissions performance following ageing (see [2] for a discussion of this aspect). As regards the source of sulphur as an input to the system, the fuels used in [1] and [2] featured sulphur levels of a comparable order of magnitude; the total quantity of fuel consumed is not identical for the CNG engine and LPG engine employed in the ageing studies, but again the total mass of fuel consumed can be considered to be of the same order of magnitude, since the energy demand of the ageing procedures used on the engines showed limited differences; furthermore, the number of cycle repetitions was identical for both studies/engines.

In order to allow visual comparison, the two sets of results are plotted separately below in Figures 11 and 12.

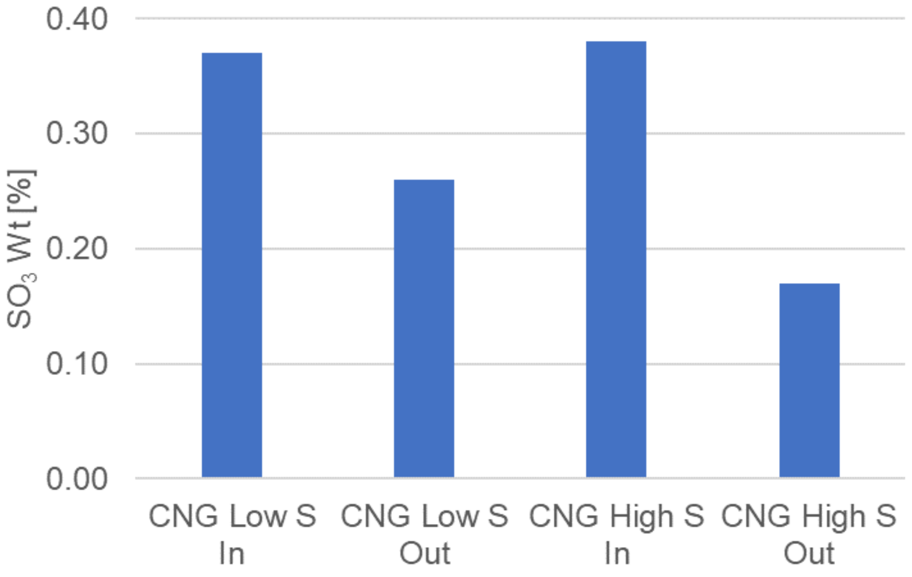


Figure 11 Sulphur abundance in samples from CNG test objects, measured by WD-XRF.

For the CNG test objects, there was a clear tendency for the inlet sample to have a higher sulphur abundance than the outlet. The impact of fuel sulphur level was variable: the inlet abundances were essentially identical (difference <3%), thus giving no correlation between that parameter and the fuel sulphur level. The outlet abundances revealed an in verted correlation, since the sample aged on high sulphur fuel showed a lower abundance of that element (difference 35%).

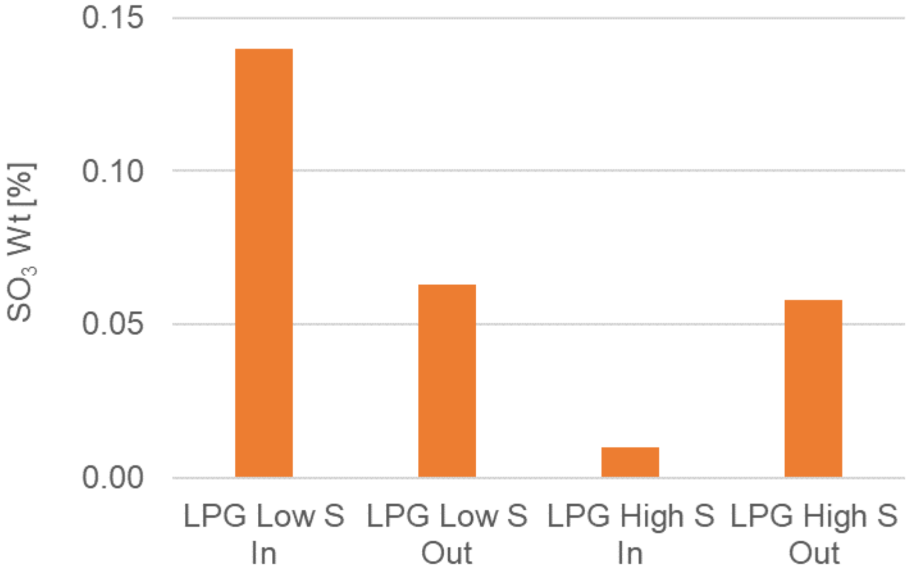


Figure 12 Sulphur abundance in all samples from LPG test objects, measured by WD-XRF.

For the LPG test objects, there was a large difference between the inlet abundances (55%), again showing an inverse correlation with the fuel sulphur level, as was the case with the CNG units. While the outlet abundances were similar for both LPG test objects (difference <8%), the inlet abundance of the LPG High S unit was at a very low level, showing different behaviour than the other three test objects, for which $S_{inlet}>S_{outlet}$ in all cases.

While WD-XRF results are obtained from homogenised samples which present a holistic representation of the overall chemical composition of the cross section, the inlet and outlet samples are not necessarily representative of the entire volume of the monolith from which they were taken. Especially for TWCs which have been subject to extended high-temperature ageing (as was the case with all four test objects examined in this study), the formation of cracks and other small-scale mechanical defects may lead to uneven flow through the monolith, since the exhaust gas stream will have a tendency to follow the path of least resistance. In light of the possibility the aforementioned effects contributing (at least somewhat) and their evident implications for emissions performance, it can be stated that further analysis of additional samples taken from the inlet and outlet zones, as well as intermediate points, would significantly reduce the uncertainty associated with the measured abundances. (Note however, that quantitative assessments of sulphur abundance obtained via the SEM method are also available from this study and are indeed presented in the following section of this report.)

When reviewing the results for abundance of sulphur, an important consideration is the baseline level of that element which was present in the test objects before any ageing was carried out – and to what degree this might differ between the inlet and the outlet and between test objects. The abundance of sulphur atoms in pristine (unaged) TWCs was not assessed in this study, since all test objects had been aged, as described previously. Despite conducting exhaustive enquiries, it was not possible to obtain quantitative S abundances for the test objects, nor for other TWCs of similar type. It was, however, confirmed that while industry-standard ceramics (cordierite) do not include S atoms in their idealised structures [4], [5], the raw mineral sources that are used to produce monoliths and other elements of the TWC typically include low but measurable quantities of sulphur. Various additives used prior to the extrusion process [4] may also contain at least some sulphur; a certain proportion of the sulphur from the aforementioned sources is inevitably carried over into the final product. High-temperature kiln firing – the final stage of the monolith manufacturing process [4] – removes a range of impurities and can be assumed to result in all remaining S atoms present in the fired monolith being in a form which will not have a detrimental impact on TWC performance. That is to say, a certain abundance of S atoms will remain in the monolith, not present in the elemental form, but within compounds which have survived the kiln firing process and are therefore by definition stable at very high temperatures. The quantitative abundance and qualitative distribution of S atoms may vary somewhat between TWCs, although TWCs of the same type, from the same manufacturer and originating from identical or closely-spaced production batches are likely to have at least similar levels and distributions of S atoms. However, the same assertion cannot be made with the same degree of confidence when comparing monoliths of different type, especially where they were produced some time apart and possibly by different manufacturers. As the experimental work performed in this study (and in the ageing studies themselves [1], [2]) did not include analysis of pristine (unaged) TWCs, it is not possible to comment any further on the observed tendencies for sulphur abundances in the test objects. Specifically, the question as to what proportion of the measured sulphur abundance present in the test objects prior to any ageing being carried out cannot be answered without further measurements carried out on equivalent test objects or supply of such data from a third party.

6 GRAPHICAL COMPARISONS OF SEM RESULTS; FURTHER DISCUSSION

While SEM results may be understood as being primarily qualitative in nature, the mapping process generates quantitative data, which may be used to examine elemental abundances in the areas examined. As each sample was mapped 5 times, and as each map area contained at least 2 indicated areas, quantitative data obtained from those areas could be collated and processed to produce a mean measured abundance, together with associated uncertainty. The division of sites into edge and channel categories was maintained. Based on this approach, quantitative plots were produced based on data obtained via SEM analysis. In analysing these results, it is important to recall certain points:

- the relatively limited number of measurements and the relatively high uncertainty associated with each measurement – reflected in the magnitude of the error bars in the plots below,
- the non-holistic nature of the SEM technique and the arbitrary choice of the indicated areas,
- the potential for strong shielding effects owing to limited electron penetration through the washcoat,
- the fact that SEM response is proportional to atomic mass (and is therefore significantly weaker for light elements such as sulphur than for PGM).

Figures 13 and 14 show results for the CNG test objects, separated according to the nature of the indicated sites (edge/channel), as well as by sample type (inlet/outlet).

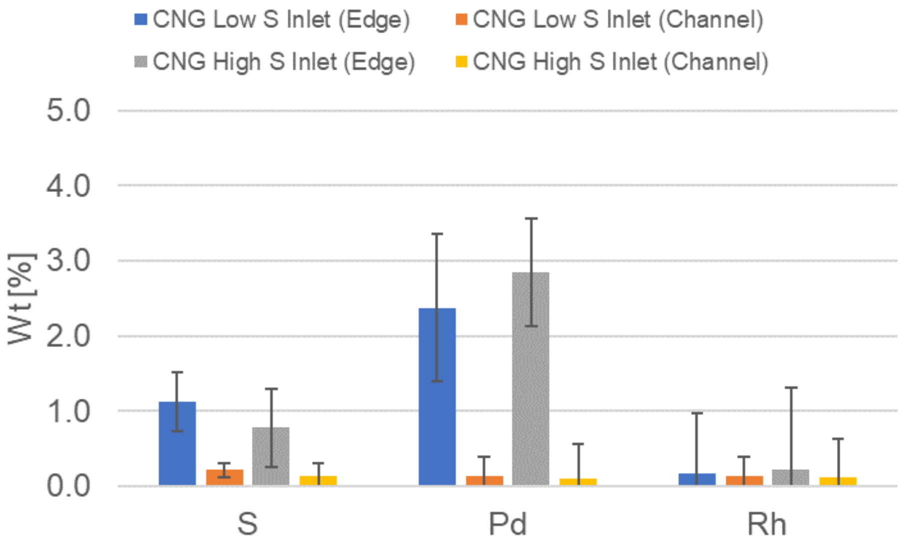


Figure 13 Abundances S, Pd and Rh in the inlet samples of the CNG test objects, measured by SEM and divided by nature of site.

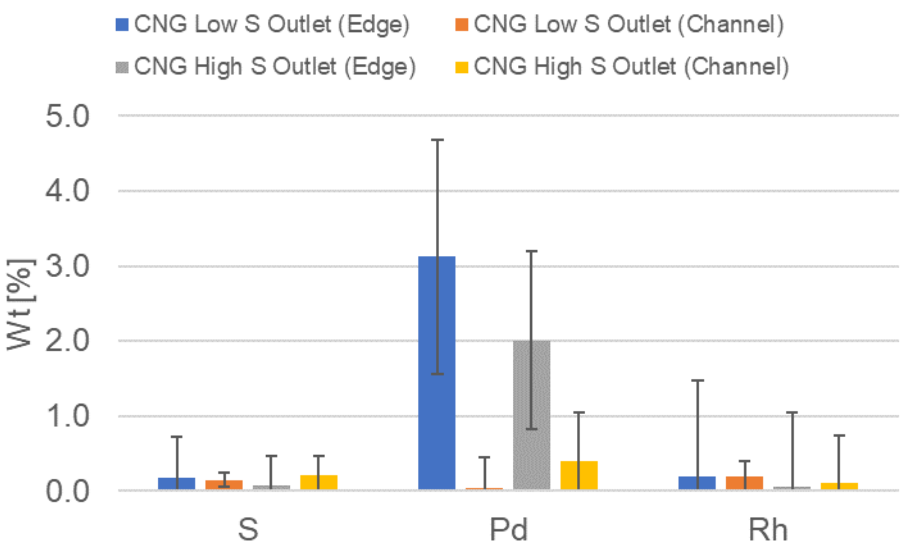


Figure 14 Abundances S, Pd and Rh in the outlet samples of the CNG test objects, measured by SEM and divided by nature of site.

Due to the large disparity in abundance between Pd and Rh (and S, in certain cases), the same plots are shown below without palladium.

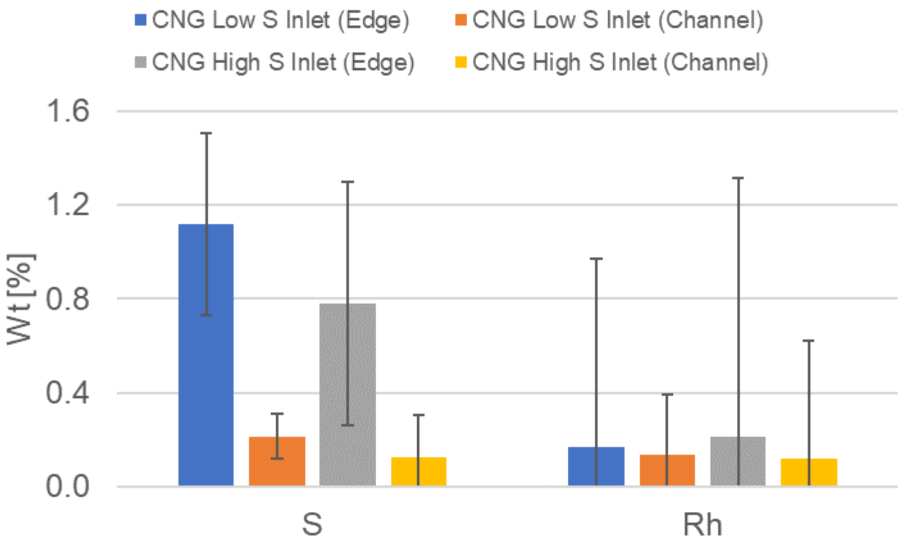


Figure 15 Abundances S and Rh in the inlet samples of the CNG test objects, measured by SEM and divided by nature of site.

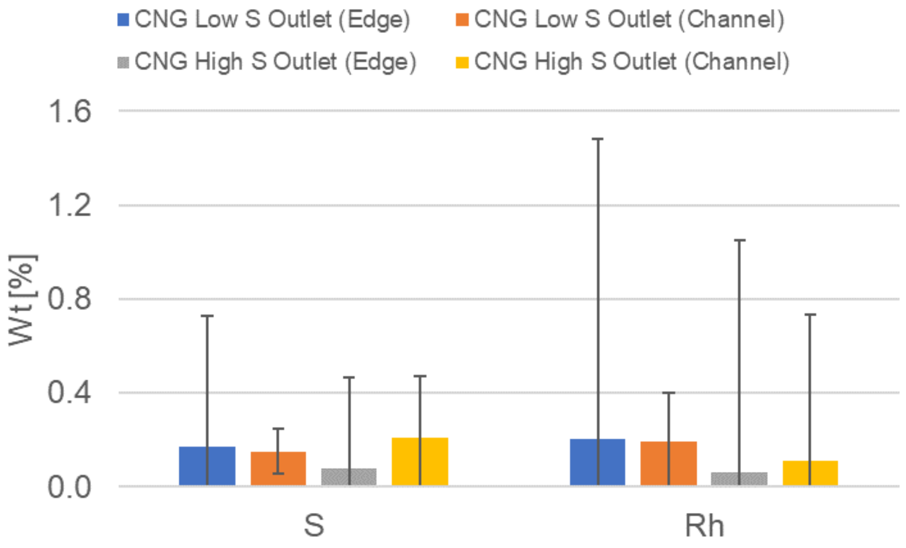


Figure 16 Abundances S and Rh in the outlet samples of the CNG test objects, measured by SEM and divided by nature of site.

A fundamental observation relates to the fact that calculated uncertainty values are for the most part very high – often significantly higher than the mean value of the measurements. For comparisons of abundances of PGM and S between test objects (i.e. Low vs High), the WD-XRF results are considered a much more reliable source, although the holistic abundance values generated by that technique are unable to distinguish between edges and channels. Differences in abundance were observed between edges and channels; some such differences appeared to be significant, despite the significant uncertainty associated with each measurement (and each calculated mean value). Abundances of Pd were much higher at edge sites than channel sites; for S this effect was in evidence at the inlet, but for Rh at the inlet and Rh and S at the outlet the low abundances of those elements and the very high uncertainty mean that no real trend is discernible.

As the co-occurrence of sulphur on PGM was a principle point of interest, and since quantitative SEM data were available for S, Pd and Rh, those data were co-plotted, again divided by edge/channel and inlet/outlet. For reasons of clarity, the datapoints are shown without error bars.

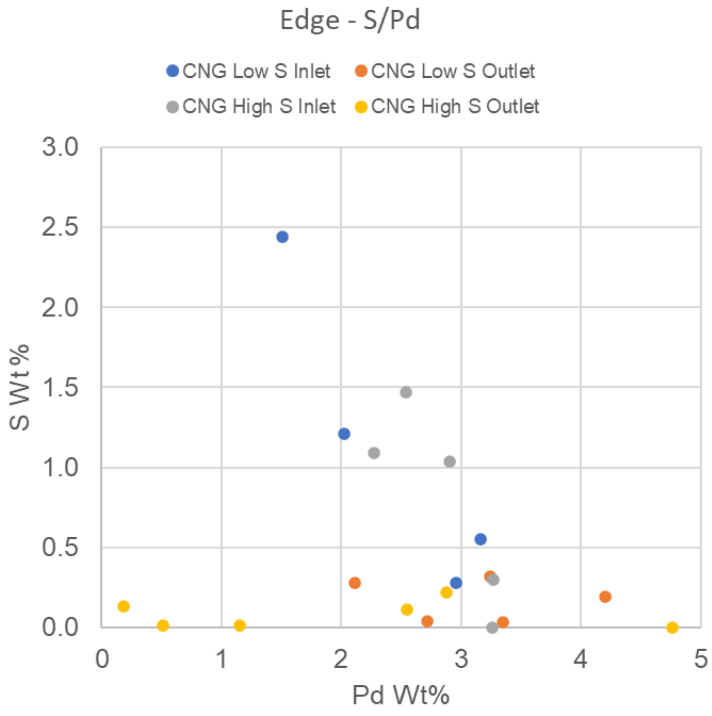


Figure 17 Co-plot of S and Pd abundances for the edge sites of samples from the CNG test objects, measured by SEM.

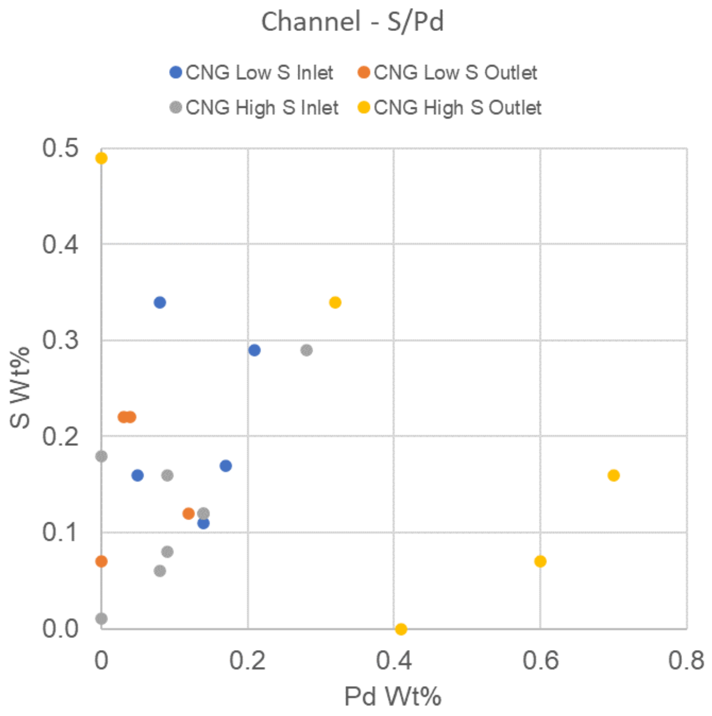


Figure 18 Co-plot of S and Pd abundances for the channel sites of samples from the CNG test objects, measured by SEM.

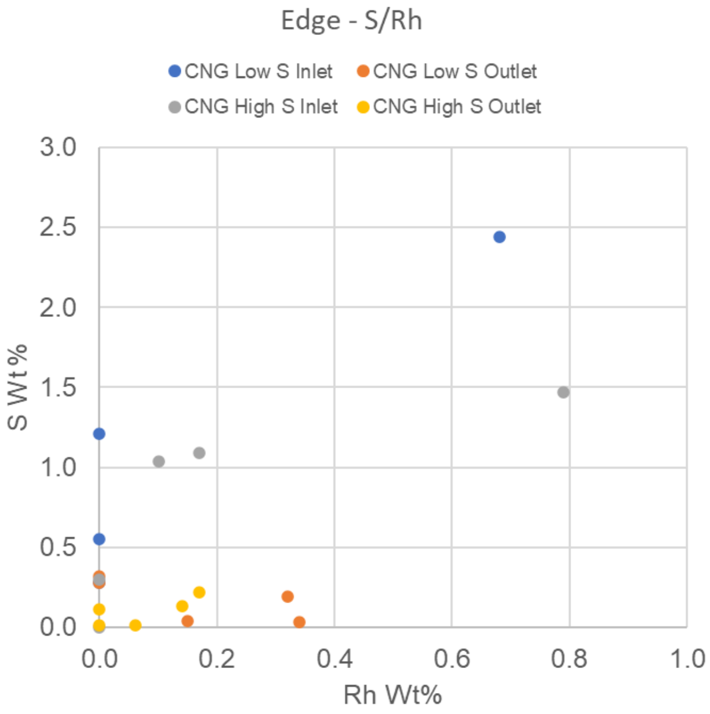


Figure 19 Co-plot of S and Rh abundances for the edge sites of samples from the CNG test objects, measured by SEM.

