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Title

Laboratory Evaluation of Diesel Oxidation Catalysts for NO_2 Formation

by

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Work performed for:

CAMIRO (Canadian Mining Industry Research Organization)

Project: P-002249.001
CMIN #:6840309

Version: May 2016

Canada

EXECUTIVE SUMMARY

In 2012, CanmetMINING completed a study (1) for Vale mining operations in Sudbury to determine the effect of in-use diesel oxidation catalysts (DOCs) on NO_2 production. For this purpose, Vale removed several DOCs from the underground mine vehicles and sent them to CanmetMINING for laboratory evaluation. The report indicated that some DOCs could produce excessive amounts of NO_2 under certain engine operating conditions. Hence, a new project was started to include more in-use DOCs from other mining company operations also (Glencore Sudbury, Glencore Timmins, and Vale Creighton) to determine if similar DOC behaviour is found from other mining operations. In addition, some new advanced formulations DOCs for NO_2 suppression were also evaluated. It should also be noted that new test protocols were developed and used in this study.

For this study, sixteen in-service DOCs from various mining operations and five new DOCs from manufacturers were received for testing at the CanmetMINING Diesel Research Laboratory in Ottawa. The testing included two types of protocols; Progressive Load Tests (PLT) and Vehicle Transient Tests (VTT). The vehicle transient test included four types of engine dynamometer simulated test cycles (LHD, pickup, utility and tractor). All DOCs were tested on an engine dynamometer in a controlled laboratory environment, and basic engine parameters and exhaust gaseous emissions for carbon monoxide (CO), carbon dioxide (CO_2), nitric oxide (NO), oxides of nitrogen (NO_x), and total hydrocarbons (THC) were measured.

The study identified several different types of DOC catalyst formulations which were categorized into three groups: Group 1) Active formulations; Group 2) Neutral formulations and; Group 3) Advanced formulations.

All DOCs reduced carbon monoxide and total hydrocarbons. The change in NO_2 specific emission (g/kWh) over the transient test cycles ranged from an increase of 446% to a decrease of 47% for in-use Group 1 and 2 DOCs. In general, the increase in

NO_2 formation was much higher than the reduction for the in-use Group 1 and 2 DOCs. The new advanced Group 3 DOCs, however, reduced NO_2 (g/kWh) emissions by an average of 73% (range from 47% to 94%). Therefore, advanced formulation DOCs designed for NO_2 suppression, can be used in mines to reduce NO_2 exposure under similar equipment operating duty cycles.

Some efforts were made under this project to develop a quantitative predictive model for in-use DOC performance, however, the accuracy was not sufficient and will require further research into thermal modelling of catalyst substrates. Nevertheless, it is still possible to use the test data to identify segments of vehicle operation where the risk of NO_2 formation is high.

By carefully auditing the mine fleet applications, consortium partner mines can use the results from this work to estimate the risk of NO_2 formation from their underground vehicles, and formulate an action plan to remove or replace older Group 1 types; evaluate Group 2 types; and develop purchasing specifications for advanced Group 3 type DOCs. This will lower the overall NO_2 formation in underground operations and ensure only the most advanced DOC formulations are present in the mine.

Further, a flow chart to estimate the risks of NO_2 formation from underground DOCs is derived from the limited testing of DOCs, and is provided in Figure 13.

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INTRODUCTION

The main purpose of this study is to determine the effect of in-use diesel oxidation catalysts (DOCs) on exhaust NO_2 emissions, and at the same time, evaluate those new advanced formulation DOCs that are designed to supress or reduce NO_2 emissions.

Diesel oxidation catalysts function by using the oxygen present in diesel engine exhaust to oxidize various toxic pollutants, such as carbon monoxide (CO) and hydrocarbons (HC), over a metallic catalyst. Although this is considered a benefit, some catalyst formulations can also oxidize the nitric oxide (NO) in diesel exhaust to nitrogen dioxide (NO_2) which is detrimental to overall air quality, as NO_2 is more toxic than NO. Further, in 2012 the American Conference of Governmental Industrial Hygienists (ACGIH) reduced NO_2 TLV from a value of 3.0 ppm to 0.2 ppm (2). It should be noted that many mining jurisdictions derive their regulations from ACGIH recommended TLVs. Therefore, it is very important that concentrations of NO_2 in confined spaces like underground mines should be controlled as much as possible, and alternatives should be found to not only control NO_2 emissions but to also reduce NO_2 formation. There are new types of DOCs using alternative coating formulations to reduce NO_2 formation. These DOCs reduce CO and THC concentrations without increasing NO_2 concentration. Some of these DOCs were recently analysed and reported (3). One of such advanced DOC reduced NO_2 mass emissions by 29% over the ISO-8178 C1 mode cycle (4, 7).

The earlier laboratory study (1) on the evaluation of in-use DOCs from the Vale Sudbury operation was successful; as it clearly identified that some DOCs could produce excessive amounts of NO_2 under certain conditions. Most of these in-use DOCs increased NO_2 formation. This work provided a review of the various DOC types in-use at Vale however; the data obtained was not comprehensive enough to conclude whether the entire Vale DOC fleet NO_2 formation potential was high enough to merit action.

Therefore, a new project was proposed to look at the following items in order to generate a definitive statement on the potential of DOC NO_2 formation and a subsequent action strategy:

1. A new test protocol would be developed that would provide information about:
   - The NO_2 formation potential over the full catalyst operating range.
   - In-use vehicle exhaust temperature profiles.
   - NO_2 formation over simulated mining vehicle duty cycles.

2. DOC's from other mining operations (Glencore Sudbury, Glencore Timmins, and Creighton Vale) would be tested.

3. Some new advanced formulation DOCs designed for NO_2 suppression would be obtained from aftertreatment manufacturers for laboratory evaluation.

For this study several in-use DOCs were obtained from mining operations. Similarly, several advanced DOCs to supress NO_2 formation were obtained from the aftertreatment device manufacturers. The testing was done on an engine dynamometer using a Detroit Diesel heavy duty engine (6063-WK32, 11.1L, Series 60) and ultra-low sulphur mining diesel fuel. The gaseous measurements included carbon monoxide (CO), carbon dioxide (CO_2), nitric oxide (NO), oxides of nitrogen (NO_x), and total hydrocarbons (THC).

This study would generate data about the NO_2 conversion efficiency of each test catalyst. In order to evaluate the NO_2 formation potential of the underground application, it would be necessary to overlay the exhaust temperature cycle of the existing or advanced mining vehicle application to the catalyst performance curve.

If the vehicle application generates sufficiently high exhaust temperatures in the catalyst NO_2 formation range for significant periods of time, then a risk of high NO_2 formation potential exists and the catalyst should be removed from service and/or replaced with a newer, NO_2 suppression type DOC or with other type of aftertreatment device.

This project developed a methodology for DOC/vehicle NO_2 formation potential analysis. Such a methodology could be incorporated into an expert tool for engineering analysis to properly select catalysts for new and existing applications. Such a tool would require additional input from stakeholders for vehicle exhaust temperature tracing and vehicle documentation. It may require confirmation of this work by further testing of DOCs under real mining operations in the field.

EXPERIMENTAL APPROACH

This section provides information on the test engine, test fuel, and test procedure for the evaluation of DOCs.

All the DOCs were evaluated at the CanmetMINING diesel emissions research laboratory in Ottawa. This laboratory is registered to ISO 9001:2008 standards. In addition, the test facility is recognized as an Accredited Testing Laboratory by the Standards council of Canada to comply with the requirements of ISO/IEC 17025 for specific tests. This facility has been used extensively for engine emissions testing and certification as well as aftertreatment technology performance measurement.

Test Engine

The engine used for the testing was a Detroit Diesel heavy-duty engine (6063-WK32, 11.1L, Series 60), rated at 242 kW at 2100 rpm. This engine complies with CSA-M424.2-M90 standard for application in Canadian non-gassy underground mines, CANMET Approval #1007 (5).

Table 1 provides engine specification data for the engine used in this study.

Table 1 – Engine specification data

Make	Detroit Diesel
Model	6063-WK32, Series 60
Serial number	06R0442911
Displacement	11.1 Liter
Rated power	242 kW @ 2100 rpm
Fuel rate at rated power	53.4 kg/h
Peak torque	1539 N.m @1200 rpm
Intermediate speed	1260 rpm
Aspiration	Turbocharged, charged air cooled
Fuel system	DI, Electronically controlled fuel injection
Max air intake restriction-clean air filter	3 kPa
Max exhaust backpressure	10.1 kPa
Low idle speed	600 rpm
High idle speed	2225 rpm

Test Fuel

The diesel fuel used for this study is an ultra-low-sulphur mining diesel fuel with a sulphur value of 7 mg/kg. This fuel was analysed by CanmetENERGY, and a copy of the fuel analysis results is given in Appendix A.

Test Cycle

The DOC test protocol for this study consists of two types of tests cycles; a progressive load steady state cycle and a vehicle transient cycle to simulate actual mining operations (LHD, Tractor, Pickup, and Utility vehicle).