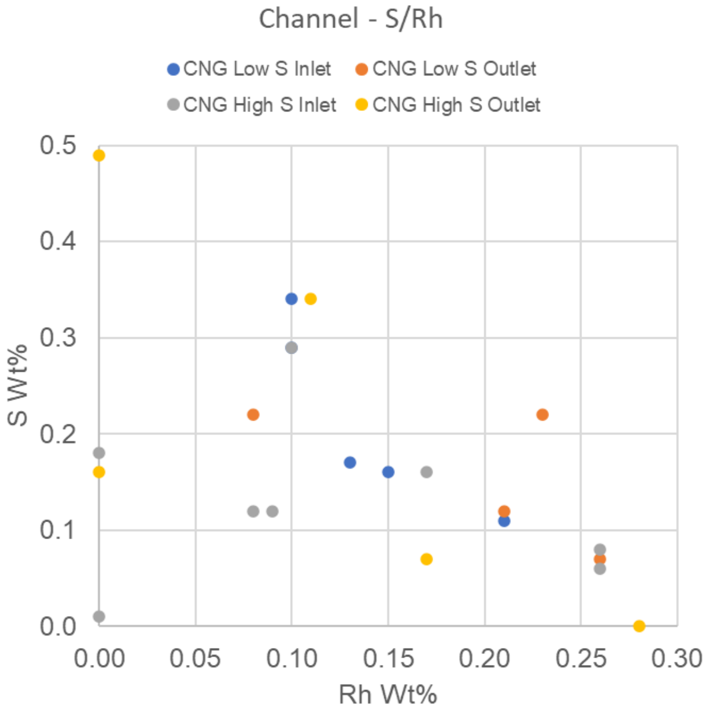


Figure 20 Co-plot of S and Rh abundances for the channel sites of samples from the CNG test objects, measured by SEM.

As the figures above show, the main difference between edge and channel sites was in terms of the abundances of both Pd/Rh and S, which were much higher at edge sites. In all cases, no clear correlational trend between the abundance of S and Pd or Rh was apparent at edge or channel sites, especially when considering the uncertainty associated with the measurements (not shown in the plots).

Equivalent plots for the SEM measurements performed on the LPG test objects are shown in Figures 21-28.

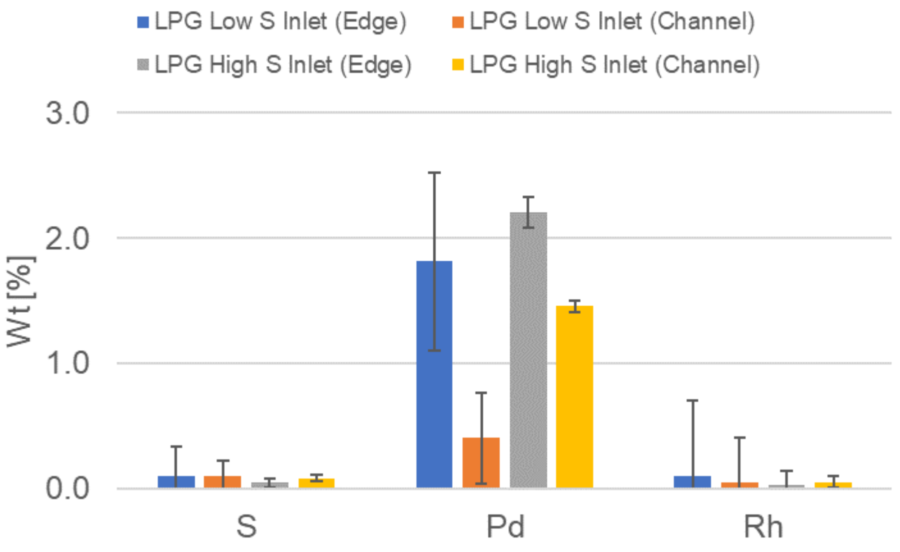


Figure 21 Abundances S, Pd and Rh in the inlet samples of the LPG test objects, measured by SEM and divided by nature of site.

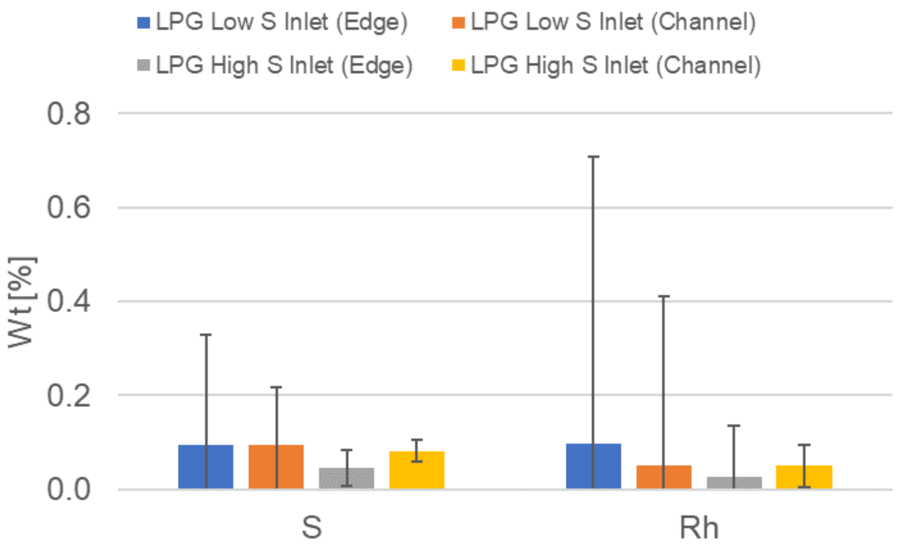


Figure 22 Abundances S and Rh in the inlet samples of the LPG test objects, measured by SEM and divided by nature of site.

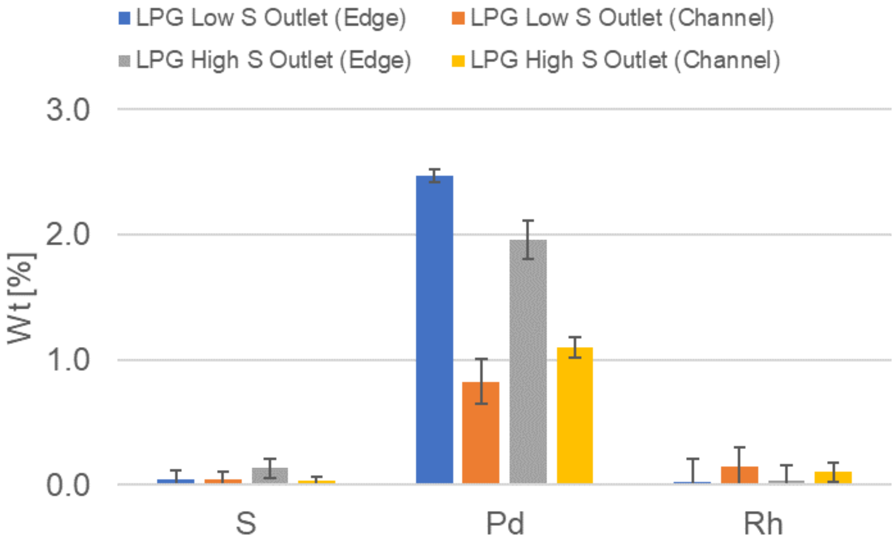


Figure 23 Abundances S, Pd and Rh in the outlet samples of the LPG test objects, measured by SEM and divided by nature of site.

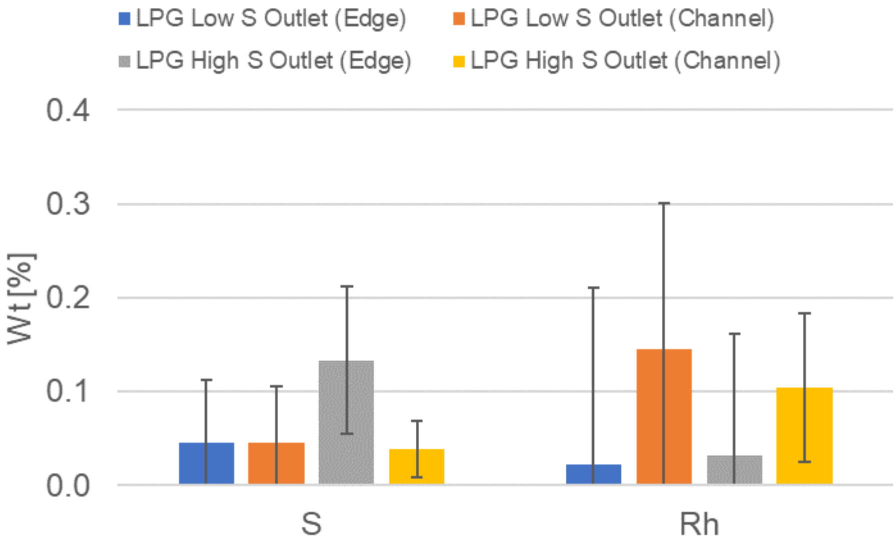


Figure 24 Abundances S and Rh in the inlet samples of the LPG test objects, measured by SEM and divided by nature of site.

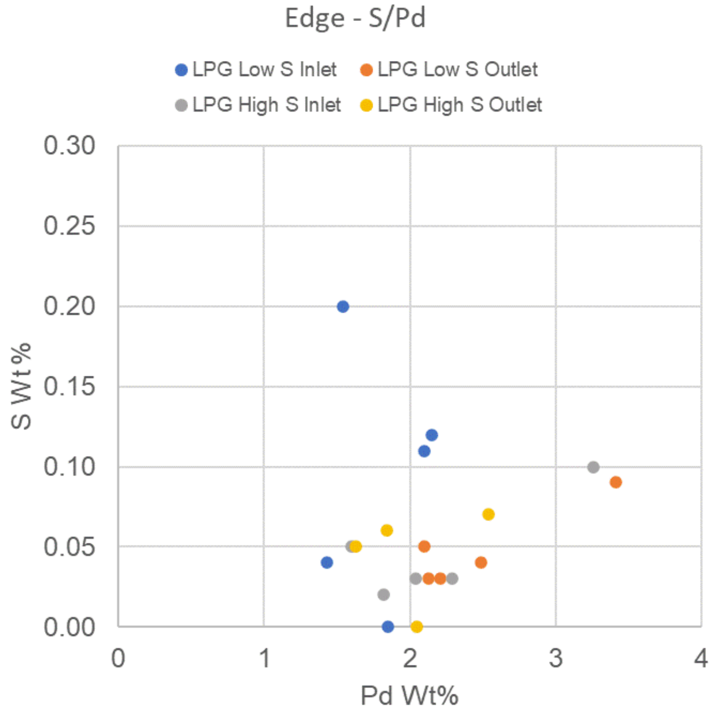


Figure 25 Co-plot of S and Pd abundances for the edge sites of samples from the LPG test objects, measured by SEM.

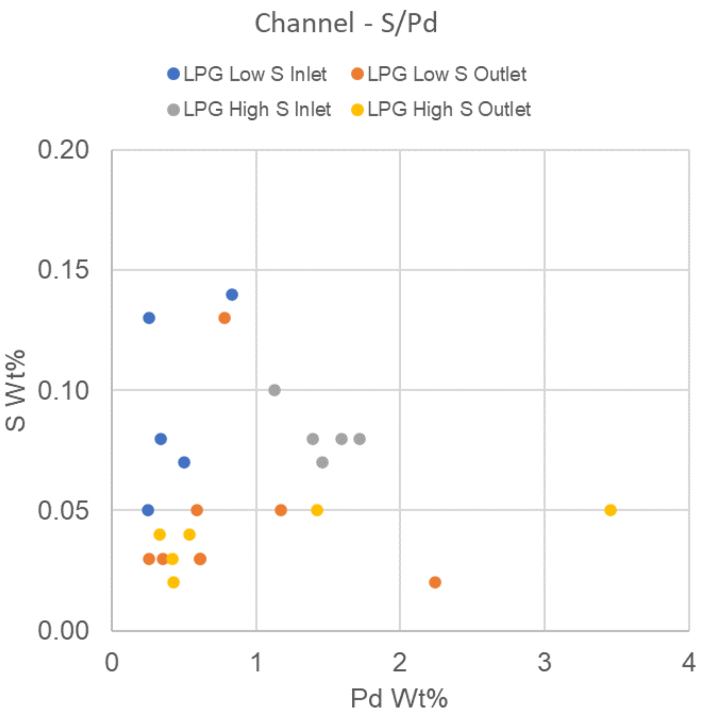


Figure 26 Co-plot of S and Pd abundances for the channel sites of samples from the LPG test objects, measured by SEM.

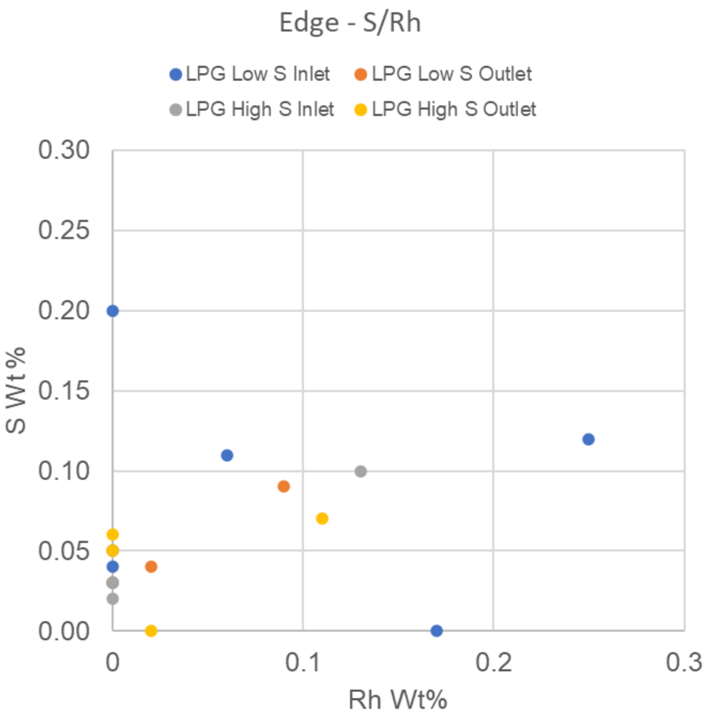


Figure 27 Co-plot of S and Rh abundances for the edge sites of samples from the LPG test objects, measured by SEM.

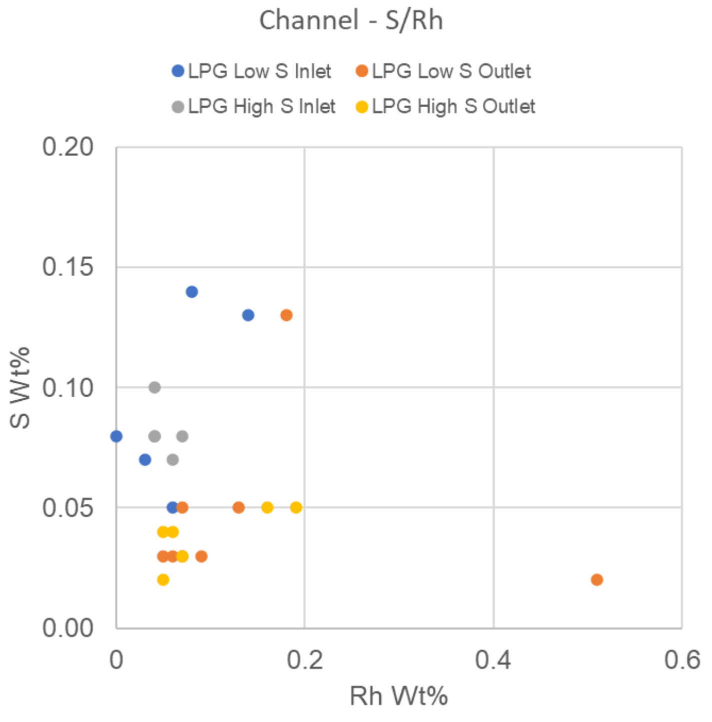


Figure 28 Co-plot of S and Rh abundances for the channel sites of samples from the LPG test objects, measured by SEM.

The observed tendencies for the LPG test objects were, generally speaking, similar to those observed for the CNG test objects, as described above. Only Pd showed edge/channel differentiation considered likely to be significant. The lack of any significant correlation regarding co-location of S and Pd/Rh was apparent from the co-plots of results for those elements.

7 FINAL CONCLUSIONS

Aged three-way catalytic converters (TWCs) were subjected to chemical analyses using advanced laboratory methods. The aim was to quantify quantitative and qualitative differences in the samples, which had been exposed to exhaust gas generated by light duty engines running on two fuel types (CNG, LPG) and with two different sulphur levels (Low, High). Vehicle tests showed that the CNG TWC conversion efficiency was sensitive to sulphur content, while this was not the case for the LPG TWC. At the end of the vehicle tests, it was assumed that this was due to a better desulphation process in the LPG TWC, due to differences in equivalence ratio at high load between the two powertrain types (lean burn with CNG and rich mixture with LPG). The purpose of this study was to check and provide evidence for this assumption. Investigations using WD-XRF, ICP-OES and SEM techniques permitted quantification of certain observable differences between the test objects and between the two samples taken from each test object. However, trends were not consistent in all cases. While the CNG test objects showed much higher abundances of sulphur than their LPG counterparts, the key parameter of interest, namely TWC sulphur content, was not observed to correlate with the sulphur level of the fuel used for ageing (i.e. high vs low). This finding is unexpected, especially given the fact that for the CNG TWCs, a significant accumulation of sulphur was expected, as attested to by the emissions results [1]. The possibility of removal of sulphur atoms from the test object during the ageing process (and even during emissions testing) is mentioned in [1] and discussed in detail in [2]. A lack of quantitative information on the distribution of sulphur atoms throughout the test objects' entire volume – as well as on the sulphur content of the test objects in their pristine state – currently precludes further analysis of this point. The limited number of sites chosen for the SEM analyses affects the statistical significance of the quantitative SEM results and imposes certain limitations on the qualitative conclusions which can be drawn from the SEM images and accompanying data. Quantitative SEM results where the measured weight concentration was zero (or very close to zero) mean that the uncertainty of the mean value taken from the limited number of observations is high and observed differences are, in many cases, very unlikely to be statistically significant. Thus, considering the overall statistical significance of the quantitative SEM results, as well as the inherent limitations of the SEM technique concerning sensitivity to elements of lower atomic mass (such as sulphur), no definitive conclusions could be drawn regarding the potential existence of a significant correlation concerning the co-occurrence of S and Pd (or Rh). Further factors contributing to this are: shielding effects, the limited depth of electron penetration and the lack of a control (i.e. analysis of an unaged TWC of each type).

Certain changes which may have occurred in the test objects during the ageing process, which can have an impact on emissions conversion efficiency, would not necessarily have been revealed by the methods employed in this study. This category includes very small-scale changes such as reductions in available surface area suffered by metal oxides, and certain forms of atomic migration and rearrangement, not limited to processes such as sintering and clustering (see [5] for a recent review; see also [6]), as well as modifications to the electrical properties of the TWC's active layer [3]. Such phenomena (or lack thereof) may have had appreciable impacts on the performance of the test objects during their respective emissions testing programmes ([1], [2]) and may result from the complex interactions between fuel type, specific ageing conditions and indeed fuel sulphur level. Data relating to changes of the aforementioned type in the test objects could not be obtained in this study for reasons relating to the methods used, the number of observations and the lack of control measurements.

The different measured sulphur levels between the CNG and LPG TWCs are likely to support the fact that the desulphation process occurs more in LPG operating conditions than in CNG operating conditions. However, the fact that the high-sulphur CNG and the low-sulphur CNG TWCs show the same level of sulphur, whereas the high-sulphur CNG TWC lost much more conversion efficiency shows a non-systematic relationship between the sulphur content of the analysed TWCs and their conversion efficiency. Because of the fact that empirical findings did not directly link the TWCs' sulphur content with their conversion efficiency, the analysis remains inconclusive regarding its initial assumption of a better desulphation process occurring in the LPG TWC.

8. REFERENCES

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[3] Truex, T., "Interaction of Sulfur with Automotive Catalysts and the Impact on Vehicle Emissions-A Review," SAE Technical Paper 1999-01-1543, 1999, https://dx.doi.org/10.4271/1999-01-1543.

[4] Govender, S. and Friedrich, H.B., "Monoliths: A Review of the Basics, Preparation Methods and Their Relevance to Oxidation," Catalysts, 2017, 7, http://dx.doi.org/10.3390/catal7020062.

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[6] Donlon, W.T., et al., Automotive Applications of Scanning and Transmission Electron Microscopy, Industrial Applications of Electron Microscopy, 1st ed., 2002, CRC Press, USA, ISBN: 9780429222429.

Annex 1

SEM result sets for CNG test objects (TWCs 1 and 2)

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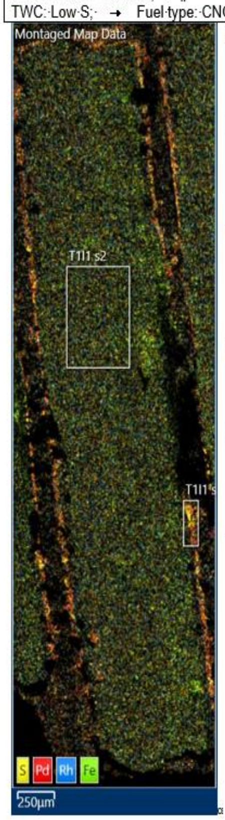

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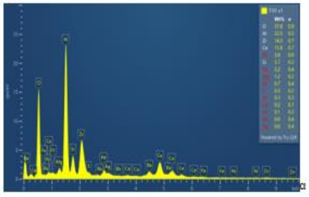

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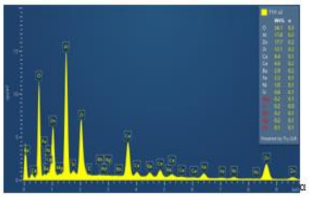

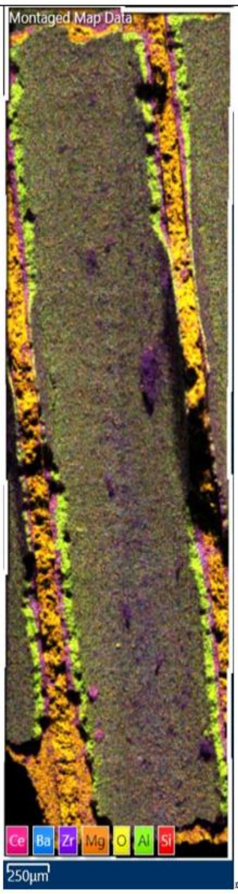

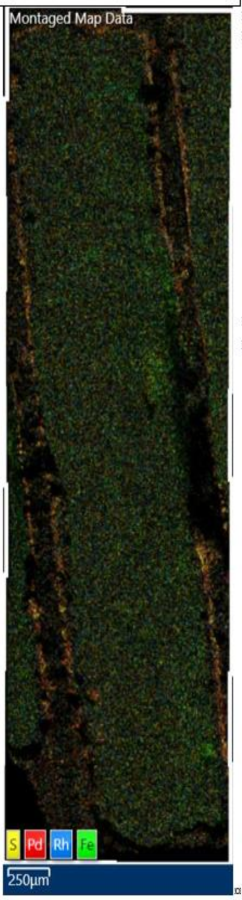

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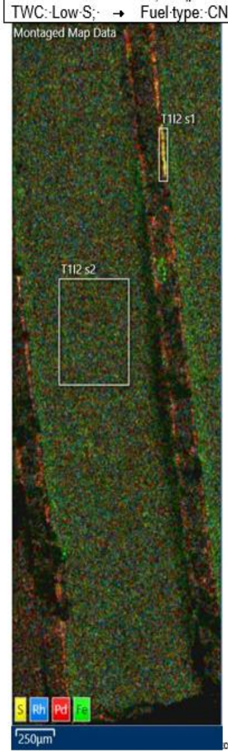

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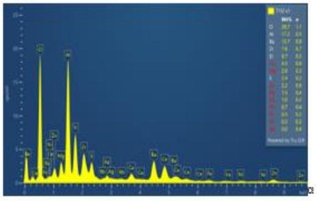

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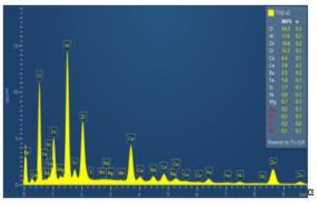

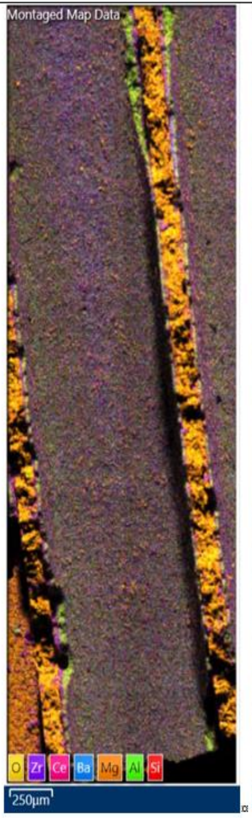

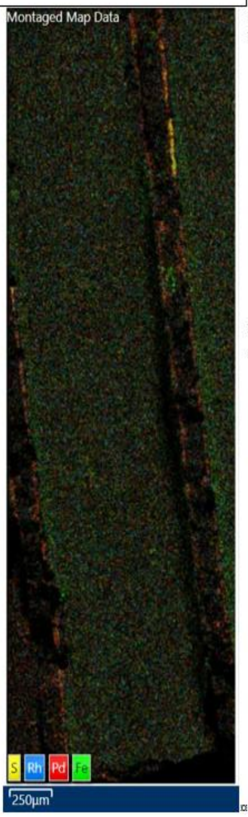

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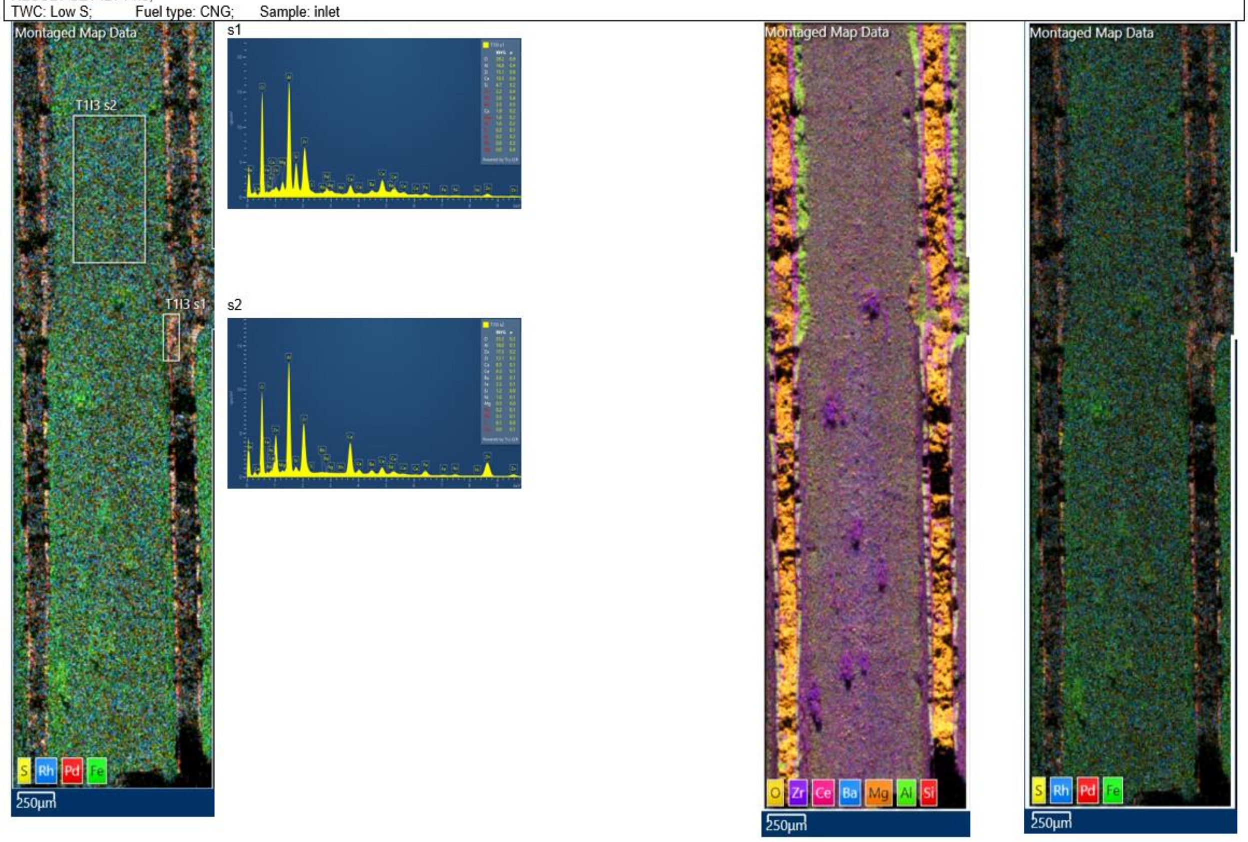

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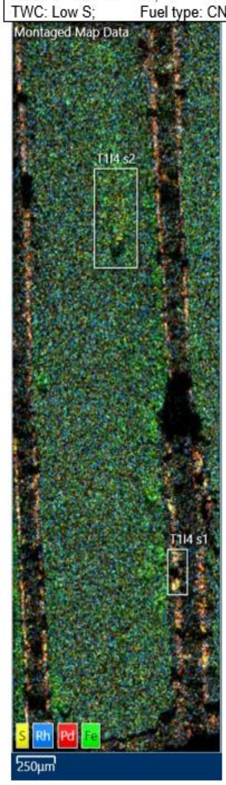

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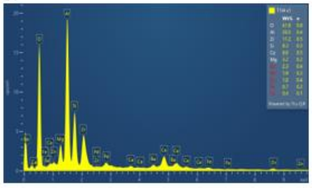

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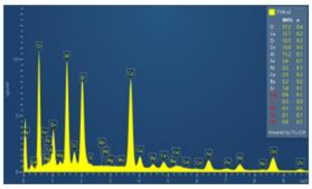

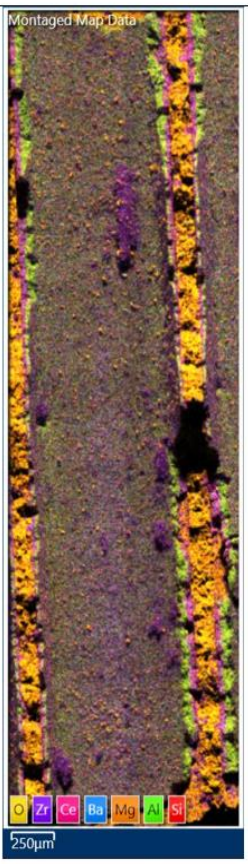

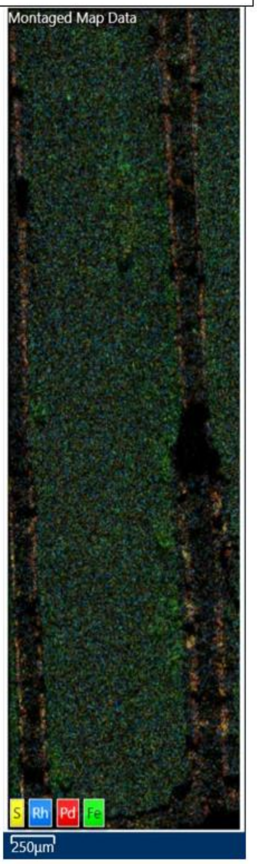

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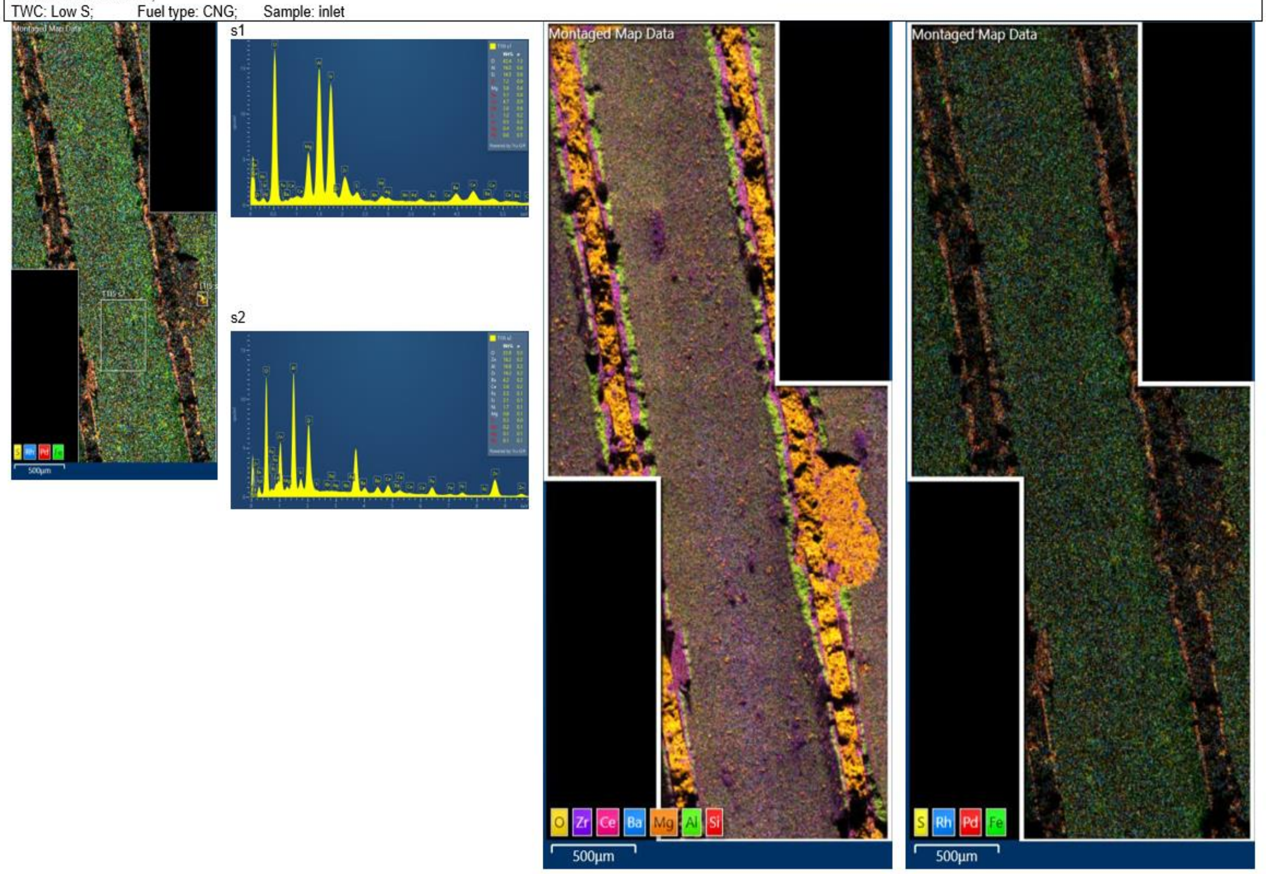

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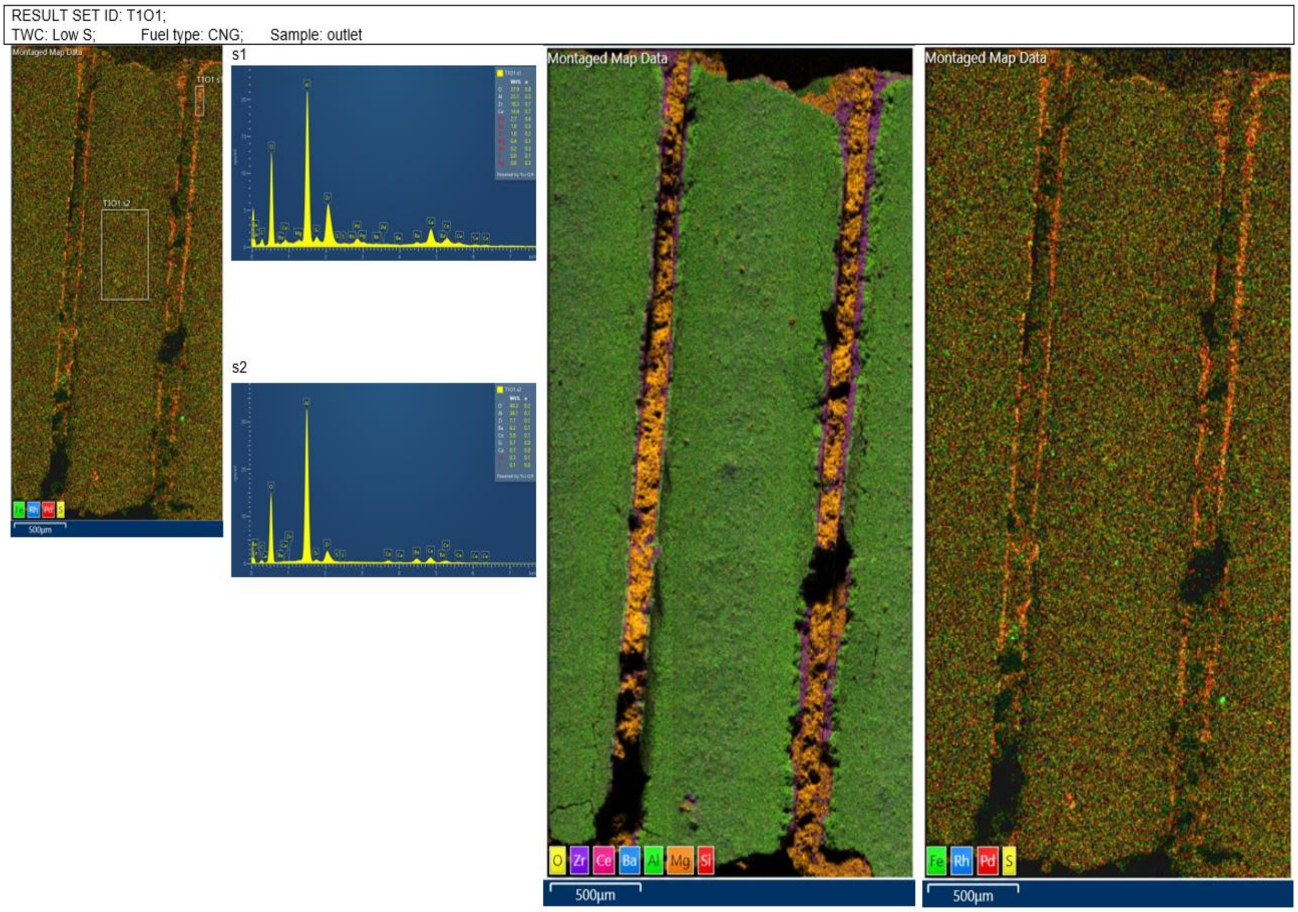

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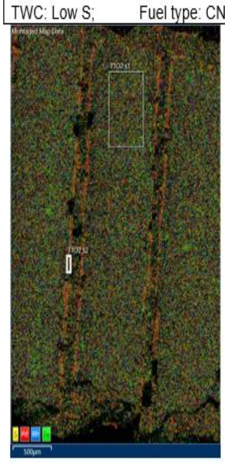

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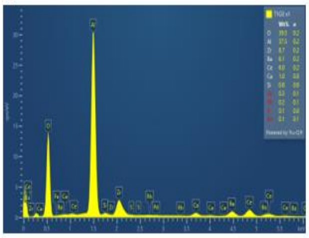

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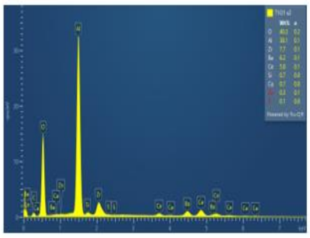