<u>Progressive Load Test (PLT):</u> The progressive load test is used to generate a performance curve for each DOC over its entire operating temperature range. The engine exhaust flow is set to the catalyst manufacturer's design point and the exhaust

temperature gradually increases as the engine load is increased, heating up the DOC. At a given temperature, the DOC will start to work and its conversion efficiency will increase. The progressive load test is useful in comparing different DOC catalyst formulations against one another and to determine the operating ranges where NO_2 formation is possible.

Vehicle Transient Test (VTT): Once the NO_2 formation ranges have been determined by the progressive load test, there is a need to simulate the DOC operation on a mining vehicle to determine if the vehicle's normal duty cycle places the DOC in a range where NO_2 formation is possible.

The in-use DOCs tested in this study were removed from actual mining vehicles operating underground. The details of each vehicle were known and so the engine and dynamometer system was programmed to approximate the specific vehicle cycle and the NO_2 formation was then monitored over the test cycle. Following Figures 1 to 4 show underground duty cycles developed from the Kidd Creek mining operation (6). For this study, 4 types of vehicle test cycles (LHD, pickup truck, tractor, and utility vehicle) were used. The utility vehicle duty cycle is an aggregate derived from bolters, scissor lifts, and boom truck operations.

The Kidd Creek mine is a hard rock mining operation with ramp access. The vehicle duty cycles are typical of hard rock mining applications. The Kidd mine is also one of the deepest operations in Canada; however the scope of this work did not include investigating the effects of depth on catalyst efficiency.