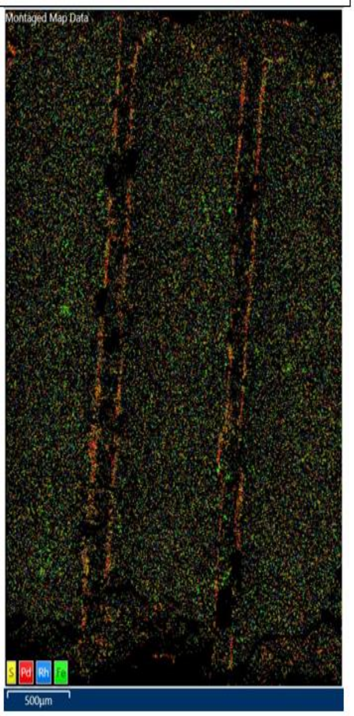

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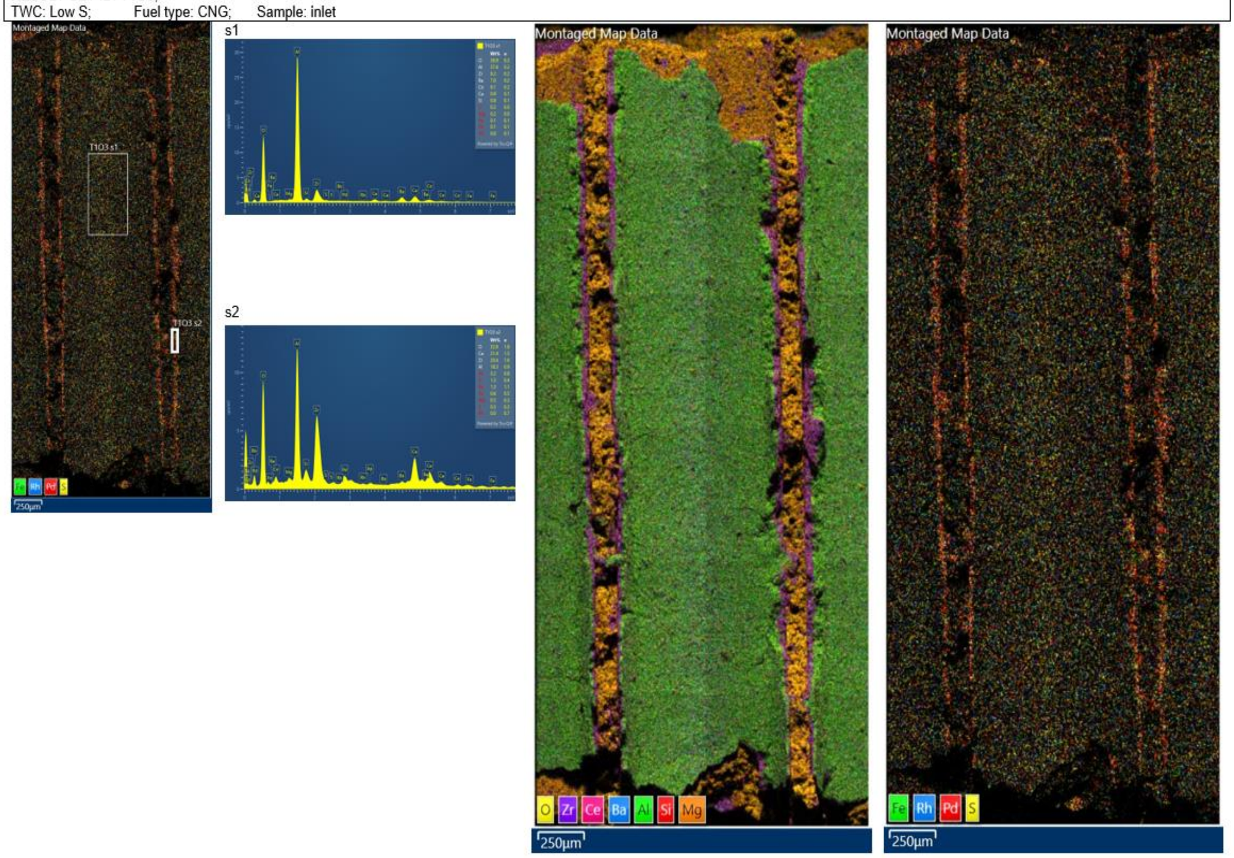

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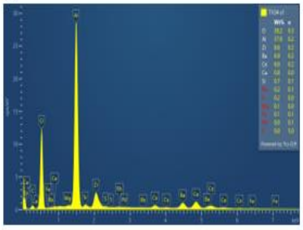

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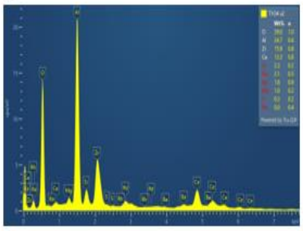

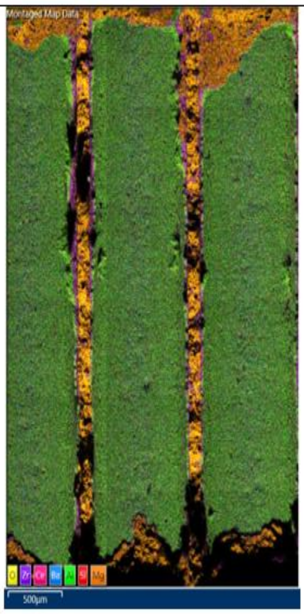

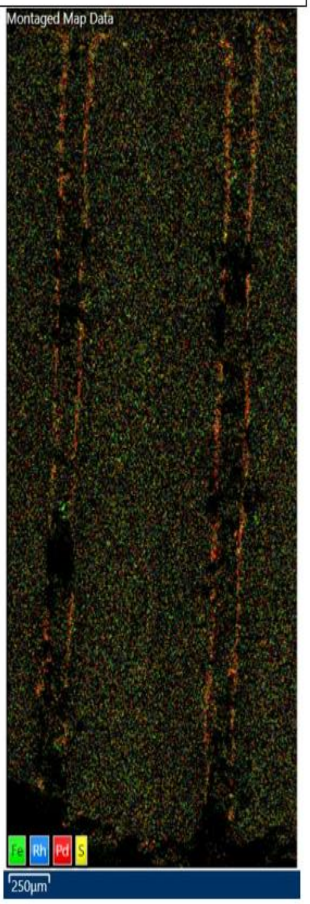

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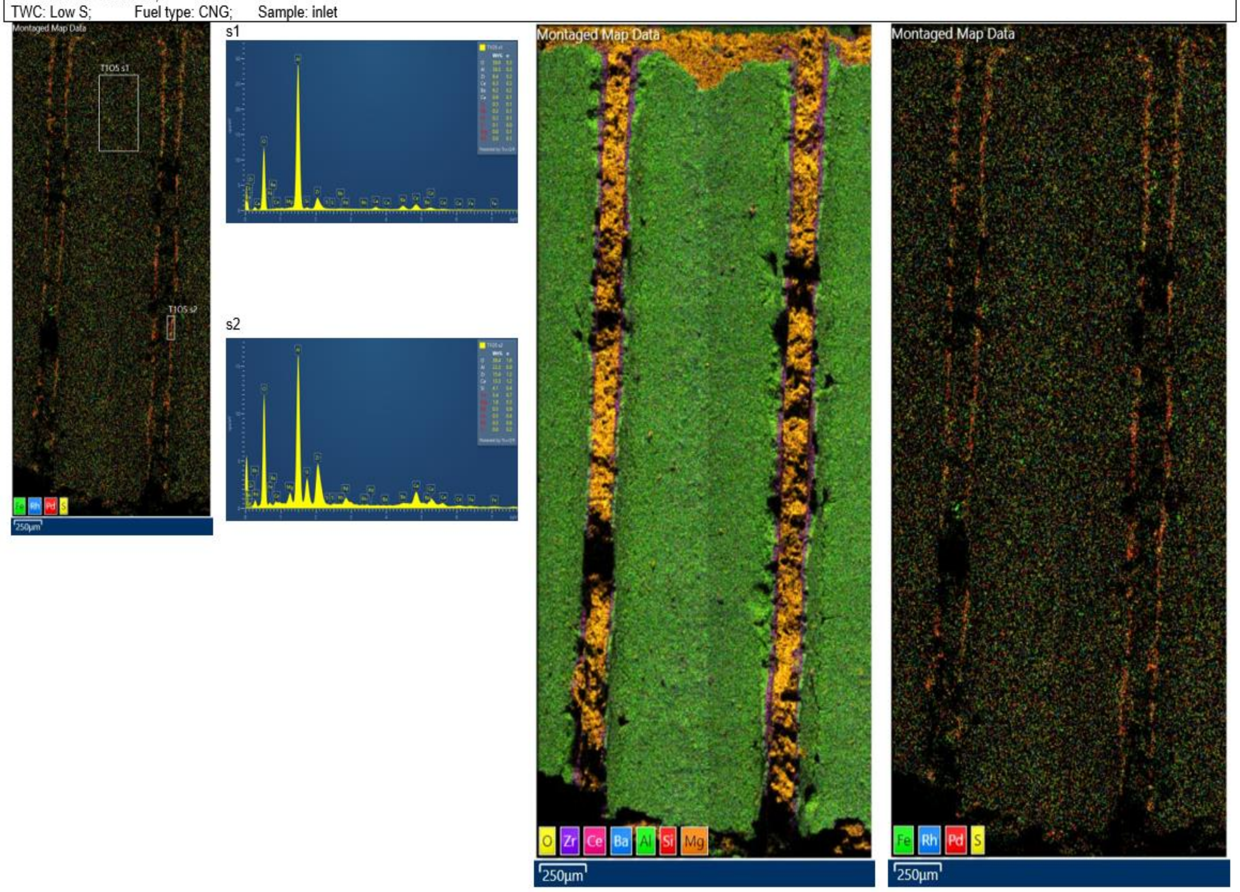

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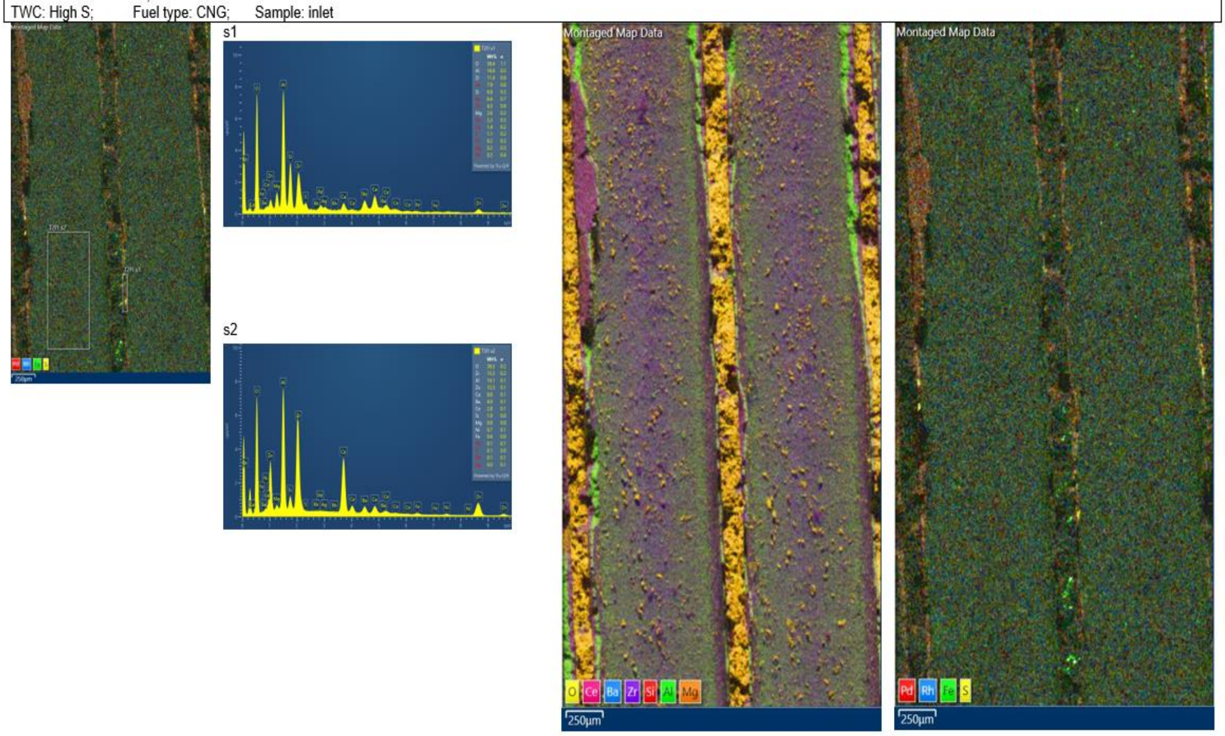

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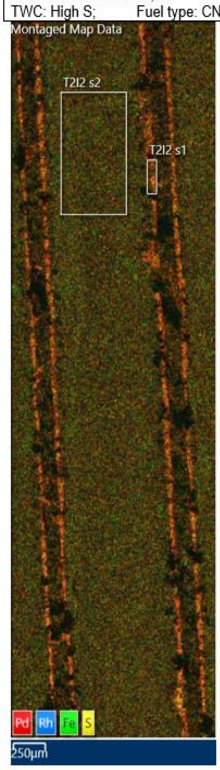

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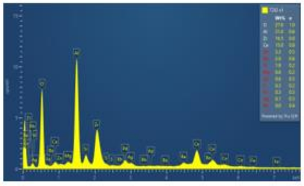

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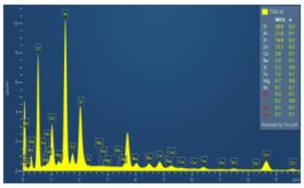

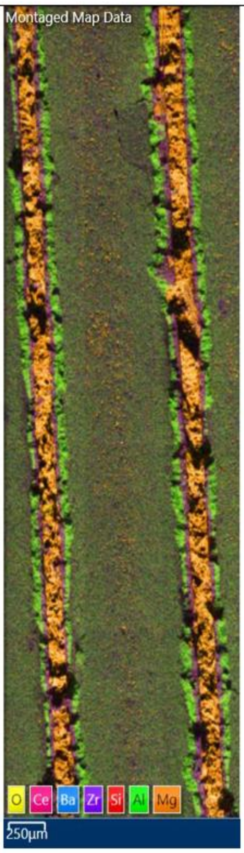

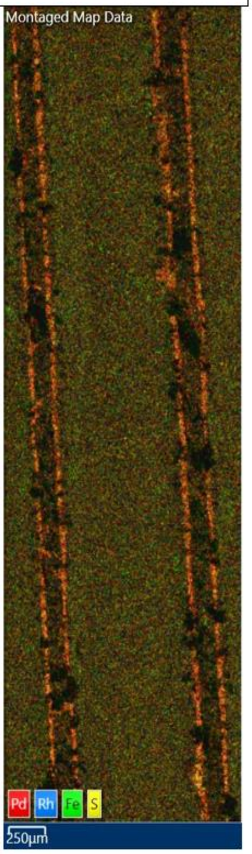

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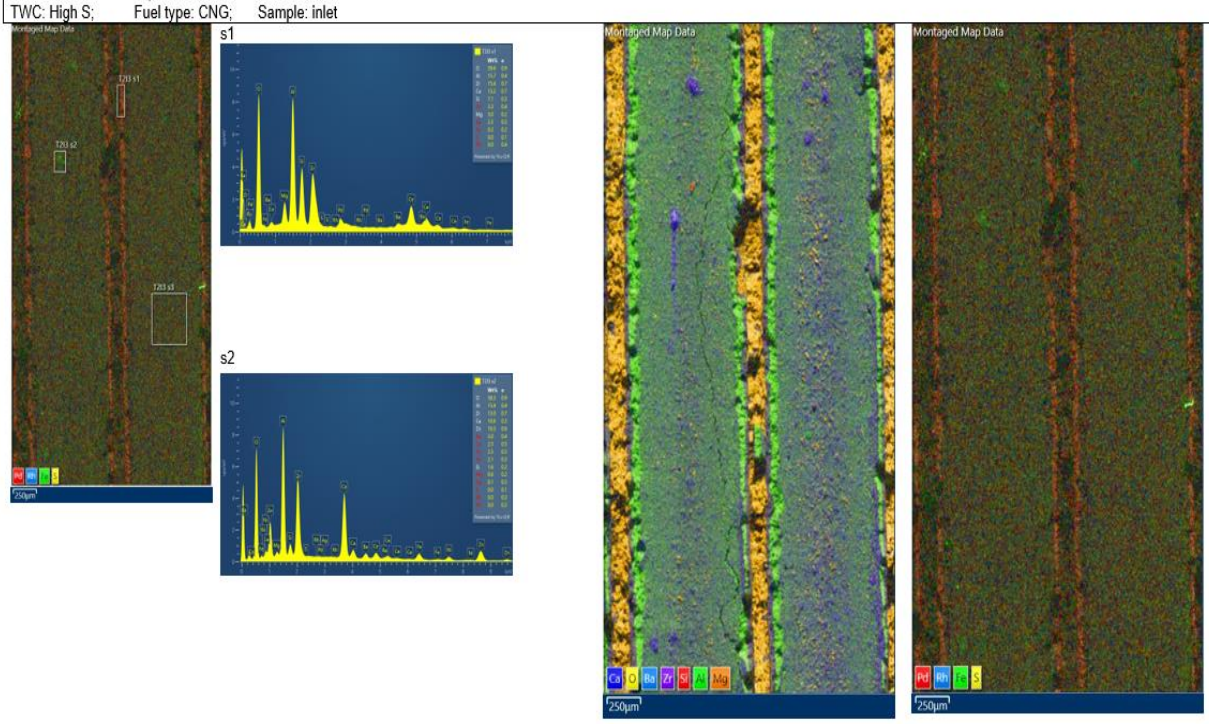

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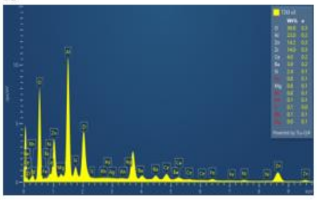

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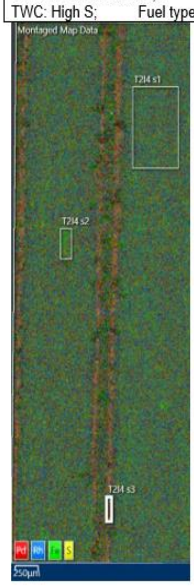

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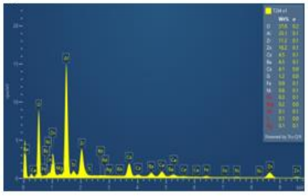

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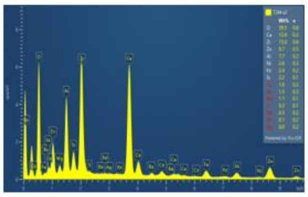

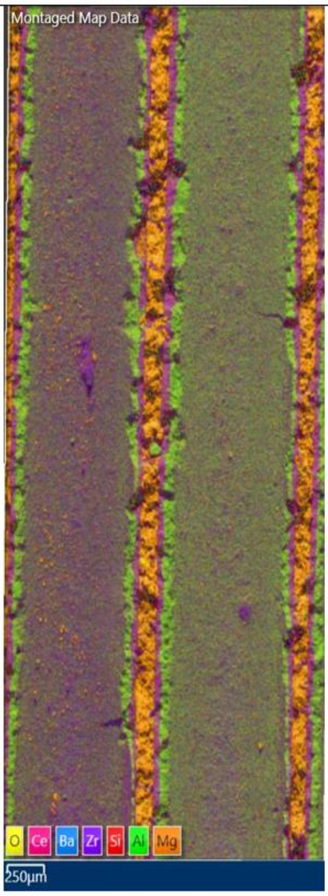

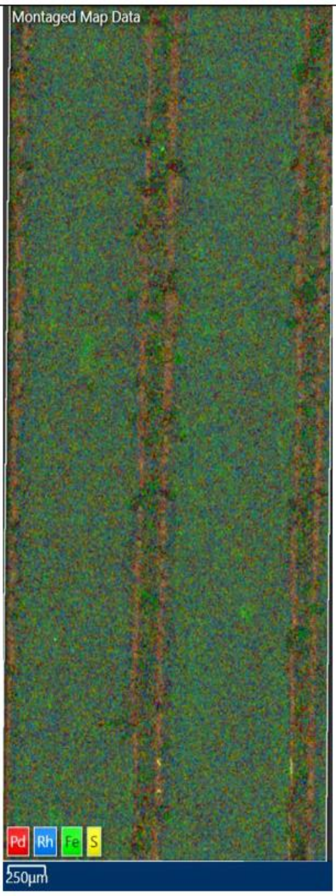

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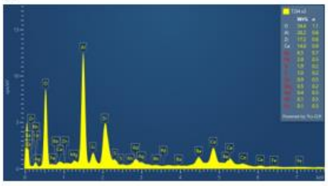

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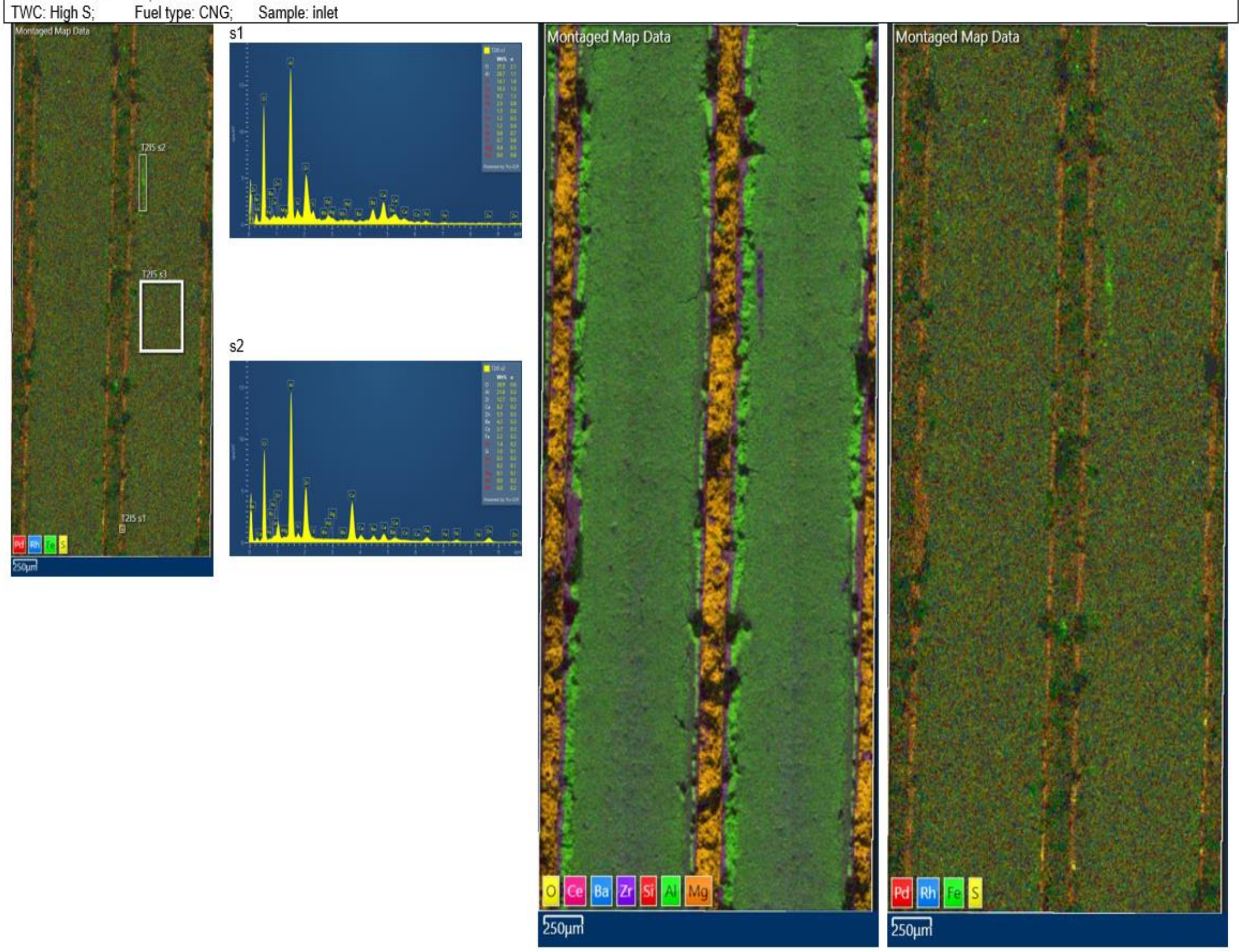

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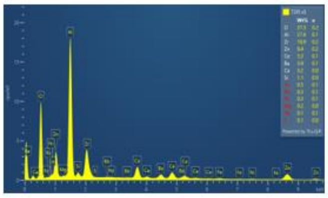

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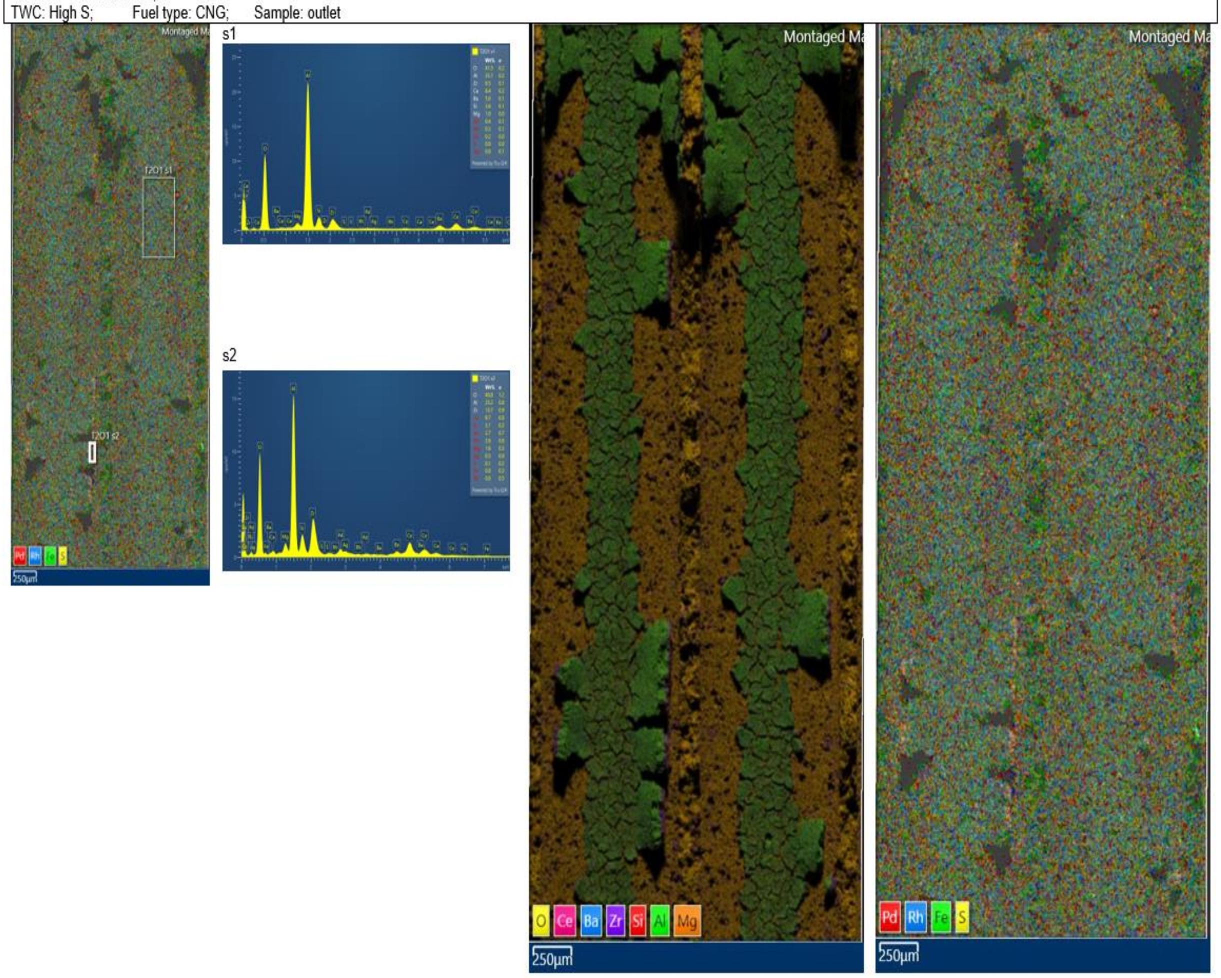

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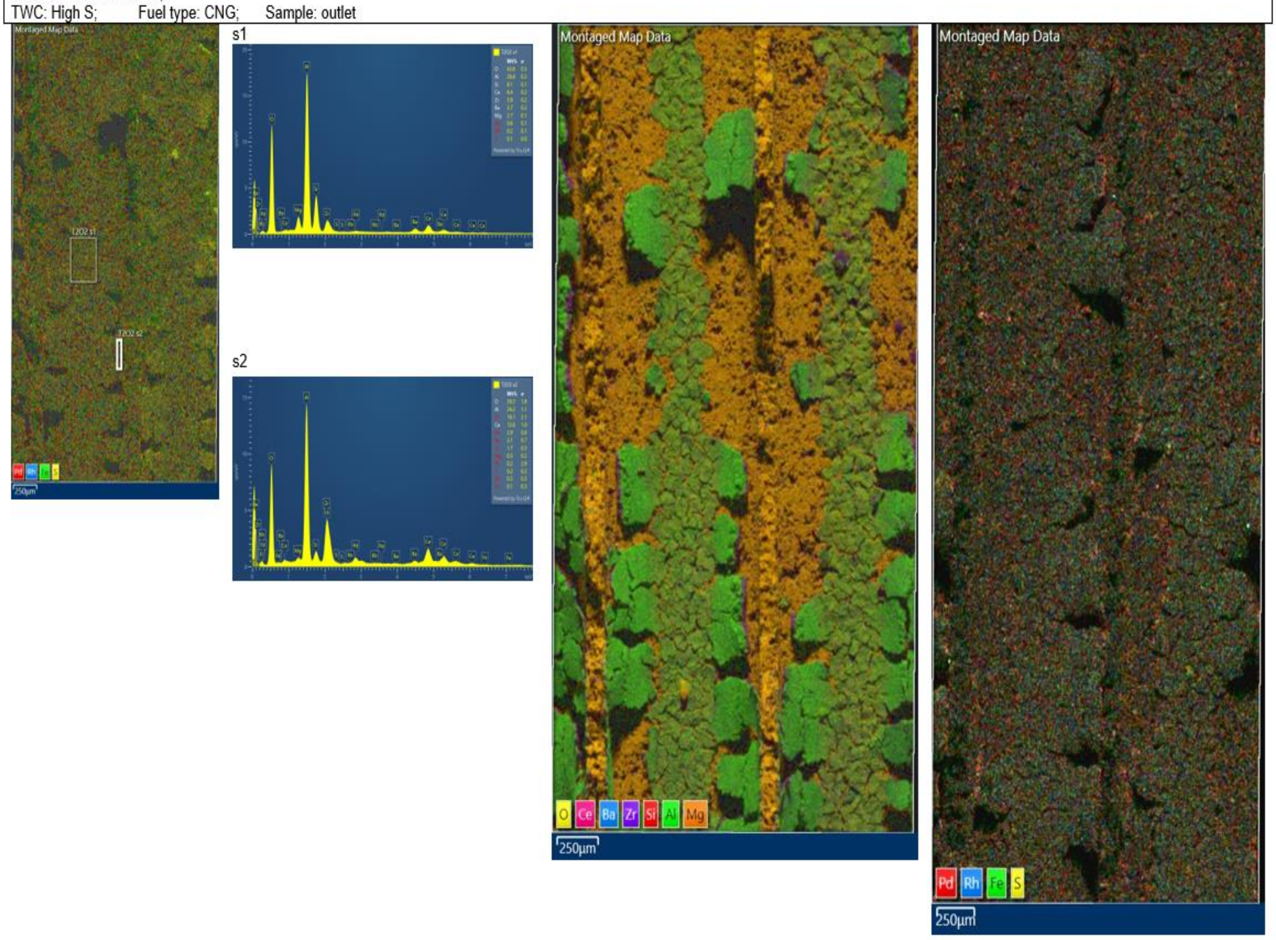

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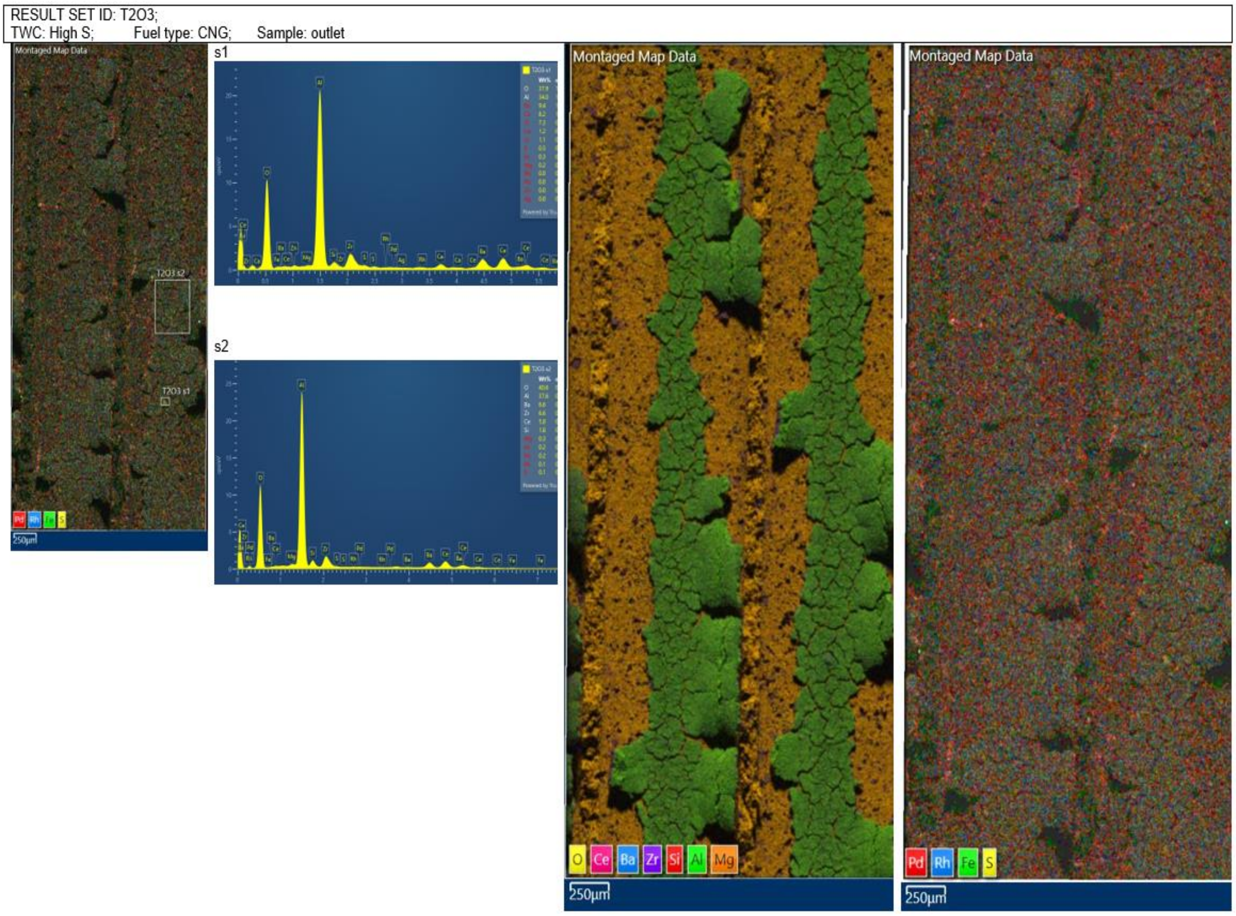

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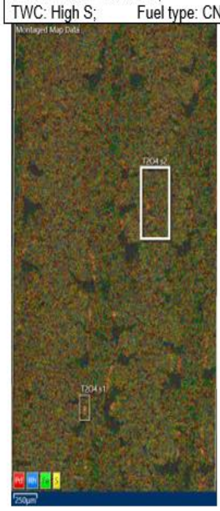

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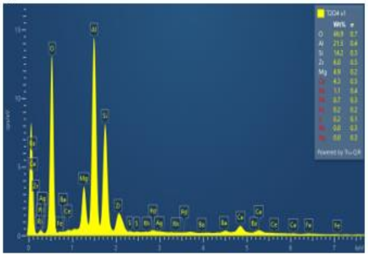

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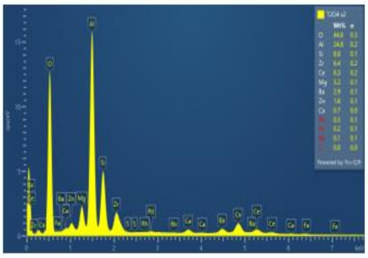
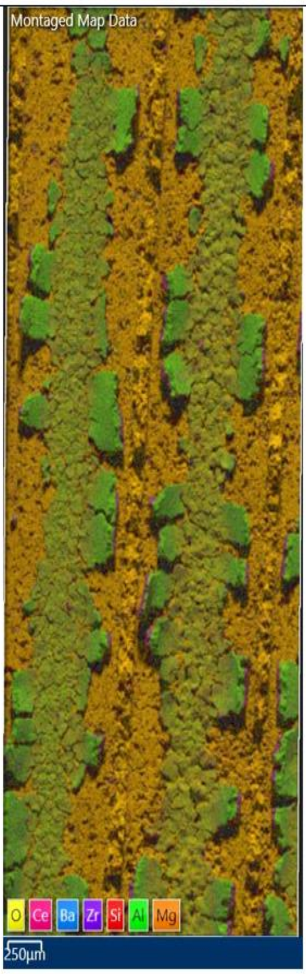
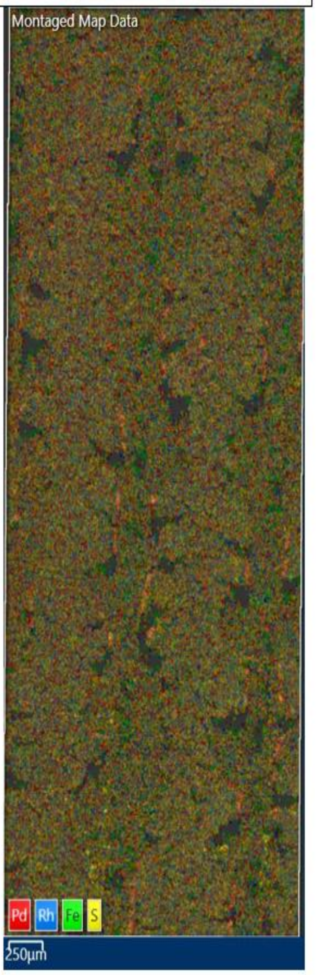
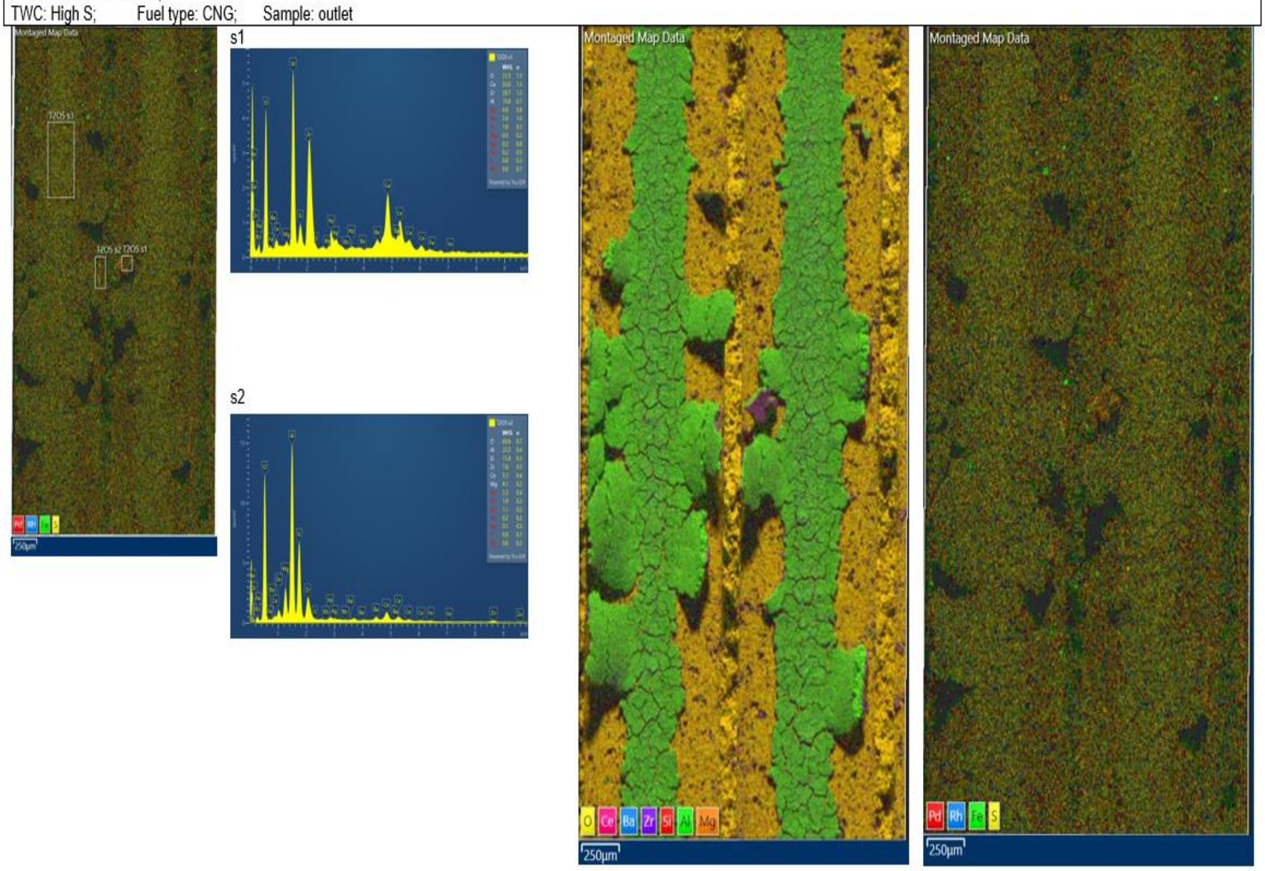