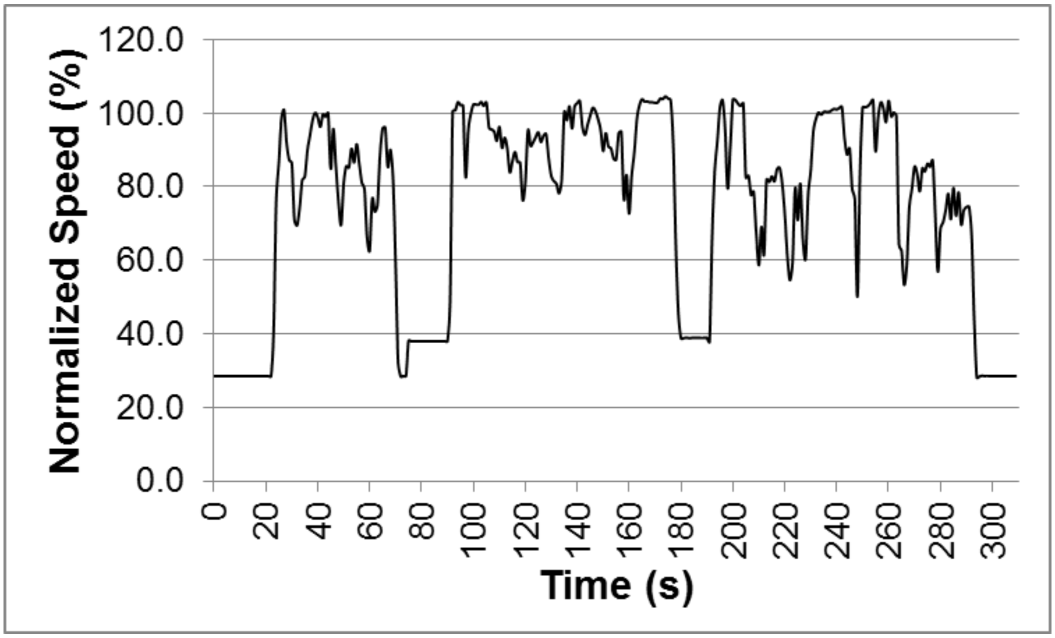


Figure 1a - Normalized speed over LHD vehicle cycle

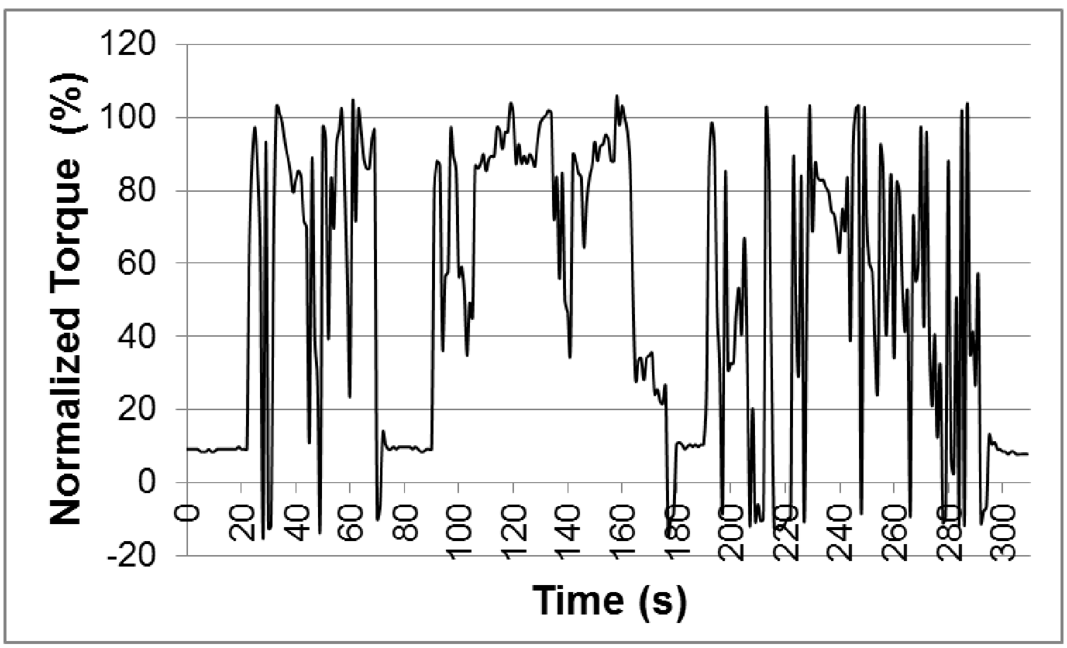


Figure 1b - Normalized torque over LHD vehicle cycle

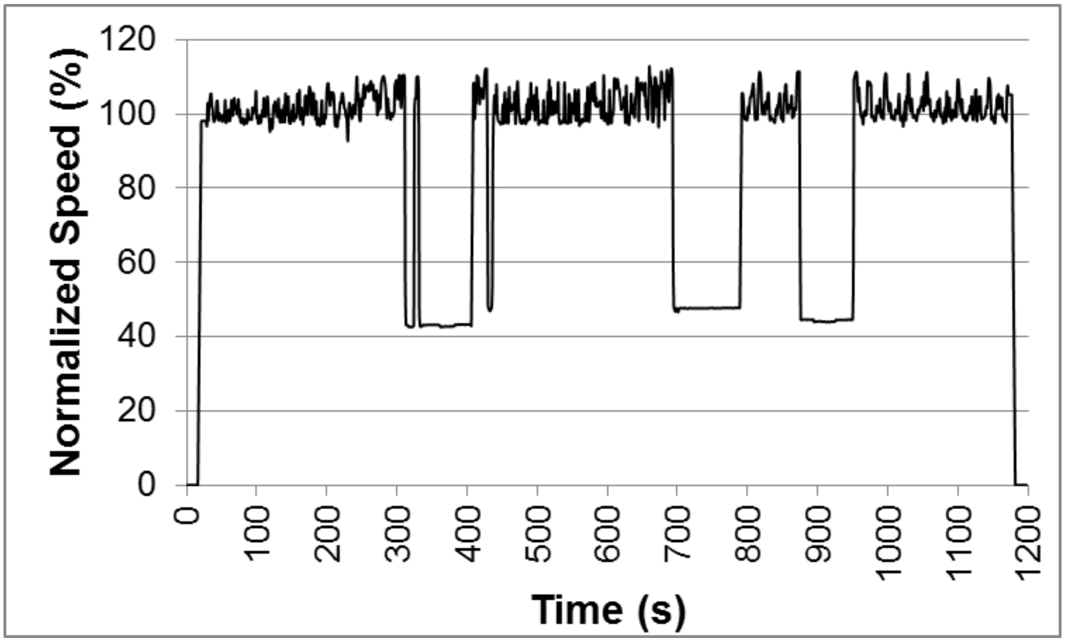


Figure 2a - Normalized speed over utility vehicle cycle

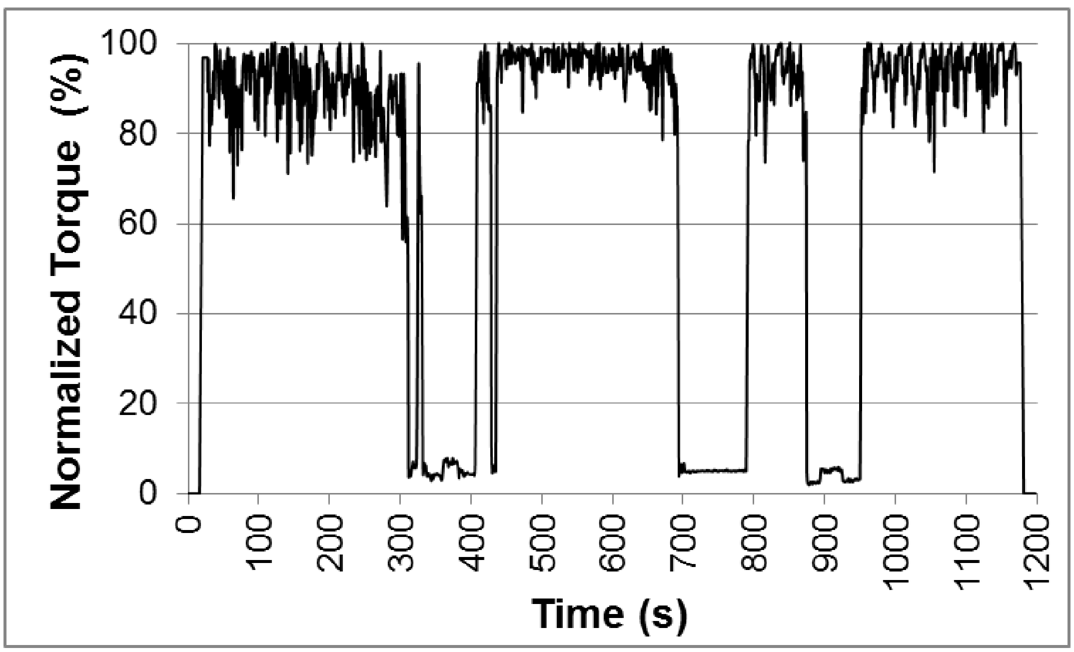


Figure 2b - Normalized torque over utility vehicle cycle

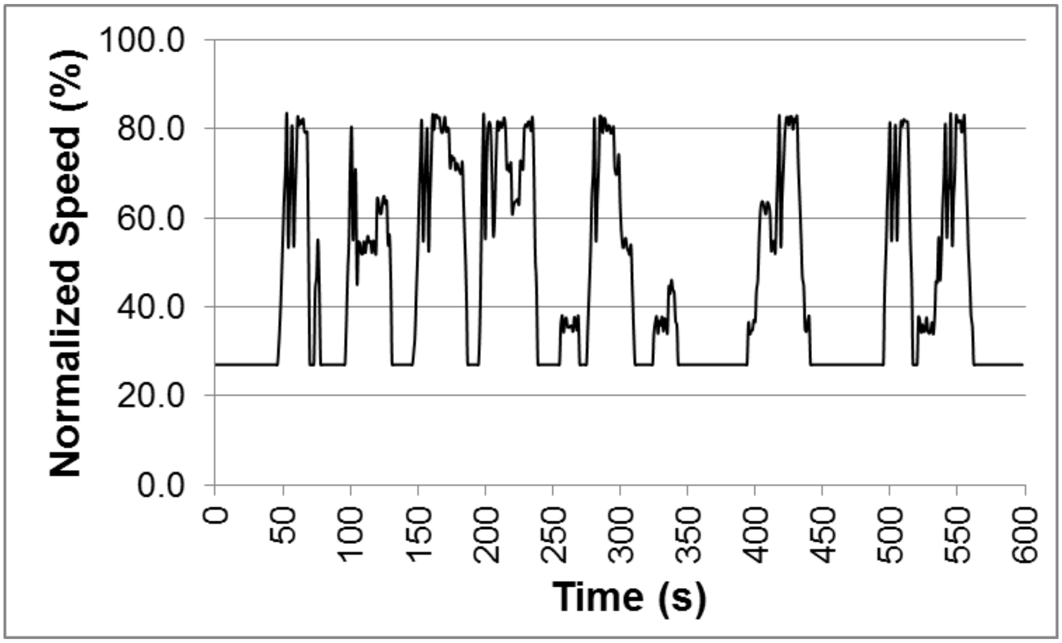


Figure 3a - Normalized speed over pickup vehicle cycle

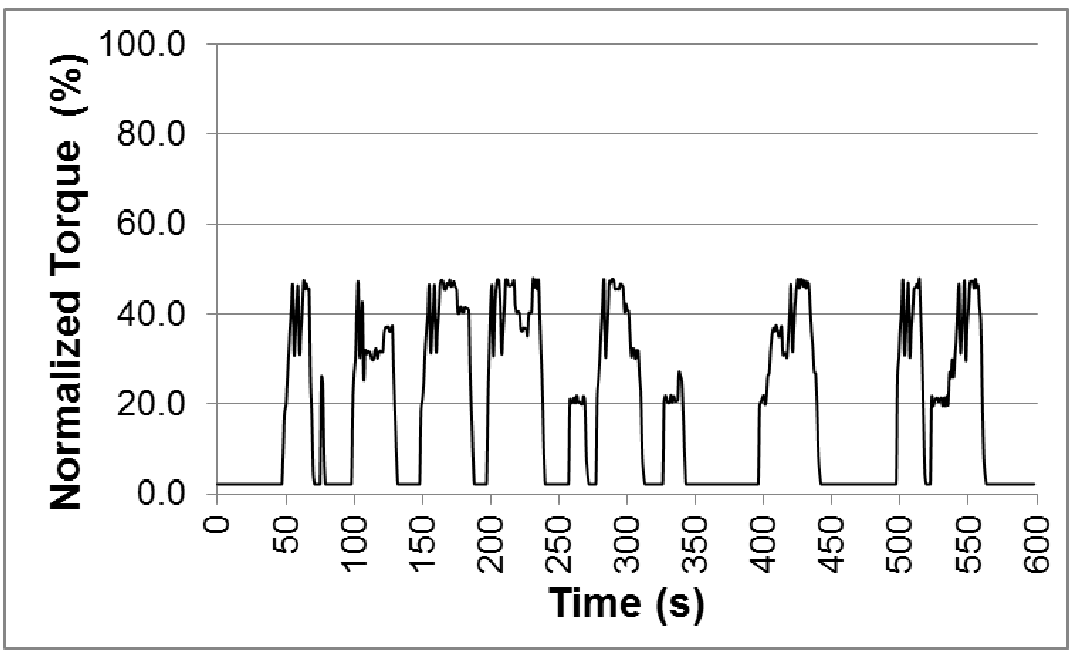


Figure 3b - Normalized torque over pickup vehicle cycle

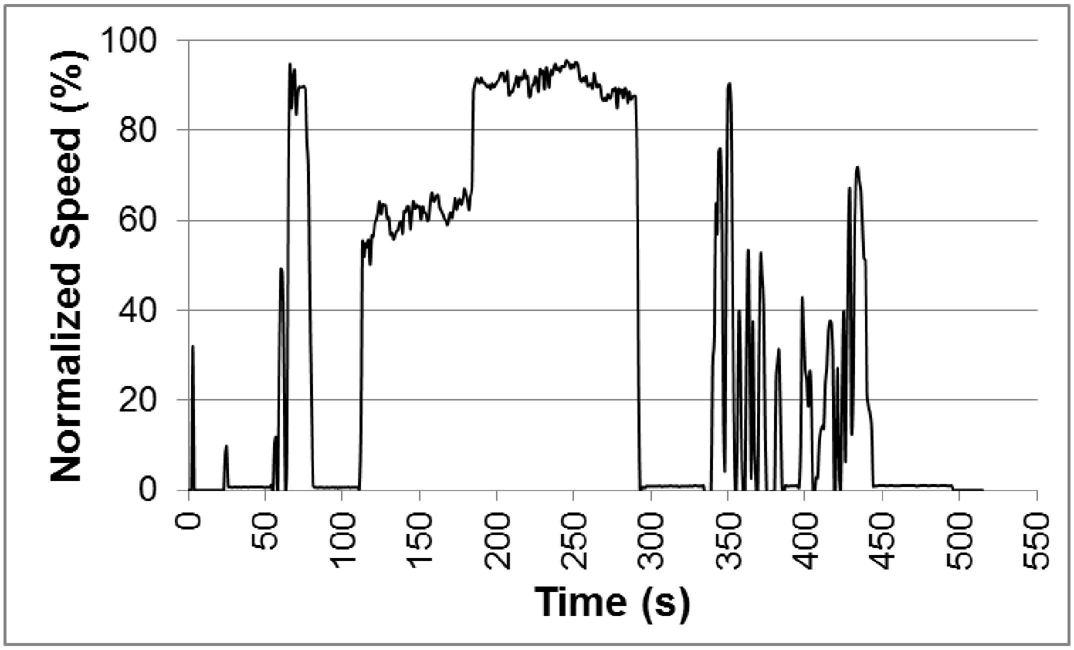


Figure 4a - Normalized speed over tractor vehicle cycle

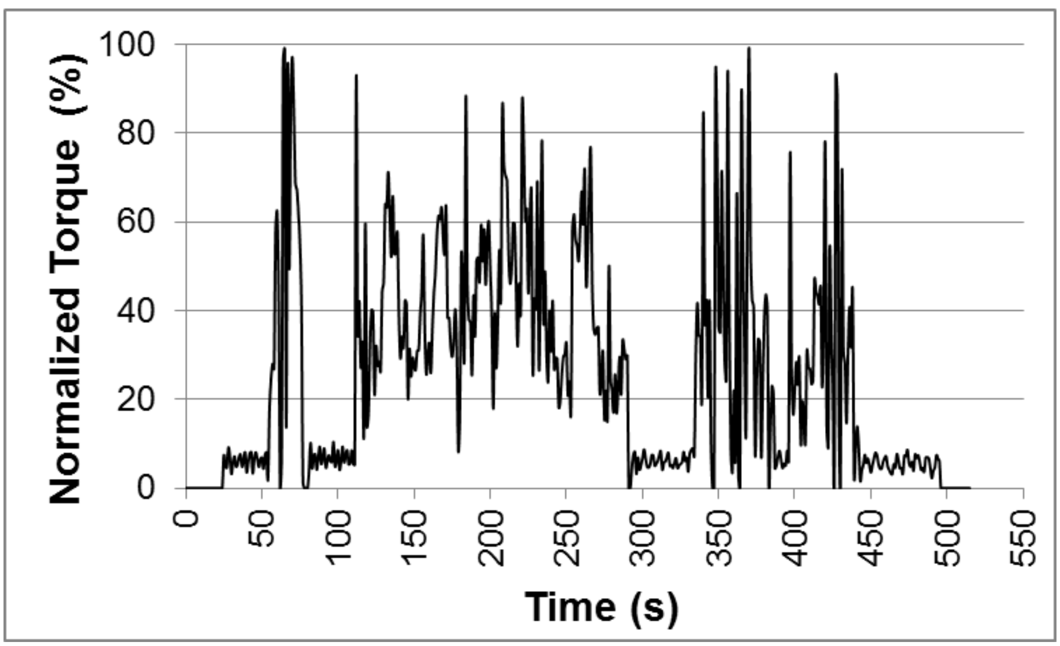


Figure 4b - Normalized torque over tractor vehicle cycle

The average value of some parameters of the transient vehicle cycles are given in Table 2. Table 2 provides data on duration of one test cycle and engine load factor. The vehicle load factor is relative to the full load and full engine speed operation. It is interesting to note that among the four transient test cycles, the tractor cycle has the lowest load factor at 11%, and the utility truck has the highest load factor at 48%. Since the steady state ISO 8178-C1 8-mode cycle is common for non-road applications, some of its values are also given in Table 2.

Table 2 – Some details on the average values for transient mine vehicle cycles

Test Cycle	Speed RPM	Torque N.m	Power kW	Load Factor %	Duration s
LHD	1587	523	87.0	36	309
Utility	1660	678	117.5	48	1198
Pickup Truck	1064	332	37.0	15	598
Tractor	1038	247	26.8	11	515
ISO 8178-C1, 8-Mode	1627	715	122	50	N/A

Diesel Oxidation Catalysts Selection

For this study, mining companies removed 32 DOCs from their underground fleets and sent them to CanmetMINING for assessment. These DOCs were examined for suitability of testing, where 16 DOCs were selected for the laboratory evaluation. These DOCs were selected in order to represent a good mix of vehicle fleet, engine and DOC type, duty cycle, and hours of use. Further, five new DOCs were provided by catalyst manufacturers for this study. These new DOCs were designed to prevent increases in exhaust NO_2 emissions. Some details on these DOCs are provided in three tables in Appendix B. The first table in Appendix B provides details on the 16 in-use DOCs that were selected for testing, the second table includes details on other 16 in-use DOCs that were not selected for testing for reasons mentioned in the last column (At the initial project progress meeting, DOCs C1, C4, C7 and C10 were removed from testing to reduce the number of DOCs for final testing), and the third table includes details on the five new DOCs that were provided by the manufactures.

Most of the in-use DOCs required significant modification or repairs than initially estimated in order to prepare them for testing in the laboratory. These modifications consisted of removing existing inlet and outlet cones and welding on new standardized cones to the catalyst element. This allowed the DOC's to be tested with a minimum of adaptor fittings resulting in less flow turbulence and restriction. In addition, inlet and outlet sample ports were added to most DOCs (where they did not exist) to allow measurement of temperatures and pressures from before and after the DOC substrate. Where the in-use DOC had been provided as a catalytic muffler, the unit was cut open and the catalyst substrate extracted and welded into a flow through canister to reduce restriction.

For this work, the in-use DOCs were tested as found and were not cleaned before testing. For notes on the effect of cleaning on DOC performance, the reader is directed to the original Vale study (1). Moreover, the scope of this work did not include investigating aging effects on DOC performance.

The advanced formulation DOCs were commissioned directly from each catalyst manufacturer. Each manufacturer was provided with the technical specifications of the laboratory engine and asked to provide a compatible DOC for underground mining applications.

Five manufacturers were requested to provide an advanced formulation DOCs for testing; identified as C31, C32, C33, C34 and C35 in this report. The advanced DOCs were physically much larger than the normal conventional DOCs, likely related to the chemical reaction characteristics of low-NO_2 formation and/or suppression. In particular, DOC C35 was significantly larger than a conventional DOC but also much larger than the other "advanced" DOCs. Also, DOC C34 was not an advanced Group 3 DOC as originally requested. It was found to have an active catalyst coating that produced high levels of NO_2. It was thus reclassified as a Group 1 DOC as shown in Table 5.

Exhaust Flow Splitter Rig

The in-use diesel oxidation catalysts (DOC) tested were designed for use on underground mining engines ranging in power size from 40 kW to 242 kW. For this study, however, one single test engine was used to produce all laboratory emissions measurements. This engine was a Detroit Diesel Series 60 rated at 242 kW at 2100 rpm.

The following describes the method used to determine the theoretical pressure drop across some smaller DOC substrates. While the full exhaust gas mass flow generated by this engine was suitable for ten of the DOC samples provided, it was necessary to partially reduce this flow to properly test the remaining, smaller DOCs. (Note: An assumption has been made that the original in-use DOC had been properly sized for each engine application, for the purpose of the following discussion). In order to reduce the full engine exhaust flow, an exhaust flow gas splitter was constructed to bypass some of the total exhaust gas flow and direct only a portion of the flow through the DOC unit under test, to simulate the exhaust flow of a smaller engine. Figure 5 shows the exhaust splitter installed on the engine to test smaller DOCs.

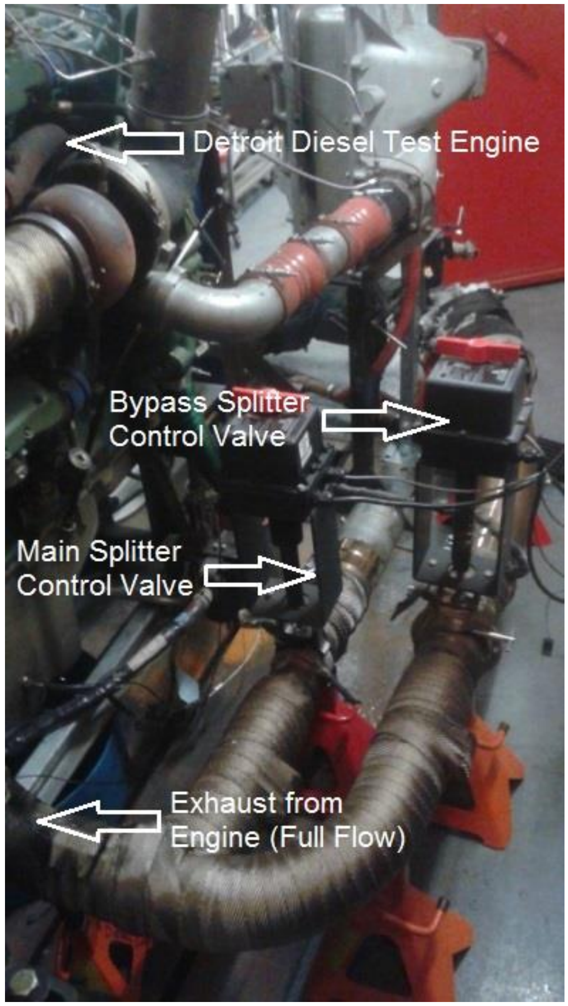


Figure 5 - Exhaust flow splitter rig

The dimensions and geometry of each test DOC was measured and the exhaust gas mass flow of the associated mining vehicle engine was determined. This data allowed the original catalyst design space velocity to be estimated. This space velocity was then used to confirm the catalyst sizing and to calculate a target in-use pressure loss across each DOC. The basic equation to determine standard engine airflow is engine displacement (liters) multiplied by speed (rpm) divided by 4 (for four-stroke cycle engines) and divided by 30,000. This gives the theoretical amount of engine airflow in cubic meters per second.

This equation is then fine-tuned by applying a volumetric efficiency based on the ratio of measured airflow to the theoretical airflow corrected for actual exhaust gas temperature and barometric pressure.

A naturally aspirated diesel engine has a volumetric efficiency of around 0.85,

a Turbocharged diesel engine (Tier 0-1) is around 1.70,

a Turbocharged and aftercooled (Tier 2-3) engine is about 2.00,

a Turbocharged and aftercooled (Tier 4) engine is around 2.25.

The engine exhaust flow passing through the DOC would develop a pressure drop across the DOC substrate. Equations 1 and 2 show the substrate channel and inlet/outlet pressure loss formulas used to estimate the DOC pressure drop prior to testing.

$$\Delta Pch = 4.84 * 10^{-4} \left(\frac{L * m}{d^2 * Af} \right) \quad - Equation\ 1$$

Where,

ΔPch – Channel pressure loss (Pa)

L – Substrate length (m)

m – Mass air flow (kg/s)

d – Hydraulic diameter (m)

Af – Free cross sectional area (m^2)

$$\Delta Pinout = 0.421 \left(\frac{Y * m^2}{Af^2} \right) \quad - Equation\ 2$$

Where,

ΔPinout – Substrate inlet and outlet effect pressure loss (Pa)

Y – Catalyst coating resistance coefficient (0.763 for the most common 200cpsi substrate)

Total pressure loss (Pa) = $\Delta P = \Delta Pch + \Delta Pinout$

Calculation of the individual flows and pressure losses for each DOC unit conditions were performed. Table 3 shows the target flow and pressure drop for each of the partial flow DOCs.