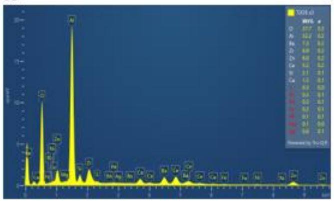




RESULT SET ID: T2O5;
TWC: High S; Fuel type: CNG; Sample: outlet



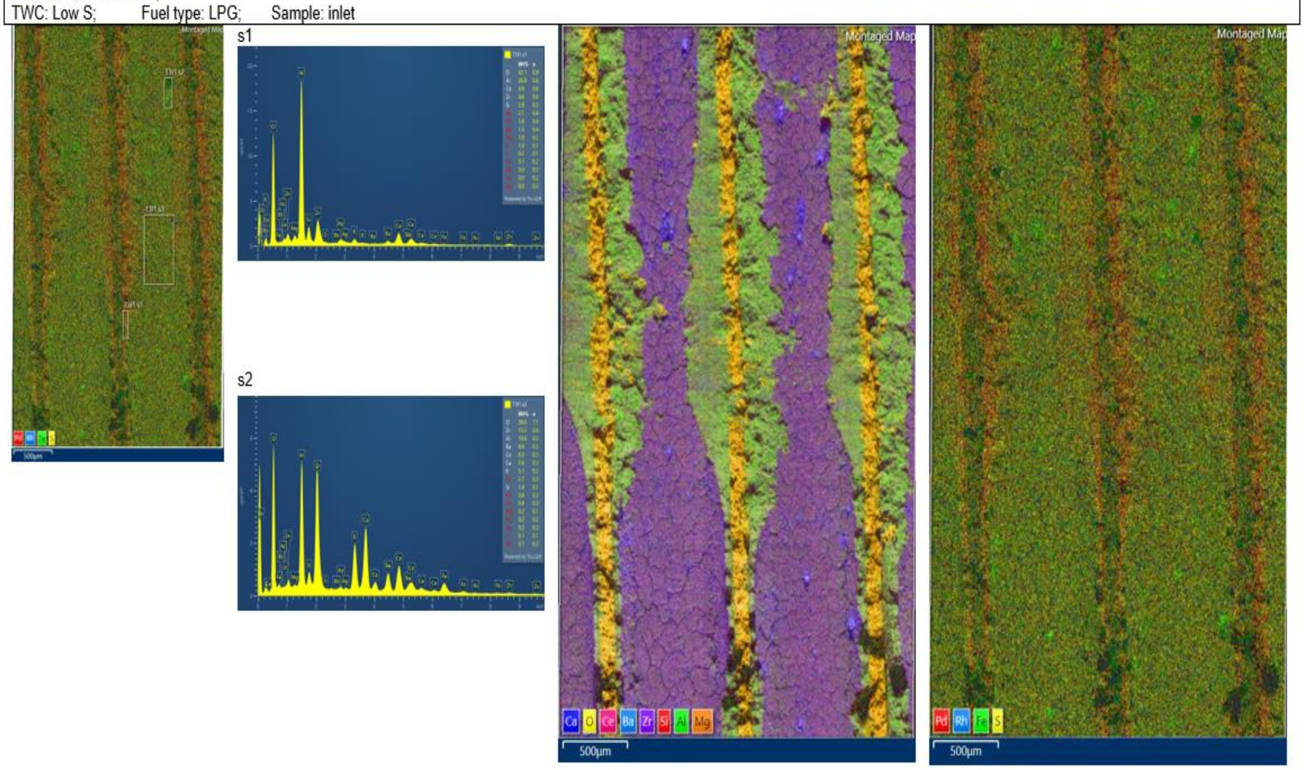
s3



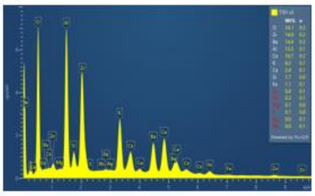
Annex 2

SEM result sets for LPG test objects (TWCs 3 and 4)

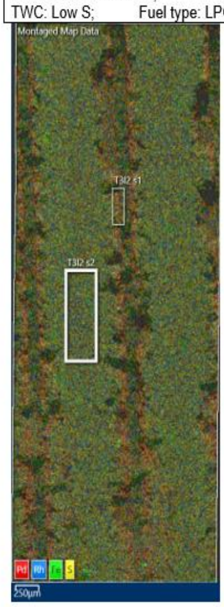
RESULT SET ID: T3I1;
TWC: Low S; Fuel type: LPG; Sample: inlet



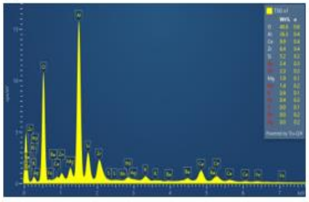
s3



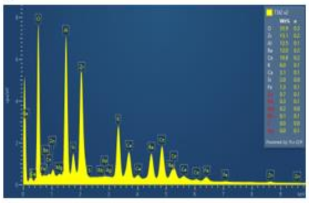
RESULT SET ID: T3I2;
TWC: Low S; Fuel type: LPG; Sample: inlet

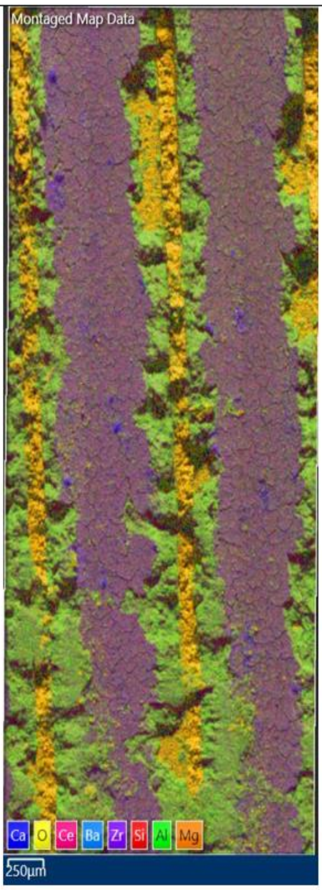


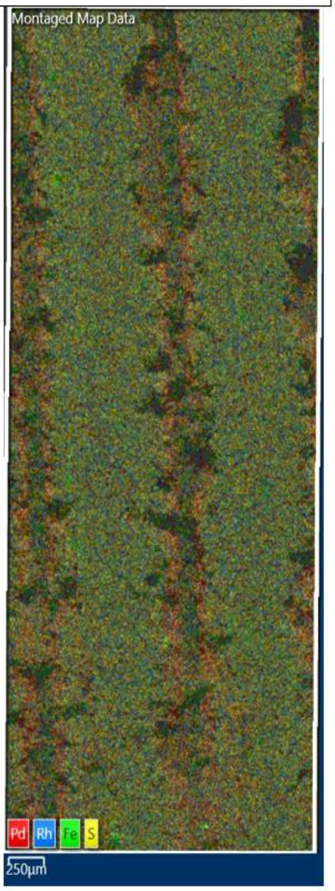
s1



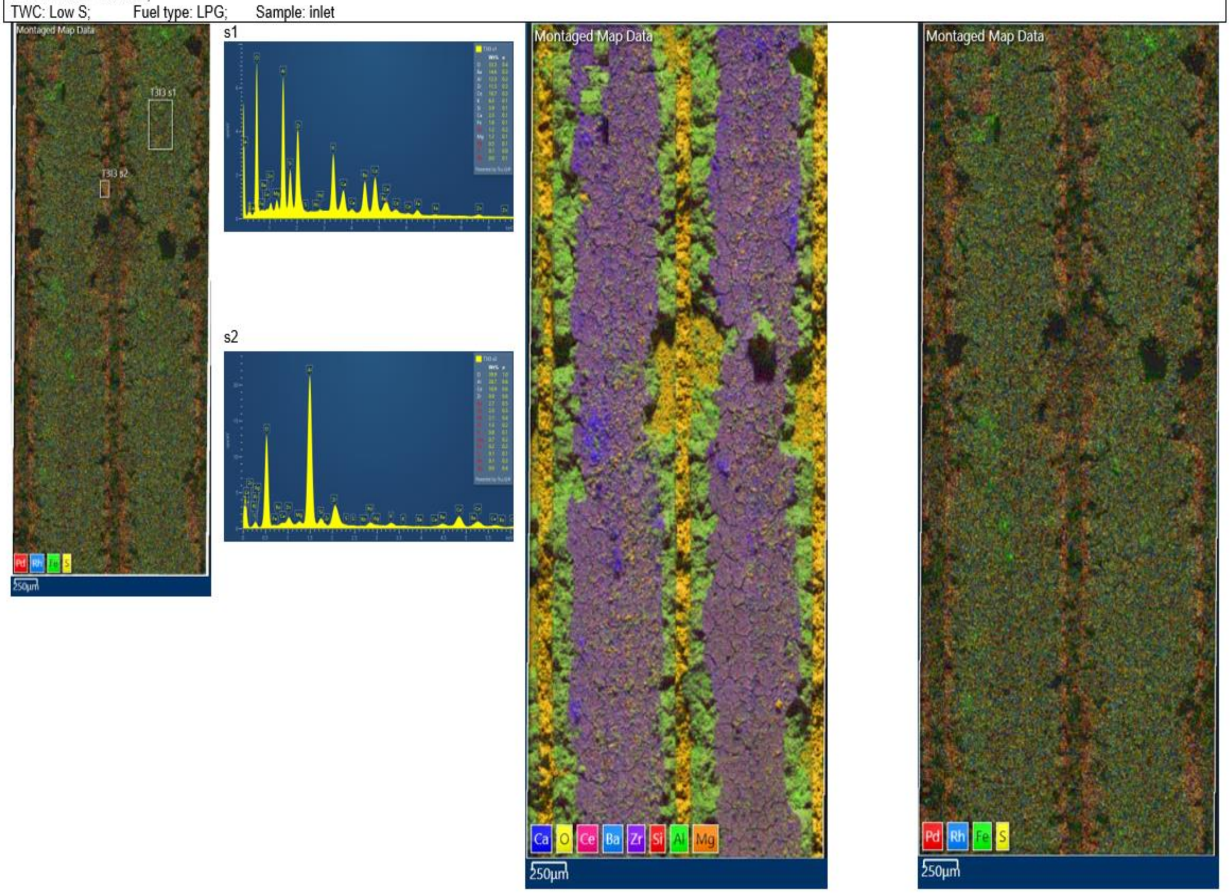
s2



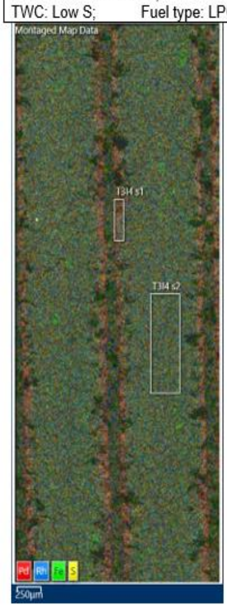




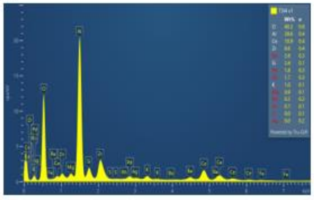
RESULT SET ID: T3I3;
TWC: Low S; Fuel type: LPG; Sample: inlet



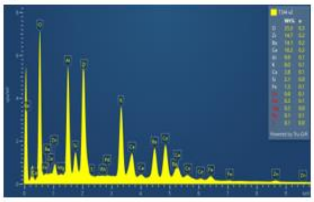
RESULT SET ID: T3I4;
TWC: Low S; Fuel type: LPG; Sample: inlet

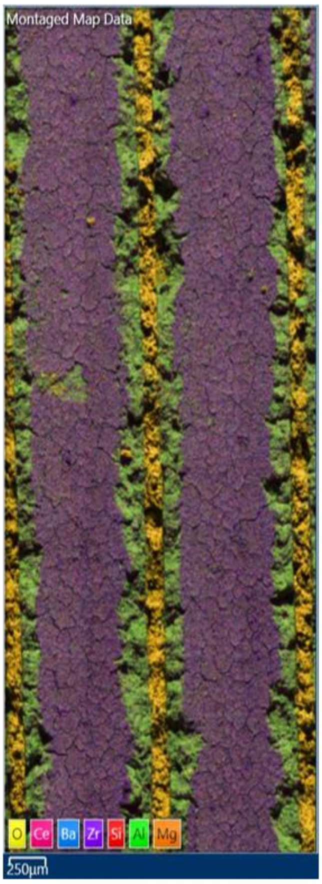


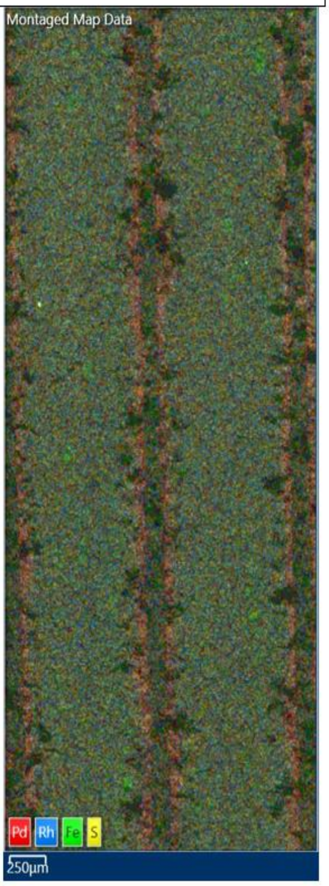
s1



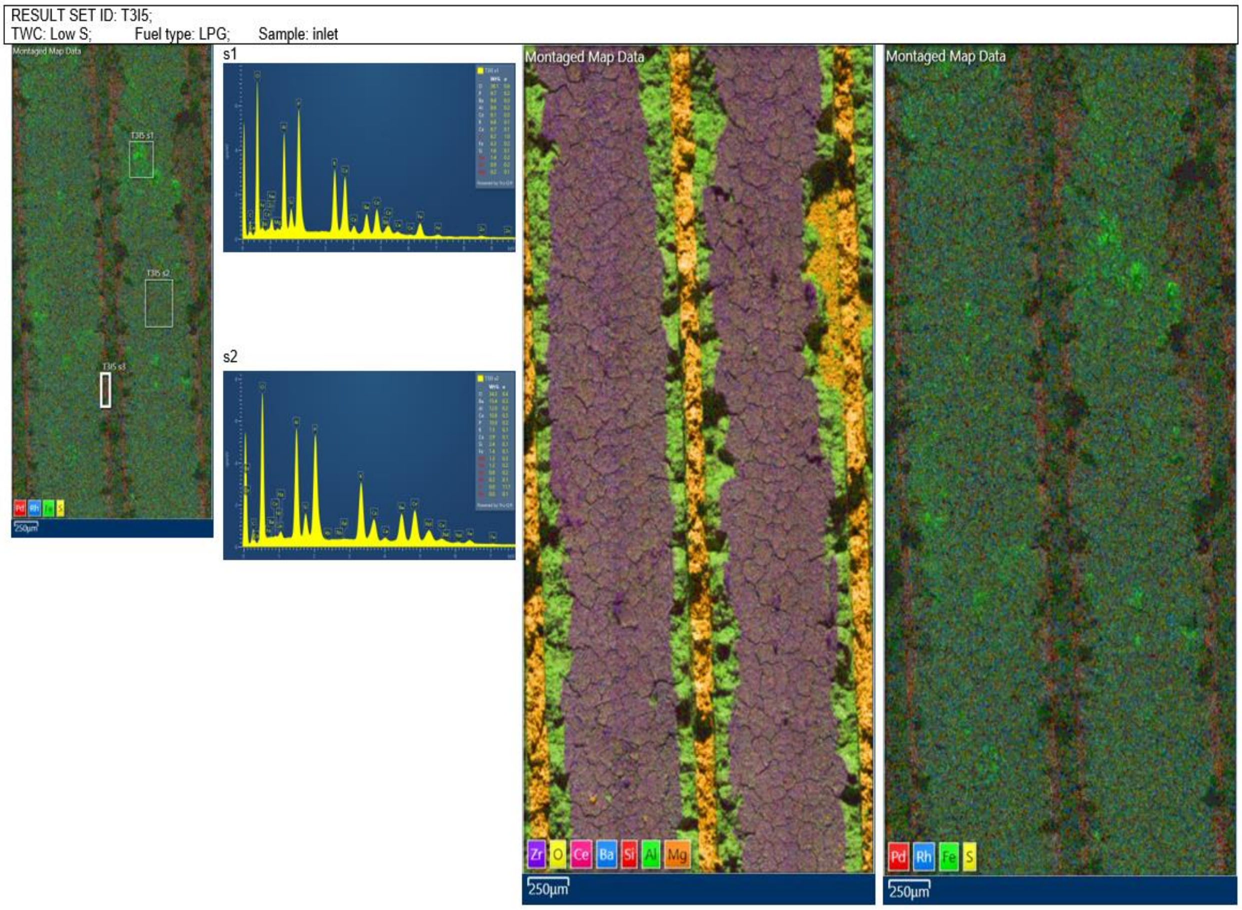
s2



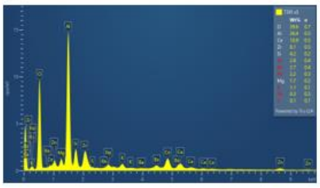




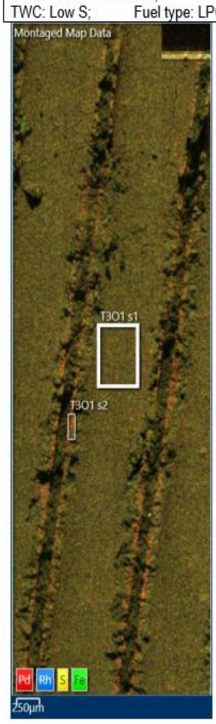
RESULT SET ID: T3I5;
TWC: Low S; Fuel type: LPG; Sample: inlet



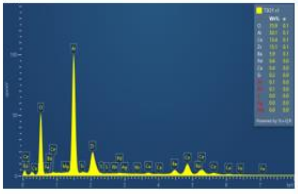
s3



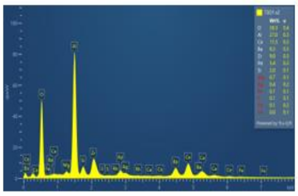
RESULT SET ID: T3O1;
TWC: Low S; Fuel type: LPG; Sample: outlet

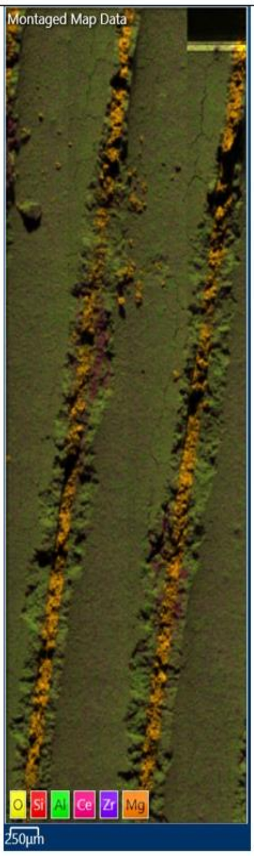


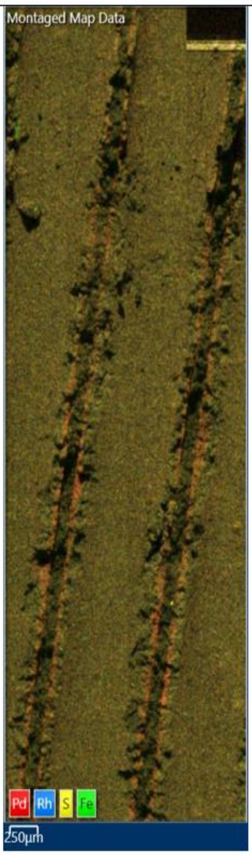
s1



s2

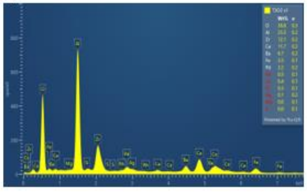






RESULT SET ID: T3O2;
TWC: Low S; Fuel type: LPG; Sample: inlet

s1



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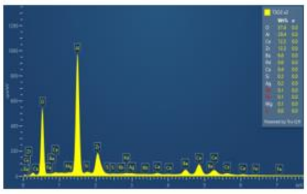
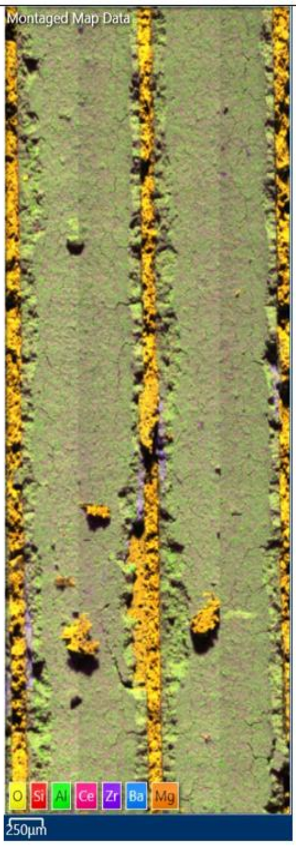
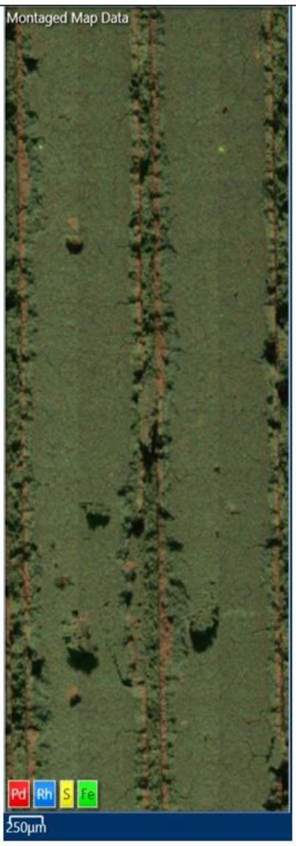
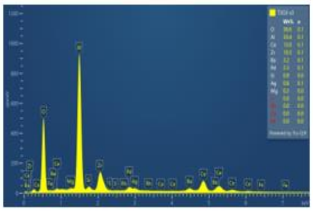