Table 3: Partial flow DOC target flow and pressure drop matrix

DOC ID	Engine Make	Engine Model	Engine kW	Displ L	RPM	VE	Intake air, kg/h	Exhaust air, kg/h	Target Delta P (Pa)
C5	Mercedes	OM 904	112	4.2	2200	2	666.0	686.0	0.75
C8	Deutz	BF4M1013C	86	4.76	2300	2	789.1	812.8	1.25
C6	Toyota	1HZ6	100	4.16	4000	0.9	509.7	525.0	1.39
C12	Iveco	N45MNS	74	4.5	2200	1.7	606.5	624.7	1.22
C13	Deutz	F3L912W	40	2.8	2300	0.9	197.3	203.2	0.82
C14	Deutz	F3L912W	40	2.8	2300	0.9	197.3	203.2	0.82
C16	Deutz	F6L912W	60	5.6	2300	0.9	394.5	406.4	0.70
C17	Mercedes	904	130	4.2	2200	2	666.0	686.0	0.75
C18	Deutz	BF4M1013C	113	4.76	2300	2	789.1	812.8	1.25
C21	Toyota	1HZ	100	4.16	4000	0.9	509.7	525.0	2.32
C23	Deutz	F4L912W	40	3.7	2300	0.9	260.7	268.5	1.10

Knowing the estimated pressure drop, the electrically operated valves in each branch of the splitter were then adjusted to achieve the target mass flow while maintaining the recommended backpressure in the exhaust system.

The target mass flow was verified with an averaging pitot tube in the exhaust piping after the DOC. Figure 6 shows the pitot tube location in the exhaust system.

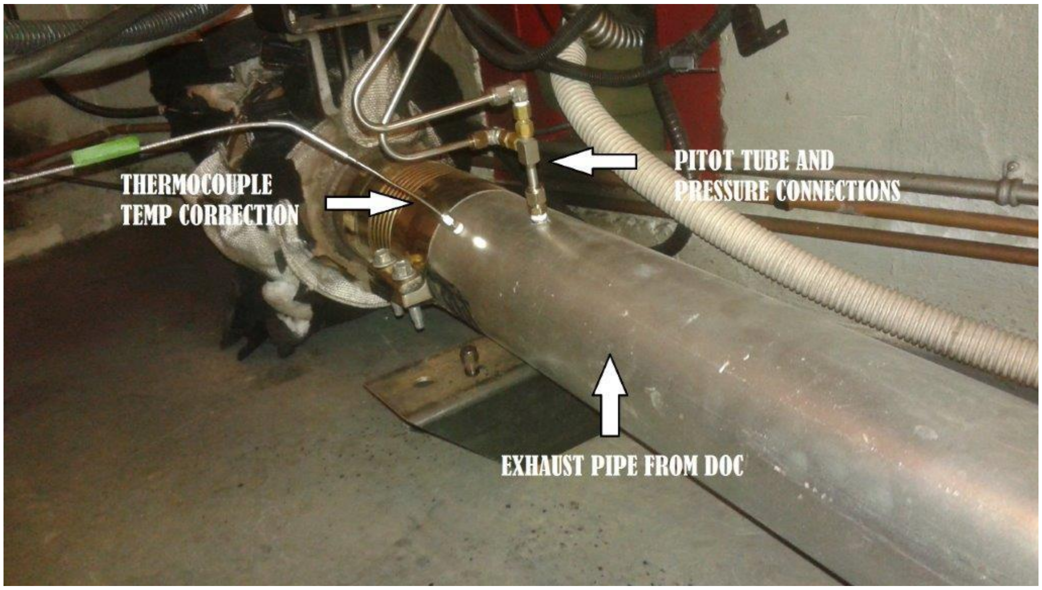


Figure 6 - Exhaust flow measuring pitot tube and thermocouple

The pitot tube was calibrated to the exhaust gas flow of the Detroit Diesel test engine. Figure 7 shows the pitot tube calibration chart.

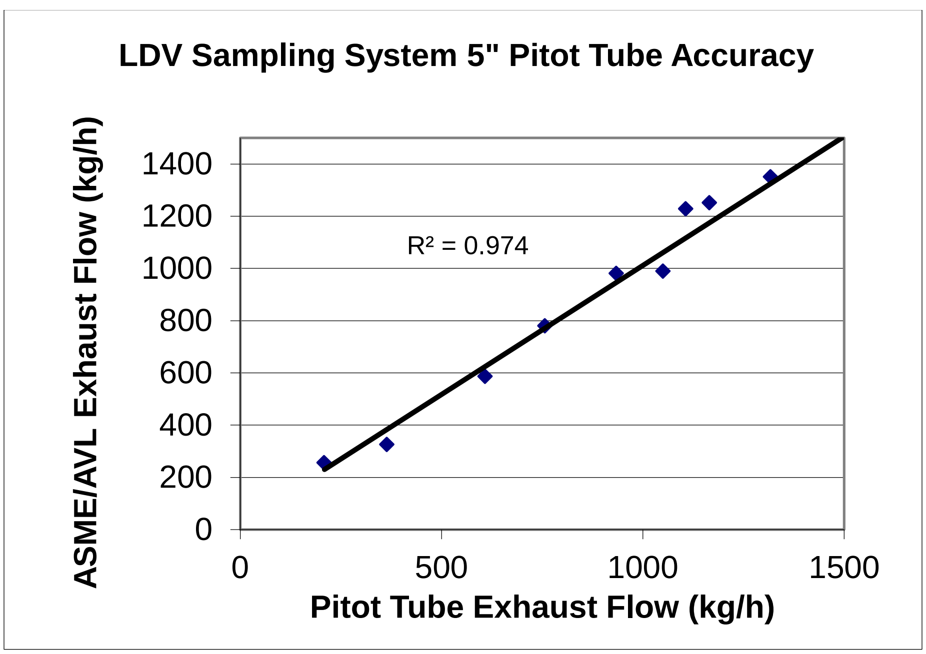


Figure 7 - Pitot tube calibration chart

Note that the DOCs were not all designed to the same space velocity. This may be due to cost considerations or vehicle packaging constraints, where a lower space velocity would require a physically larger catalyst substrate. A larger substrate would also contain more precious metals and thus be more expensive, while a smaller substrate would be less expensive, provided the required level of emissions performance is met.

This discrepancy in the application engineering of each DOC contributed to the difference in maximum achieved conversion efficiency, however, the light-off temperature (the temperature at which the catalyst achieves 50% conversion) is not as sensitive to space velocity.

Most conventional DOCs designed for unregulated vehicle applications are between 150,000h^{-1} and 300,000h^{-1} space velocity. Most of the mining vehicles fall into this category.

The advanced formation DOCs are designed at lower space velocities between 50,000h^{-1} and 150,000h-1.

TEST PROCEDURE

The Detroit Diesel engine was installed on the engine dynamometer and operated at the rated power in order to set the engine intake air restriction at the maximum value for a clean filter (3 kPa), and exhaust back pressure at the maximum value (10.1 kPa) per the engine manufacturer specifications.

Testing was done using an ultra-low sulphur fuel (Appendix A) for all DOCs (Appendix B) as described in the Test Sheet (Appendix C). The full engine exhaust flow was suitable for five in-use DOCs and five new DOCs (Appendix C, Test # 8 to 27). The baseline tests (Appendix C, Test # 1 to 7) were performed first to determine the 13 test points for the progressive load testing and the transient vehicle cycles. The remaining eleven DOCs required reduced exhaust flow, via the flow splitter, as they were removed from vehicles that produced lower exhaust flows (Appendix C, Test #28 to #49). The DOC installation in the total exhaust system through the DOC is shown in Figure 8.

Figure 8 – DOC installed in the total exhaust system

All 21 DOCs were tested over a steady state progressive load test cycle, and the related transient test vehicle cycles.

The progressive load test cycle was developed at the test engine's peak torque speed (1260 rpm). For this cycle, engine exhaust temperature was increased gradually to about 12°C per step by increasing the engine load, where corresponding values of torque and temperature were recorded. This required testing at thirty (30) points from zero load to the maximum load at 1260 rpm to define the test cycle. For the progressive load testing, thirteen (13) of these thirty (30) test points were selected (shown by triangles in Figure 9) to provide a suitable test to describe DOC operating temperature profile, and to limit the number of test points for scheduling. The final progressive load test cycle was run at 1260 rpm at thirteen (13) load points (torque value of 20, 102, 183, 264, 319, 373, 427, 481, 569, 719, 929, 1132, and 1470 Nm) as shown in Figure 9.

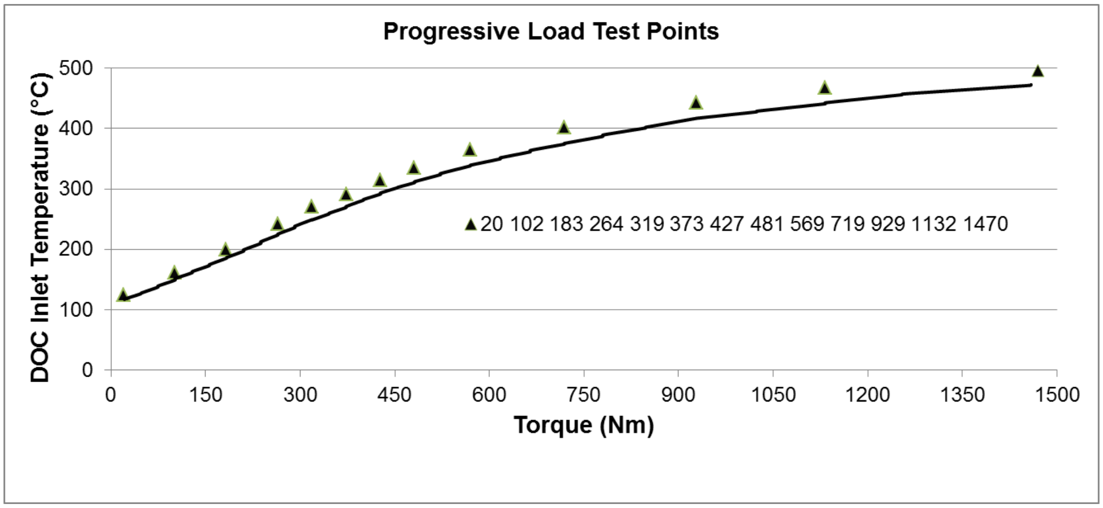


Figure 9 – Exhaust temperatures with engine torque over progressive load testing

For each of thirteen (13) test points, exhaust gas measurements were made for carbon monoxide (CO) and carbon dioxide (CO_2) with a non-dispersive infrared (NDIR) detection system, oxygen (O_2) with a paramagnetic (PMA) detection system, nitric oxide (NO) and nitrogen oxides (NOx) with a heated chemiluminescence (CLD) detection system and total hydrocarbons (THC) with a heated flame ionization detector. Engine exhaust emission measurements followed the required international ISO 8178-1 procedures (4).

For progressive load testing, gaseous emissions for CO, CO_2, NO, NO_x, and THC were made before and after the DOCs. Concentration of NO_2 was calculated by subtracting the NO value from NO_x value. A summary of basic engine parameters and exhaust gas emissions in ppm and specific emissions in g/kWh for all DOCs are given in Appendix D.

For vehicle transient testing, gaseous emissions and basic engine parameters were made on a per second basis for both the engine baseline (without a DOC), and with a DOC using one of the four transient mining vehicle cycles as previously described and listed in Appendix B. The normalized speed and torque curves for all 4 transient test cycles are shown in Figure 1 to 4.

RESULTS AND DISCUSSION

DOCs can be classified according to their potential to make NO_2 as follows: older, active formulations (Group 1), neutral formulations (Group 2) and new, advanced formulations (Group 3). The catalytic formulations are further described below. The samples of DOCs provided for this study were selected from many different vehicle applications at several underground mining operations. The color codes can be used in a decision tool to be described below. Note that the group classification system was based on this laboratory emissions testing only. DOCs were assigned into groups if they exhibited the performance generally accepted as defining the group characteristics. No chemical analysis of the DOC formulations was performed due to cost reasons.

A summary of engine exhaust emissions measured before and after the DOCs at thirteen (13) points for progressive load testing are given in the tables in Appendix D. This information is used later to determine the changes in gas emissions with exhaust temperatures and to estimate the change in emissions under a transient vehicle cycle.

The full engine exhaust flow was utilised for testing of five in-use DOCs and five new DOCs, while the other eleven in-use DOCs that were used in the mine on smaller power engines, utilised partial flow through the DOCs to match with the mine engine exhaust flow. This study used four types of mine duty cycles including LHD, utility vehicle, pickup truck, and tractor. The average emission test data over the transient test cycles are given in tables of Appendix E. These tables indicate that the basic engine parameters (speed, torque, power) for the baseline and DOC tests are within one percent, indicating that transient test cycles were repeatable, and hence the data are comparable. This data is summarized in Table 4 which provides the percent change in exhaust specific (g/kWh) emissions for CO, THC and NO_2 for all DOCs. A positive value (+) indicates an increase while a negative value (-) indicates a decrease in the exhaust specific emissions.

Table 4 – Effect of DOCs on specific emissions over transient vehicle cycles

DOC Number	Mine Engine Rated Power kW	Transient Vehicle Cycle	Percent Change in Exhaust Specific Emission (g/kWh)		
			CO	THC	NO_2
In-use DOCs tested with full exhaust flow					
C2	242	LHD	-60	-45	-18
C3	241	LHD	-70	-59	32
C15	242	LHD	-49	-51	-5
C19	241	LHD	-58	-49	-2
C20	242	LHD	-53	-51	-17
New DOCs tested with full exhaust flow					
C31	N/A	LHD	-67	-62	-71
C32	N/A	LHD	-61	-62	-81
C33	N/A	LHD	-6	-72	-47
C34	N/A	LHD	-99	-68	184
C35	N/A	LHD	-98	-72	-94
In-use DOCs tested with partial exhaust flow					
C17	130	Utility	-34	-27	-37
C18	113	Utility	-70	-49	-2
C5	112	Utility	-99	-74	154
C6	100	Pickup	-81	-54	102
C21	100	Pickup	-84	-59	179
C8	86	LHD	-55	-43	-24
C12	74	Tractor	-66	-50	18
C16	60	Utility	-91	-71	446
C22	40	Utility	-58	-38	8
C13	40	Utility	-46	-41	-47
C14	40	Utility	-64	-48	9

The platinum group catalyst formulations described as active formulations (Group 1), are what have been traditionally used since the introduction of DOCs underground. Their emissions trend towards high efficiency CO and HC reduction at moderate to high space velocities often with a commensurate increase in NO_2 formation. The use of these DOC formulations should be generally avoided as NO_2 is a hazard that negatively affects air quality.

Base metal formulations described as neutral type formulations (Group 2), have been in use for around fifteen years and are slowly entering the underground mining market. Their emissions trend towards medium efficiency CO and HC reduction at moderate space velocities, with low or zero increase in NO_2. The uses of these DOCs do not represent a significant hazard; since, NO_2 formation potential is low. They also provide for a reasonable reduction in CO and HC emissions.

Many new “advanced” catalyst formulations (Group 3) are entering the market. These catalysts have high efficiency CO and HC reduction at moderate to low space velocities with some reduction in NO_2. The use of these catalysts should be encouraged as they are a net benefit for air quality. To note, the low space velocities result in catalyst packaging that is double or triple the size of a conventional DOC so some relaxation of vehicle space constraints is required.

Cycle Based DOC Evaluation:

A transient test, developed from actual mining vehicle cycles represents the best method to evaluate the effect of a DOC on vehicle tailpipe emissions, however, there is still a need to verify DOC performance and compare them independently of vehicle cycles. The progressive load test is a cycle where the engine exhaust flow through the DOC is approximated at a specific target space velocity. The load is gradually applied to the engine which raises the exhaust temperature. In this way, the catalyst conversion efficiency can be determined independent of thermal inertia effects. In addition, the performance of the catalyst at a wide range of exhaust temperatures is known, thus aiding prediction.

An attempt is made here to estimate the effect of DOC on vehicle emissions by combining the progressive load test and the vehicle transient test. If a test engine is operated over a simulated vehicle transient cycle, a history of the exhaust temperature frequency distribution can be determined. If this distribution is overlaid on a DOC progressive load test chart, it becomes possible to estimate areas of the test cycle where NO_2 formation potential is high. If the vehicle operating cycle results in high exhaust temperatures that overlap the areas of the DOC performance curve where the NO_2 formation is positive, then there is a potential for hazardous NO_2 formation. Overlaying different types of DOC test charts can help identify good or poor candidates for vehicle emissions reduction.

It is possible for the mine to generate a vehicle duty cycle and obtain transient test exhaust temperature distributions to aid in selecting the DOC technology appropriate for the intended use. An example is given below to illustrate this concept.

Figure 10 combines the transient test temperature profile histogram and the progressive load test data percentage change in CO for DOC C3. The CO reduction (blue line) for this catalyst started at DOC inlet temperature of 185°C, and quickly reached conversion efficiency of 83% at 220°C, and reached a maximum of 98% at 300°C. It should be noted that DOC C3 reduced CO emissions at all operating temperatures of the LHD transient test cycle (cycle temperature bins shown as bars).