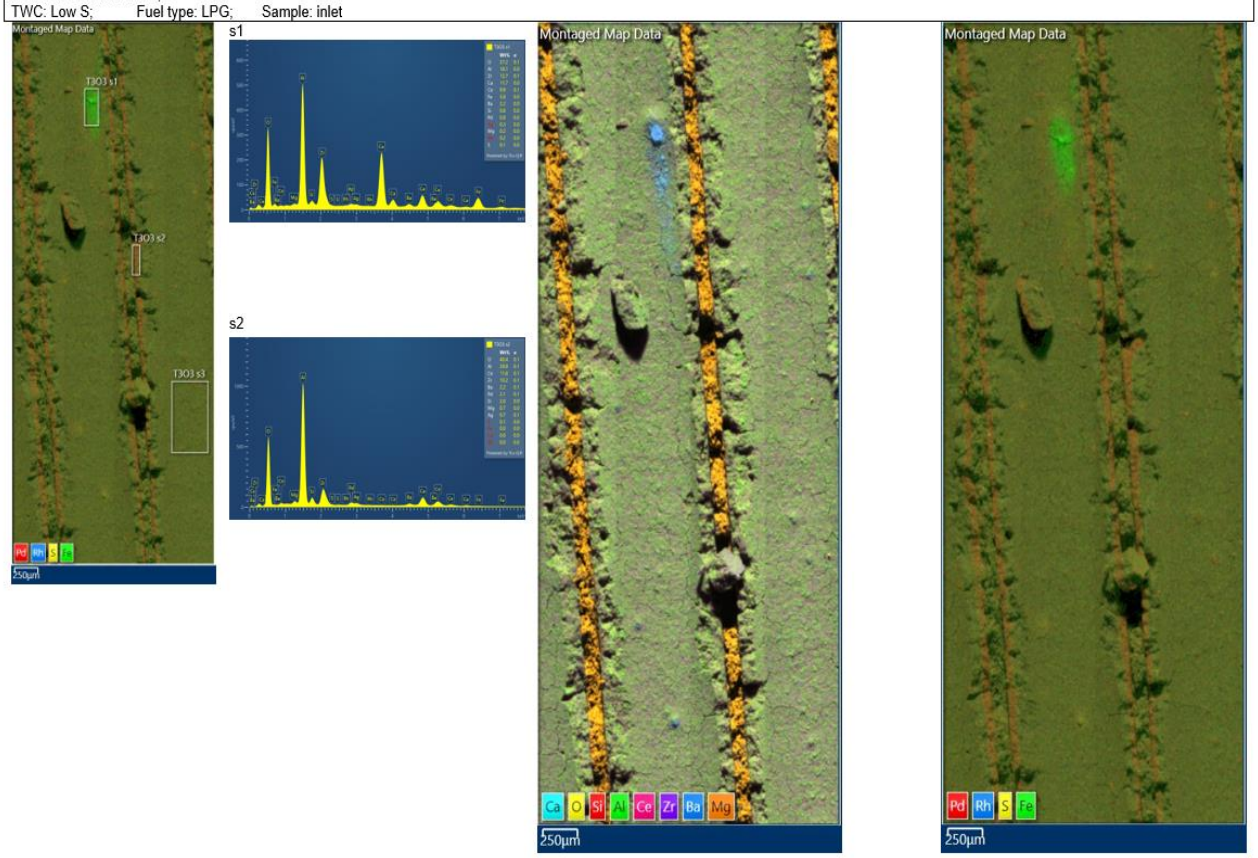




s3

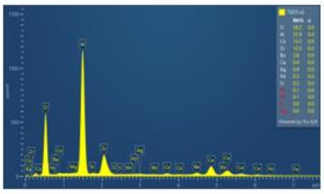


RESULT SET ID: T3O3;
TWC: Low S; Fuel type: LPG; Sample: inlet

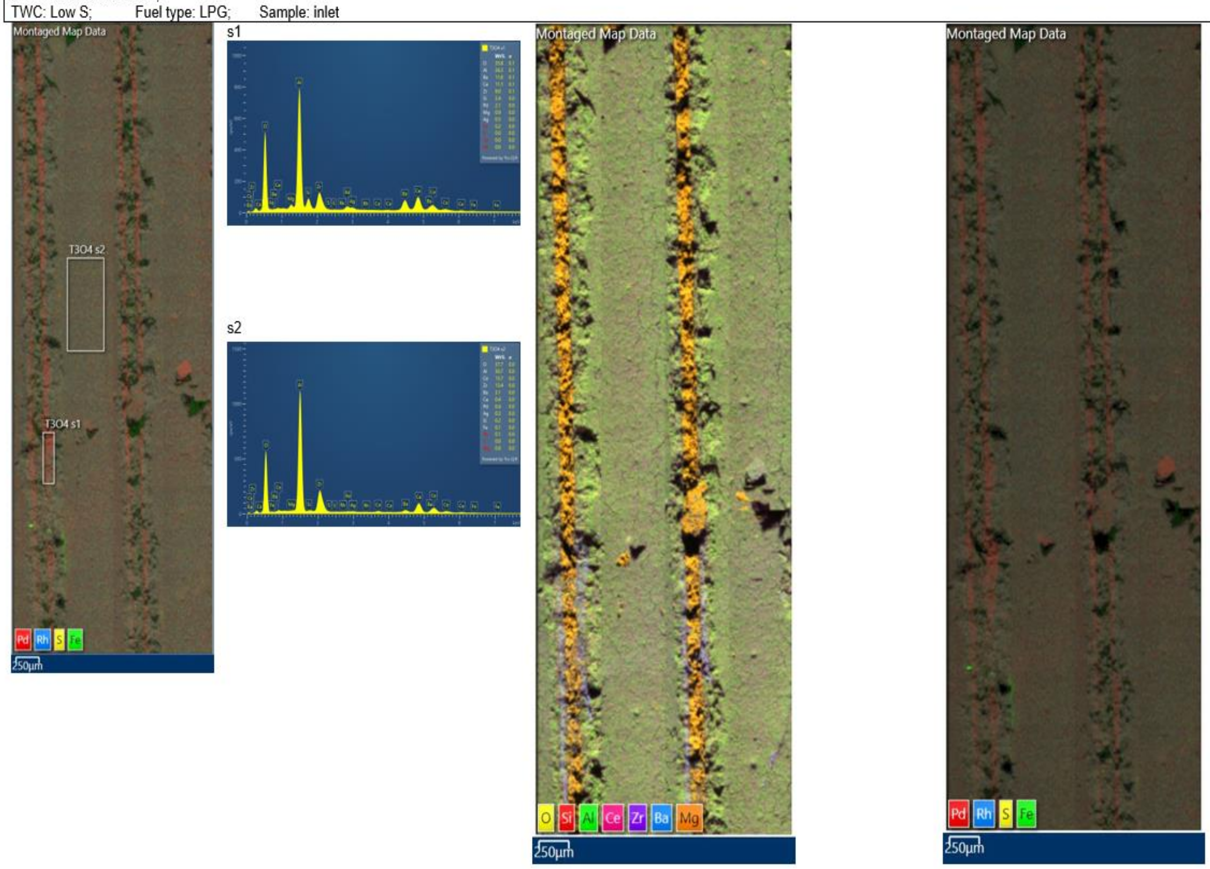

s1

s2

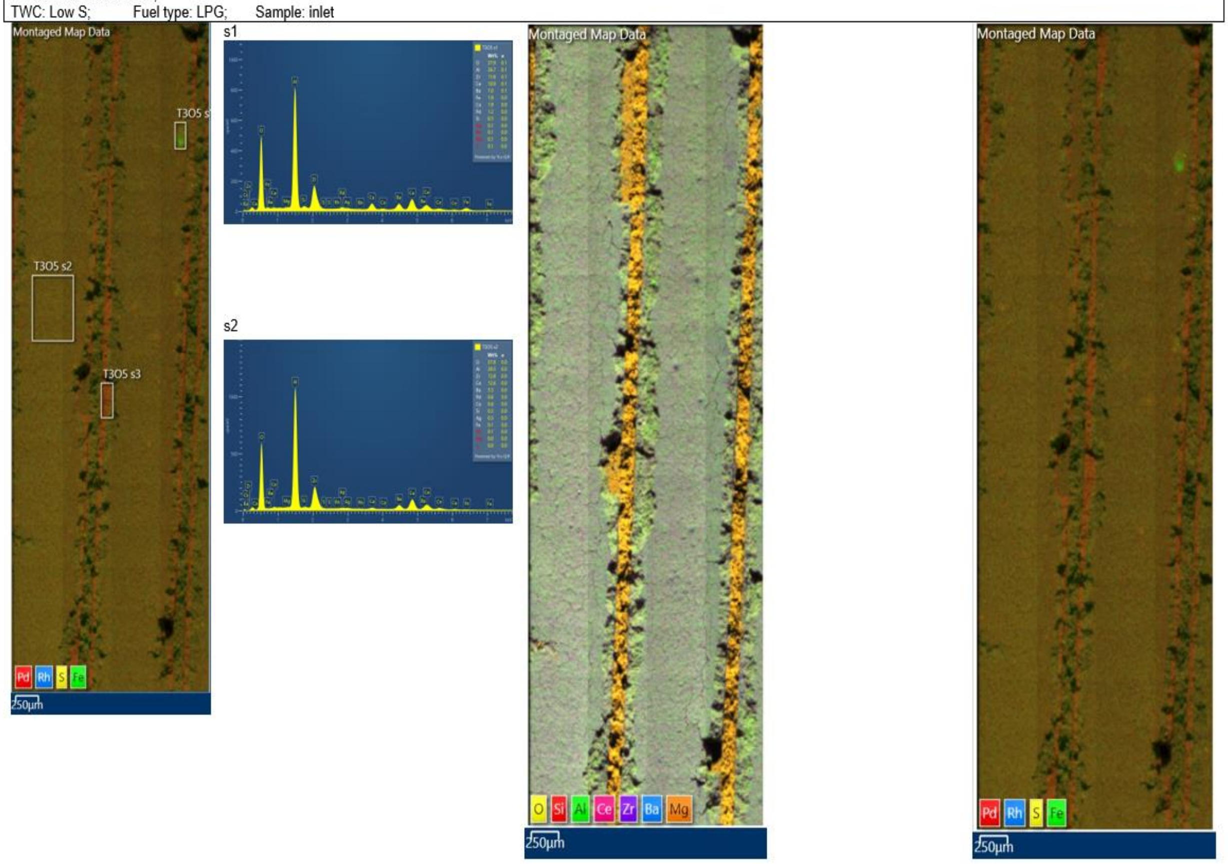
s3



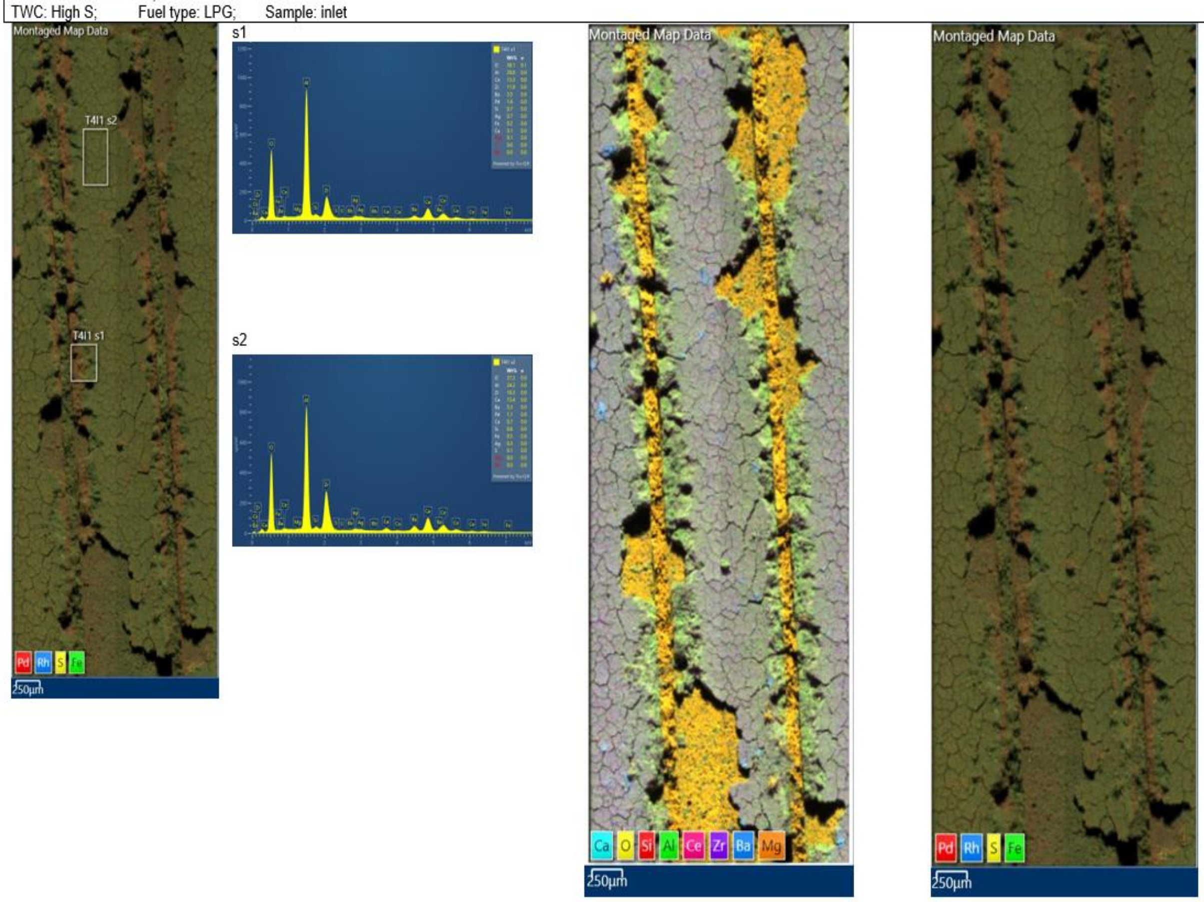
RESULT SET ID: T3O4;
TWC: Low S; Fuel type: LPG; Sample: inlet



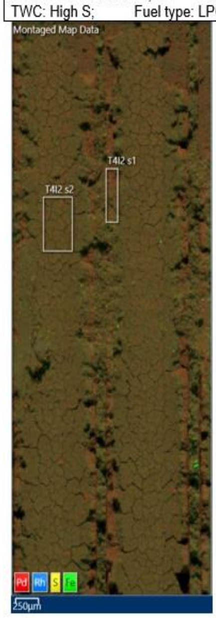
RESULT SET ID: T3O5;
TWC: Low S; Fuel type: LPG; Sample: inlet



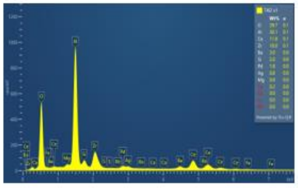
RESULT SET ID: T4I1;
TWC: High S; Fuel type: LPG; Sample: inlet



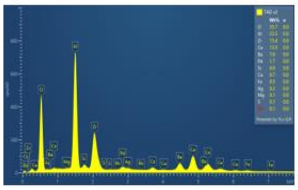
RESULT SET ID: T4I2;
TWC: High S; Fuel type: LPG; Sample: inlet

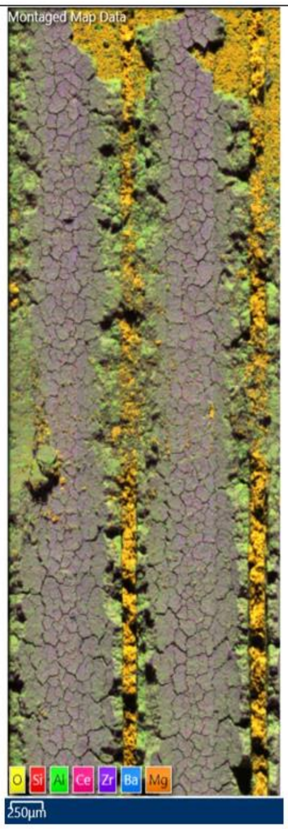


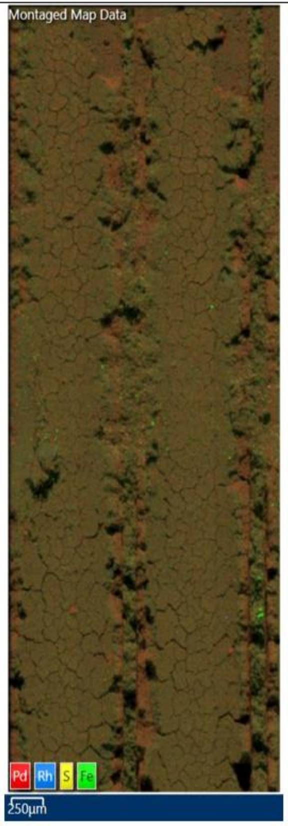
s1



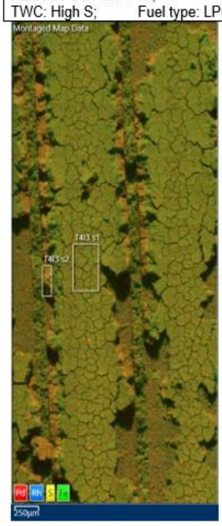
s2



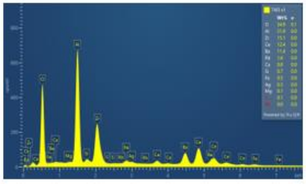




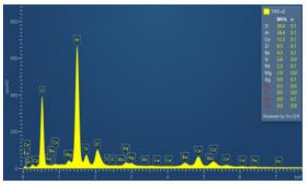
RESULT SET ID: T4I3;
TWC: High S; Fuel type: LPG; Sample: inlet

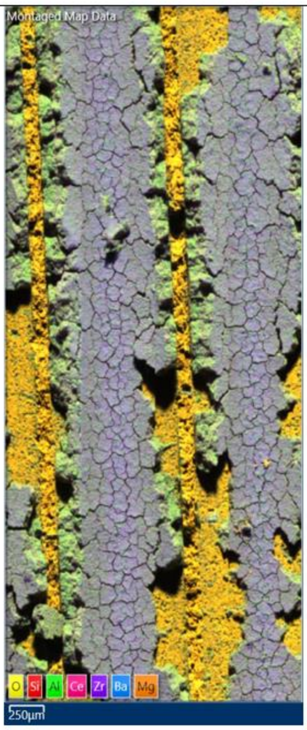


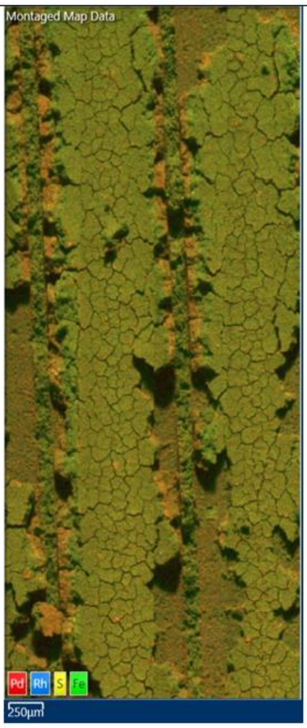
s1



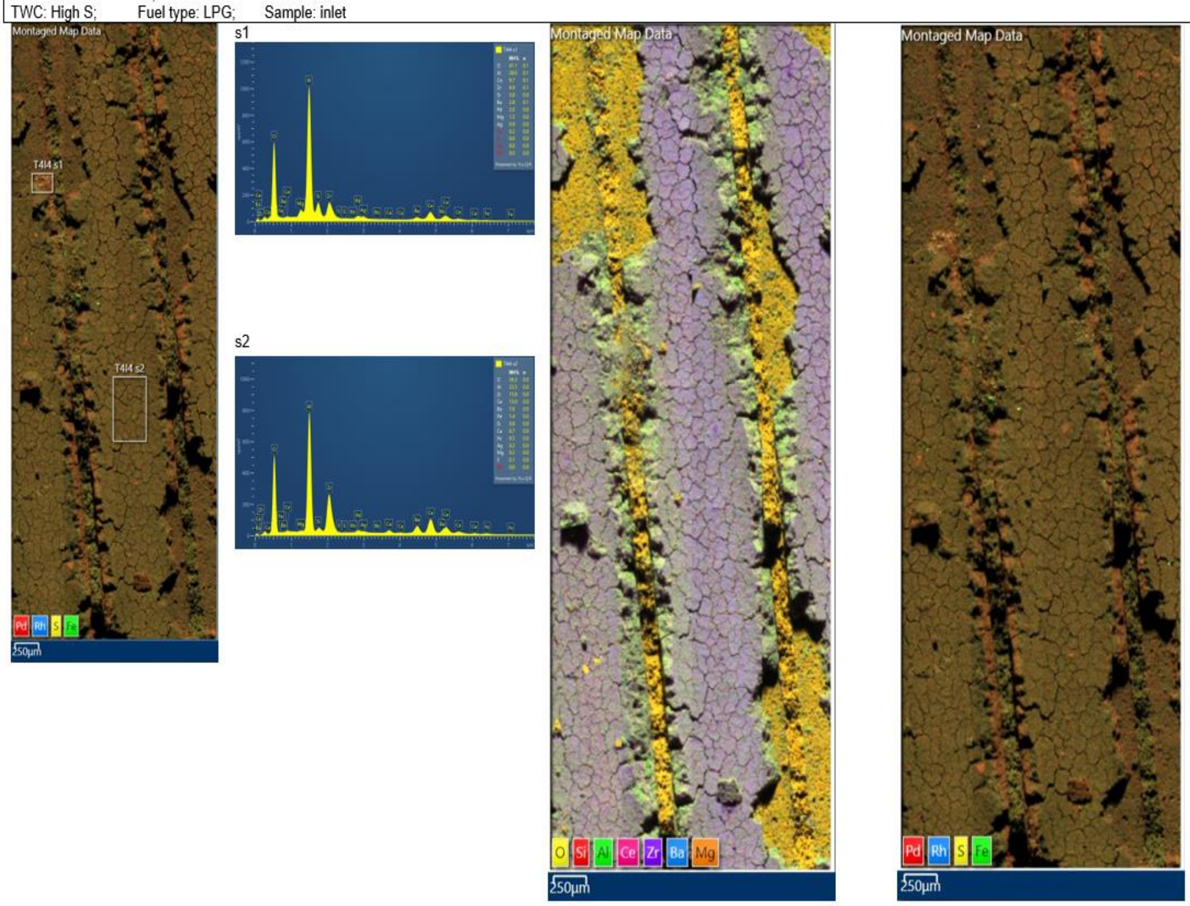
s2



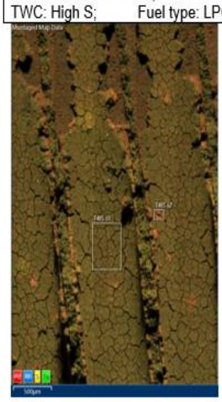




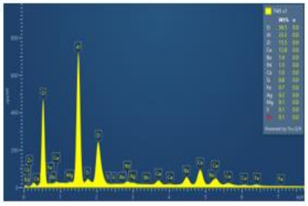
RESULT SET ID: T4I4;
TWC: High S; Fuel type: LPG; Sample: inlet



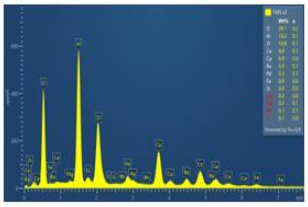
RESULT SET ID: T4I5;
TWC: High S; Fuel type: LPG; Sample: inlet

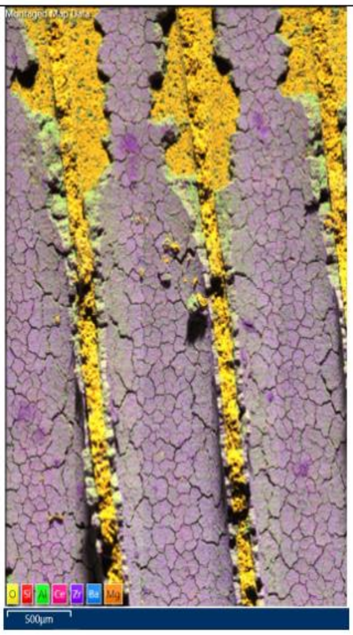


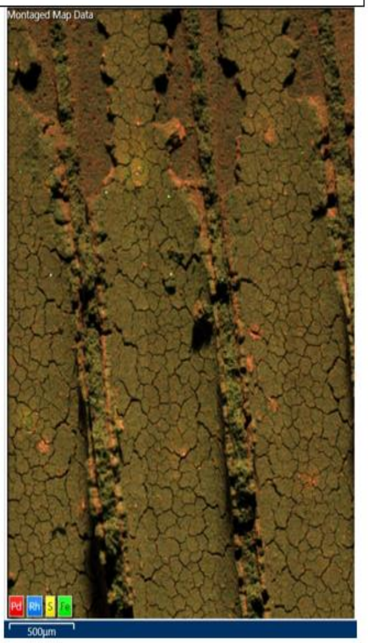
s1



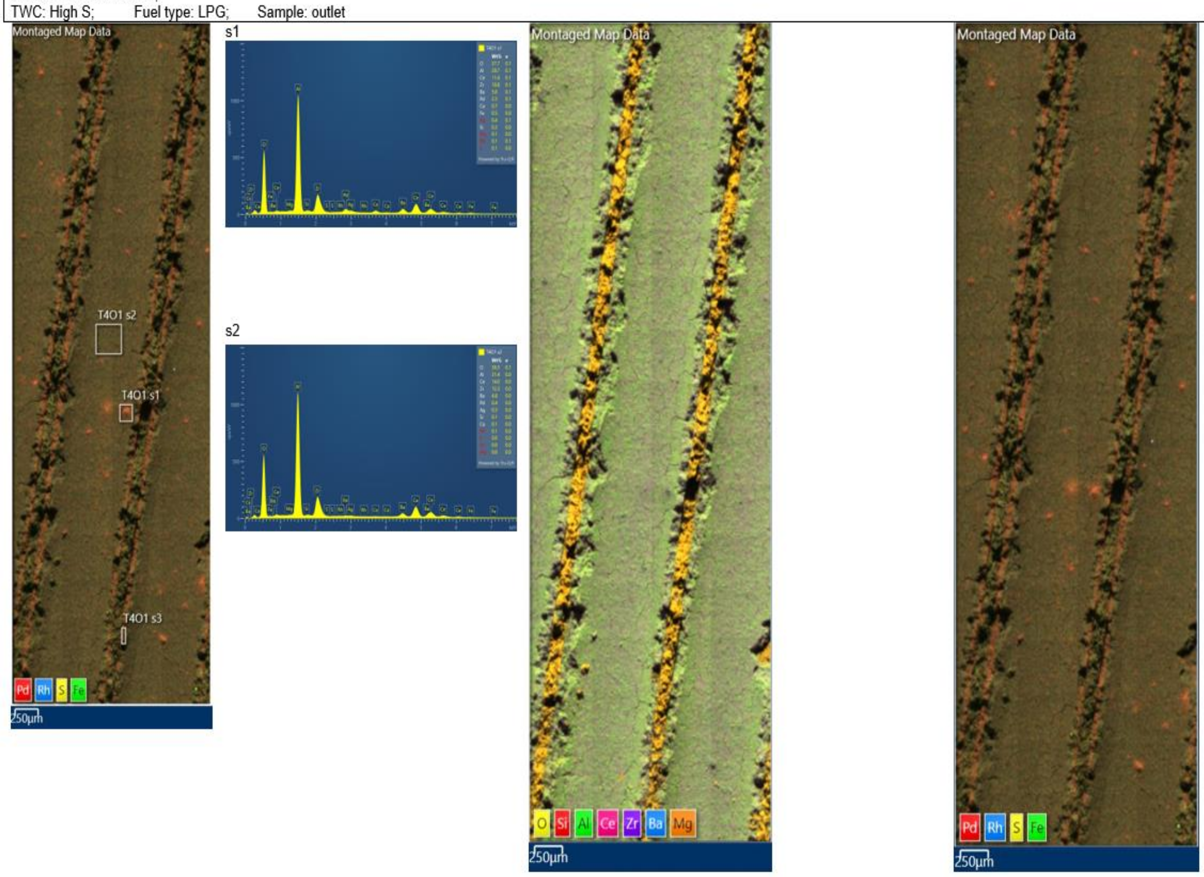
s2



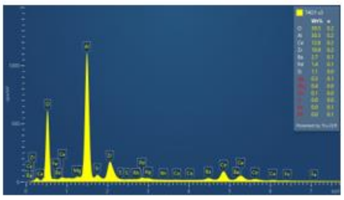




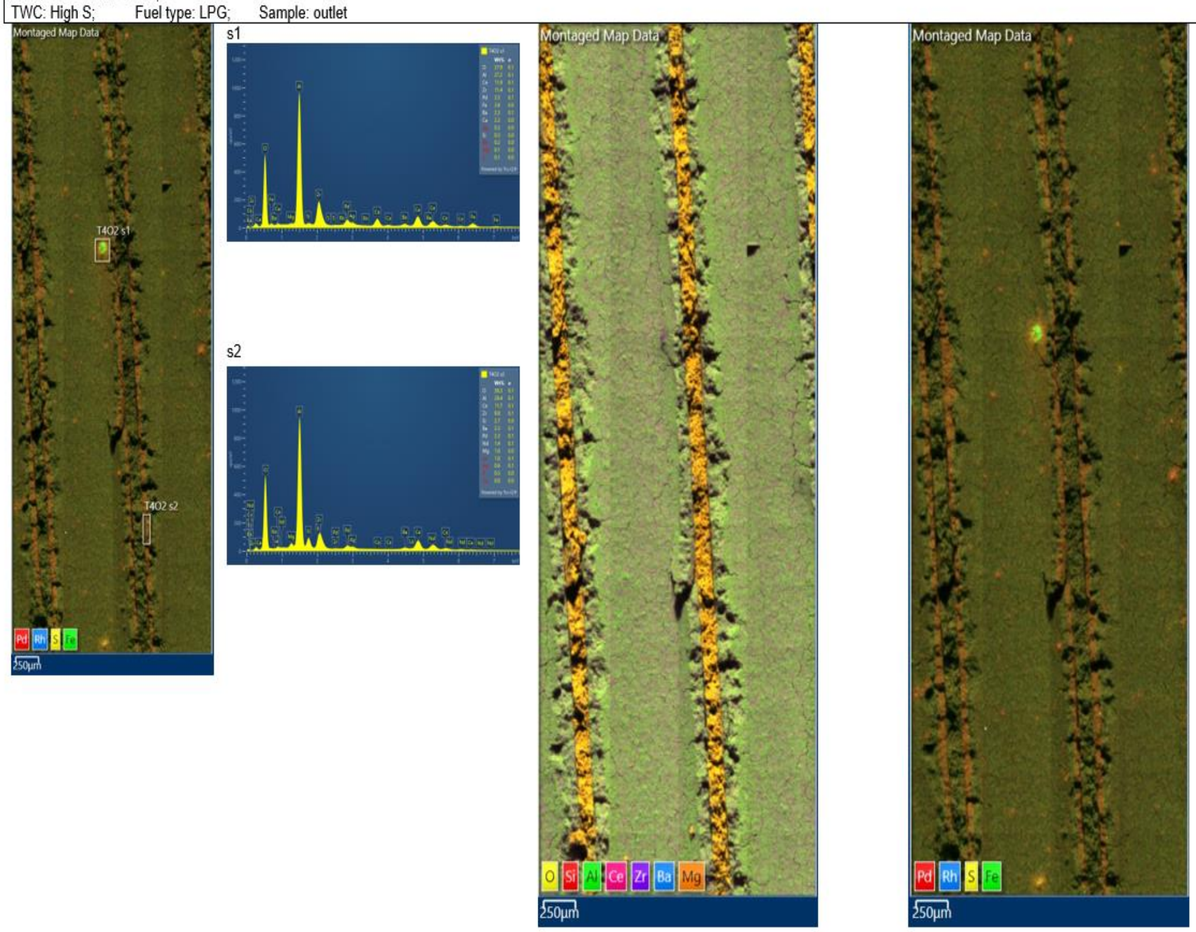
RESULT SET ID: T4O1;
TWC: High S; Fuel type: LPG; Sample: outlet



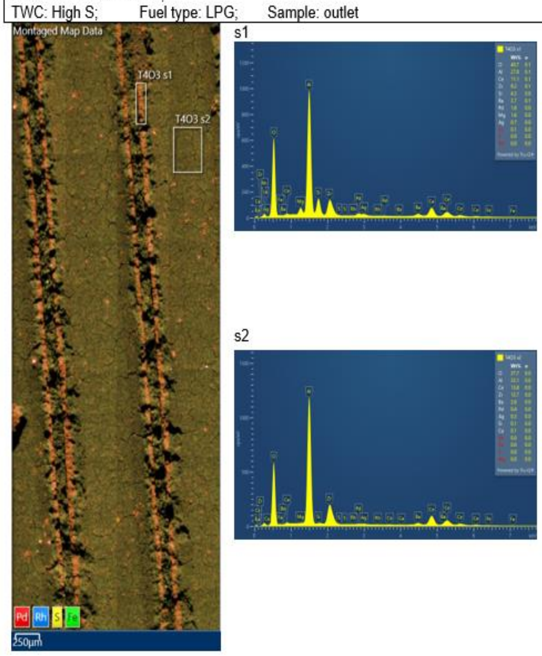
s3

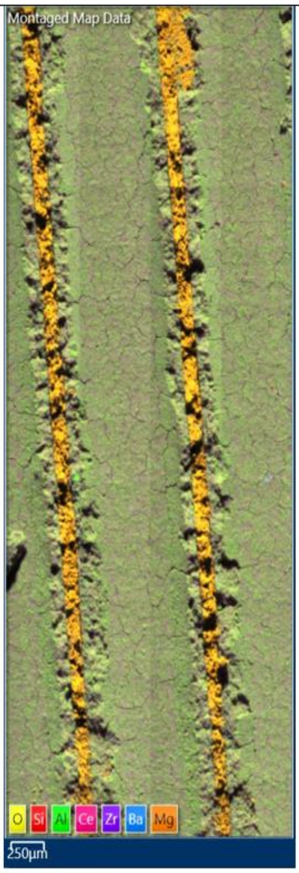


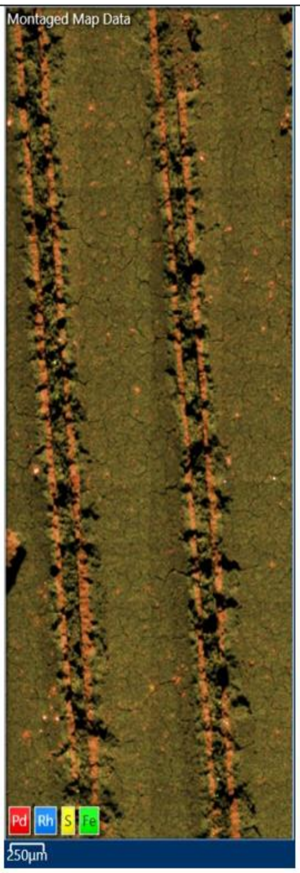
RESULT SET ID: T4O2;
TWC: High S; Fuel type: LPG; Sample: outlet



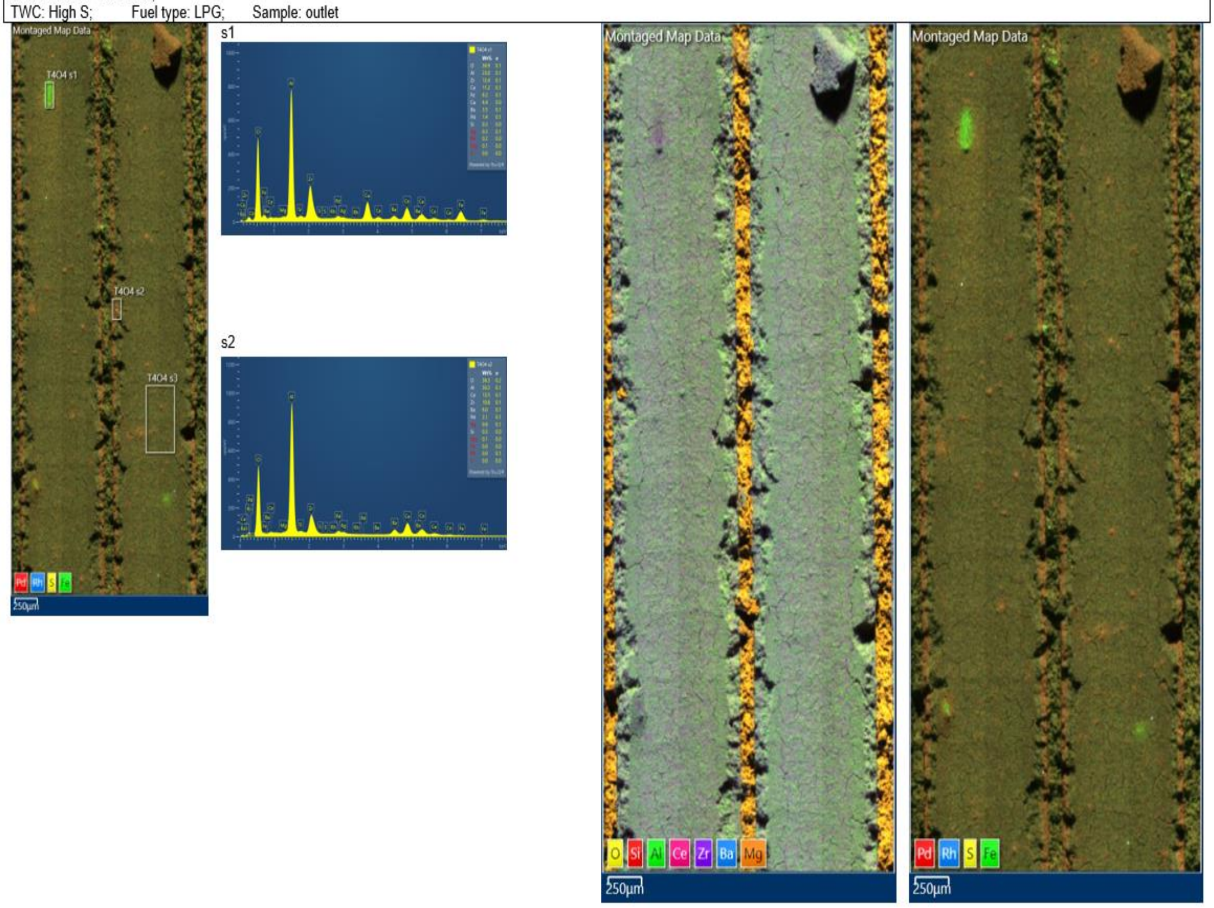
RESULT SET ID: T4O3;
TWC: High S; Fuel type: LPG; Sample: outlet



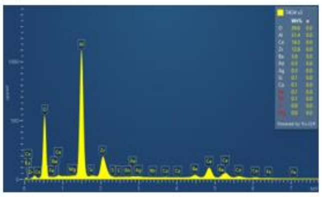




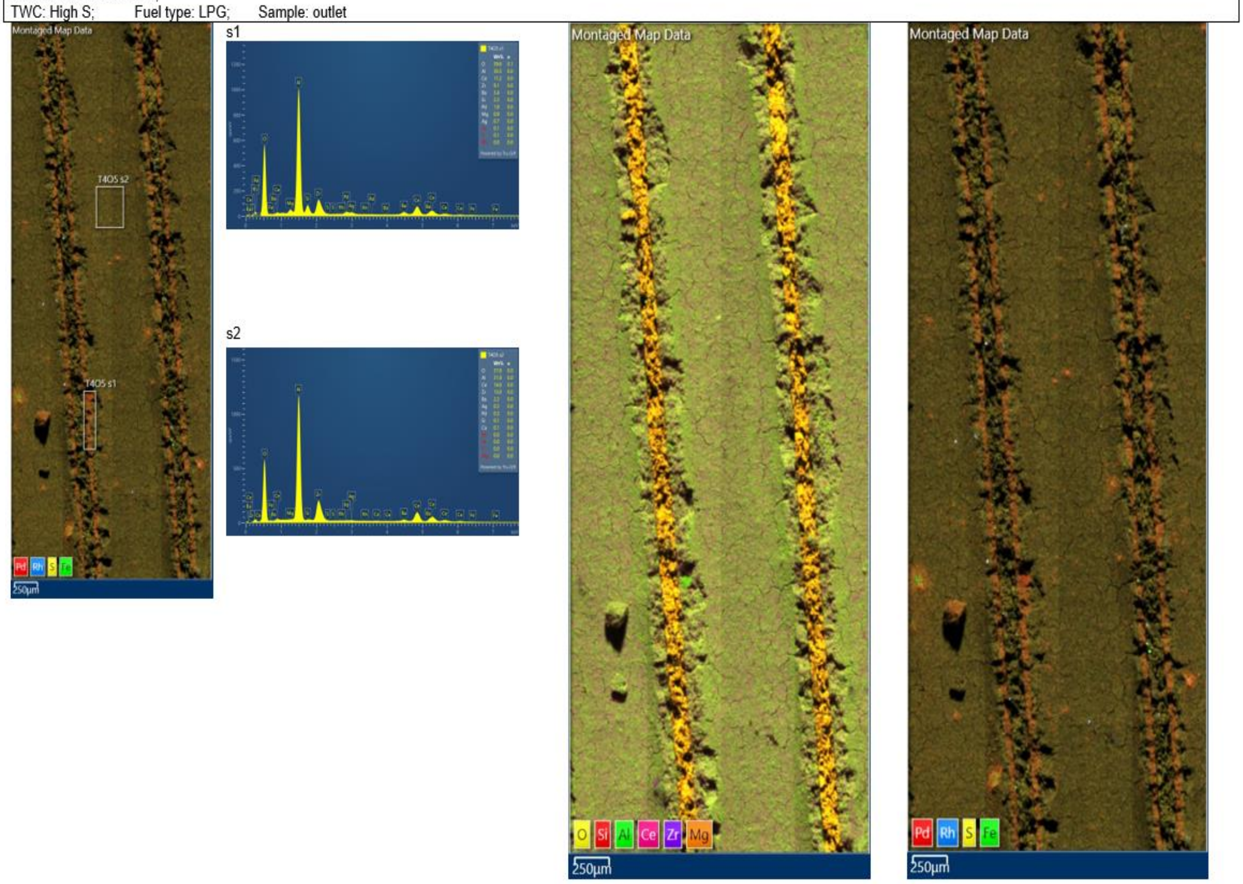
RESULT SET ID: T4O4;
TWC: High S; Fuel type: LPG; Sample: outlet



s3



RESULT SET ID: T4O5;
TWC: High S; Fuel type: LPG; Sample: outlet



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