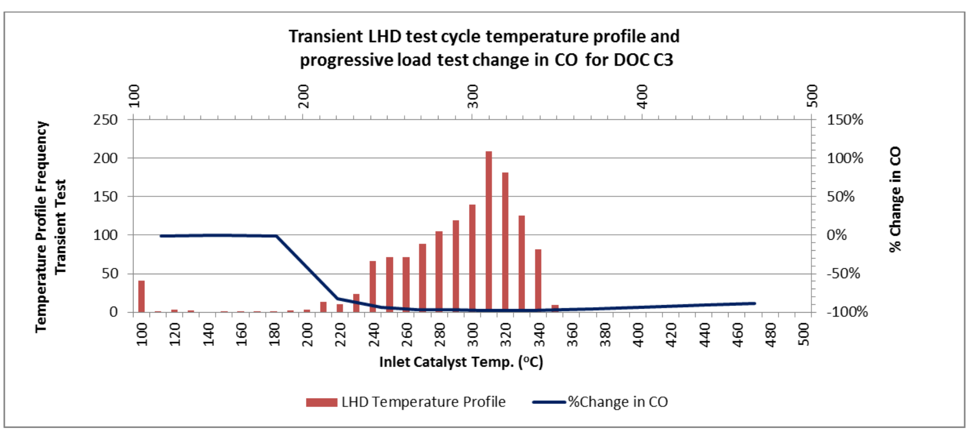


Figure 10 - Transient LHD test cycle temperature profile and progressive load test CO percent reduction for DOC C3

Similarly, percent THC reduction for DOC C3 is shown in Figure 11. THC reduction at inlet temperature of 185°C is about 3%, and then quickly reached conversion efficiency of 57% at 245°C, with a maximum reduction of 64% at 285°C. DOC C3 reduced THC emissions at all operating temperatures of the LHD transient test cycle.

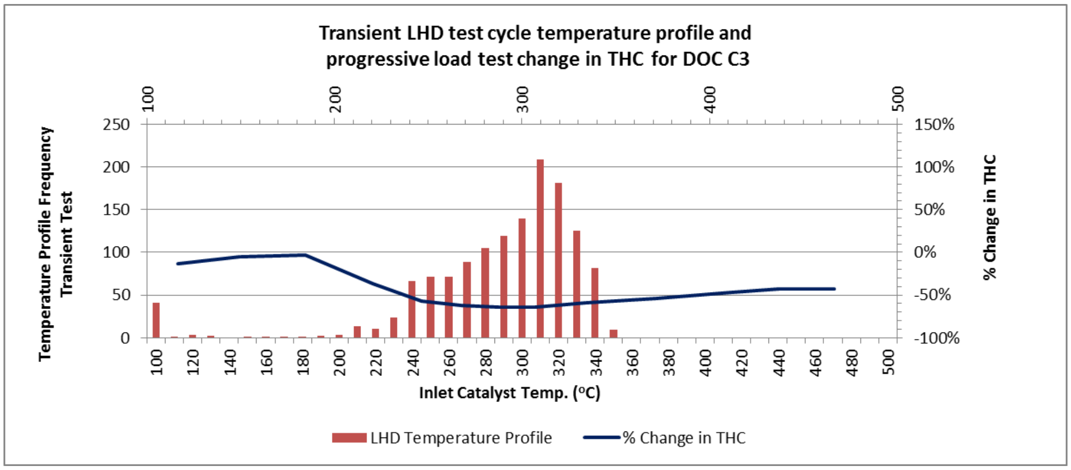


Figure 11 - Transient LHD test cycle temperature profile and progressive load test THC percent reduction for DOC C3

The percentage change in NO_2 emissions due to DOC C3 for the LHD duty cycle is shown in Figure 12. This DOC started increasing NO_2 at temperatures above 245°C, and NO_2 was increased during most of the LHD cycle. The temperature where NO_2 begins to increase is called "critical NO_2 temperature". Similarly we can determine the critical NO_2 temperature for other DOCs. The critical NO_2 temperatures for all DOCs are estimated from the NO_2 graphs of Appendix C, and are listed in ascending order in Table 5. The other corresponding data for these DOCs are taken from Table 4, and listed in Table 5.

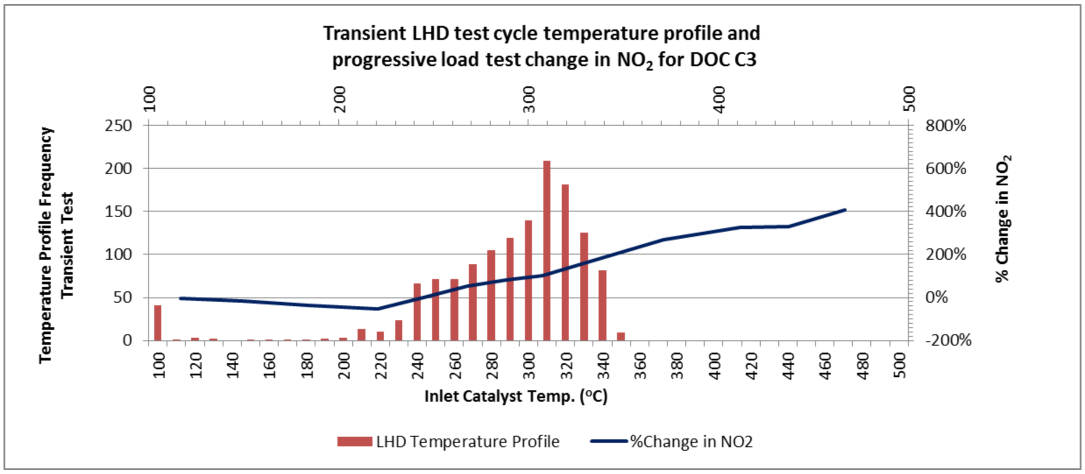


Figure 12 - Transient mine LHD test cycle temperature profile and progressive load test NO_2 percent change for DOC C3

Table 5 lists the DOCs according to Group 1, Group 2 and Group 3. Group 1 DOCs begin to make increasing amounts of NO_2 when the NO_2 critical vehicle exhaust temperature falls in the range of 210 to 250°C and continues to make NO_2 throughout the operating envelope of each equipment duty cycle. Group 2 DOCs either make or reduce relatively smaller amounts of NO_2 throughout the operating envelope of each equipment duty cycle. Advanced formulations or Group 3 DOCs reduce NO_2 for all applications when the NO_2 critical vehicle exhausts temperature is above 325 °C. In addition, they were very effective at simultaneously reducing the other toxic emissions like CO and HC.

Table 5 – Critical NO_2 temperature and change in NO_2 specific emissions over transient vehicle cycles

Group Type	DOC Number	Transient Vehicle Cycle	Critical NO_2 Temperature (°C)	% change in NO_2 (g/kWh)
1	C16	Utility	215	446
	C21	Pickup	220	179
	C5	Utility	230	154
	C34	LHD	235	184
	C6	Pickup	240	102
	C3	LHD	245	32
	C12	Tractor	245	18
2	C18	Utility	255	-2
	C15	LHD	280	-5
	C8	LHD	285	-24
	C2	LHD	290	-18
	C22	Utility	295	8
	C20	LHD	300	-17
	C14	Utility	300	9
	C19	LHD	320	-2
3	C33	LHD	325	-47
	C17	Utility	330	-37
	C31	LHD	335	-71
	C32	LHD	365	-81
	C35	LHD	370	-94
	C13	Utility	415	-47

CONCLUSIONS

In the past, diesel oxidation catalysts were viewed as a benefit and were implemented almost universally in underground mines in Canada. This study has demonstrated the necessity of evaluating these claims; since, some types of Group 1 and 2 DOC formulations can increase the production of NO_2 and thus represent a hazard to air quality.

At the same time, Group 3 advanced DOC formulations have been developed which reverse this effect and can significantly reduce NO_2 emissions from the engine over simulated equipment duty cycles. This has made it possible for a single device; properly engineered and sized; to provide reductions in CO, HC and NO_2 which is a benefit to the industry.

It is important to note that the different formulations of DOC cannot be identified visually. They must be classified with the assistance of the manufacturer and verified through independent emissions testing in the field.

Some efforts were made under this project to develop a quantitative predictive model for in-use DOC performance (APPENDIX G), however, the accuracy was not sufficient and will require further research into thermal modelling of catalyst substrates. Nevertheless, it is possible to use the test data to identify vehicle operation where high NO_2 formation potential exists.

RECOMMENDATIONS

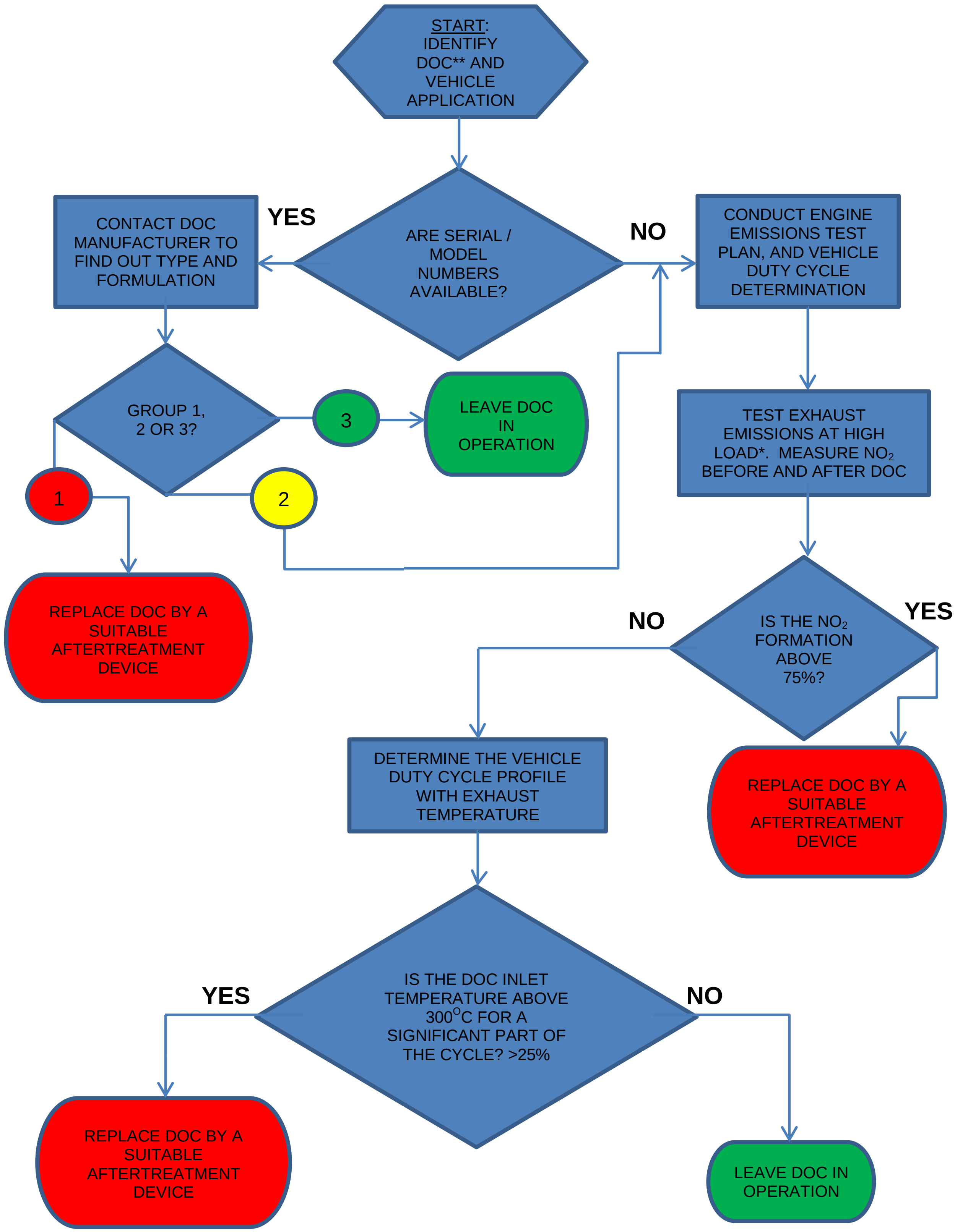
As can be seen in Table 5, most types of Group 1 (active) DOCs greatly increase NO_2 formation even at low exhaust temperatures. These DOCs should be replaced with advanced Group 3 DOCs or other suitable aftertreatment devices.

Group 2 (neutral) types are more difficult to evaluate as they are capable of reducing, increasing or maintaining NO_2 emission neutral depending on the application. As some of these DOCs are a benefit, each application should be evaluated individually to determine if there is a risk of NO_2 formation.

Group 3 (advanced) DOC types are universally a benefit as they reduce NO_2 formation while still providing excellent reductions in CO and HC.

It is recommended that the project partners develop an in-mine testing and evaluation program to identify DOC and vehicle applications which have high NO_2 formation potential and take steps to remedy this situation and replace the hazardous DOCs with newer, advanced formulas. Figure 13 shows a possible decision flowchart for evaluating the NO_2 risk of an individual DOC/vehicle application.

Such an evaluation program would involve acquiring an exhaust temperature trace at the DOC inlet and constructing a histogram of the duty cycle temperatures. These could then be overlaid on the DOC performance curve provided by the DOC manufacturer (if available) or a similar type of DOC from this project data.



* The engine emissions test must be performed at high load to ensure the DOC is in its normal operating temperature range. The transmission stall or hydraulic stall tests as mandated by the Ontario MOL are acceptable.
** This chart is derived from limited laboratory testing of selected DOCs.

Figure 13 - DOC NO_2 risk decision flow chart

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ACKNOWLEDGEMENTS

The authors would like to acknowledge the support of the following persons and companies:

- Peter Golde, Managing Director CAMIRO (Canadian Mining Industry Research Organization) for consortium financial support for this project.

- Dr. Joe Stachulak, Manager Strategic Ventilation & Diesel Research, MIRARCO Mining Innovation, Sudbury for his continued encouragement and dedication for this study, without his help and support this project could not have been completed.
- Cheryl Allen, Principal Engineer of Ventilation, Vale Ontario Operations for her engagement and suggestions for this project.

- Fred Pelletier, Superintendent Capital Equipment, Vale Operation Sudbury for supplying the catalysts for this project
- Alain Landry, Glencore-Sudbury, for his encouragement, and supplying the catalysts for the project.
- Greg Mascioli, Superintendent Mobile Maintenance, Glencore-Timmins, for supplying catalysts for this project.
- Airflow Catalyst Systems, Catalytic Exhaust Products, CDTi (formerly ECS), DCL International, and Nett Technologies for supplying the advanced catalysts for this study.

APPENDIX A

Mining Diesel Fuel Analysis

CanmetENERGY OTTAWA / CHARACTERIZATION LABORATORY
1 Haanel Drive, Ottawa, Ontario
Canada K1A 1M1
clabc@nrcan.gc.ca

2015-04-28

ISO 9001:2008
FS 64051

Client Name:	Mining and Mineral Science Laboratories	Group Number	15193
Project Code:	P-000005.001	Job Number:	
Due Date:	2015-04-28	Submitted by:	Brent Rubeli
Project Title:	CSA Mines Fuel	Index Date:	2015-04-21
Project Info:		Approved by:	Huena_Corbett

SampleNumber:	15193-01
CustomerSampleNumber:	Mines Diesel
Submission Date:	2015-04-21
Comment	Diesel Fuel

Test Results

Parameter	Method		
Carbon	ASTM D5291 modified	86.1	wt%
Hydrogen	ASTM D5291 modified	13.9	wt%
Nitrogen	ASTM D5291 modified	<0.15	wt%

Test Results

Parameter	Method		
Density @ 15°C	ASTM D4052	814.9	kg/m3
Flash Point, Pensky-Marten Closed Cu	ASTM D93	49.5	°C
Specific Gravity 60/60F	ASTM D4052	0.8156	GRAV
Sulphur	ASTM D7039	6.9	mg/kg

APPENDIX B

Details on DOCs Received for Testing

CAMIRO - DOCs selected for Laboratory Testing

DOC #	Vehicle Unit #	Vehicle Description	Service	DOC Make	DOC Model	Engine Make	Engine Model	Engine kW (HP)	Hours on unit	Vehicle Supplier	Test cycle	Group Type
Vale-Sudbury												
C2	37-099	T1400 Scooptram	Heavy	ECS	A20-0072	Detroit	6063EK32	242 (325)	20000+	Sandvik	LHD	2
C5	27-014	Scissor truck	Light	NETT	SP2918	Mercedes	OM 904	112 (150	2700	Maclean	Utility	1
C8	10-340	LT-350 3.5yd	Heavy	DCL	3205MD-1R07-21	Deutz	BF4M1013C	86 (115)	4850	MTI	LHD	2
C3	17-630	1700G Scooptram	Heavy	DCL	CE3125	Cat	C11 ACERT	241 (323)	3300	Toromont	LHD	1
C6	23-1106	Mancarrier (Jeep)	Light	ECS	A20-0718	Toyota	1HZ6	100 (134)	3400	Mobile	Pickup	1
C12	37-6067	Tractor	Light	CEP	IFIC06349	Iveco	N45MNS	74 (99)	110	Industrial Fabrication	Tractor	1
Glencore-Sudbury												
C16	U11	Marcotte U-11	Moderate	CEP	6SX	Deutz	F6L912W	60 (80)	7825	Marcotte	Utility	1
C17	GR002	Cat Grader	Moderate	DCL	DQ8R	Mercedes	904	130 (174)	6985	WajaX	Utility	3
C18	MB024	Bolter	Light	Englehard	1470	Deutz	BF4M1013C	113 (152)	707	Maclean	Utility	2
C19	LH859	1700G	Heavy	DCL	CAT OEM	CAT	C11ACRT	241 (323)	10132	Toromont	LHD	2
Glencore-Timmins												
C13	33843	Waldon Forklift		ECS	5DM	Deutz	F3L912W	40 (53)			Utility	3
C14	33940	Waldon Forklift		DCL	2000-DOQ-1R05-21	Deutz	F3L912W	40 (53)			Utility	2
C15	33683	LH514	Heavy	Finnkatalyt	FK26	Detroit	6063MK32	242 (325)	13393	Sandvik	LHD	2
C20	33673	Toro 1400	Heavy	Finnkatalyt	FK23	Detroit	6063MK32	242 (325)	7,604	Sandvik	LHD	2
C21	AM	Truck "Jeep" crew cab		CEP	5SX	Toyota	1HZ	100 (134)	7,324	Access Industrial	Pickup	1
Vale Creighton												
C22	20	Cubex D6200 Drill		Exhaust Co	PZ05C25	Deutz	F4L912W	40 (54)	1000	Sandvik	Utility	2

CAMIRO- DOCs not selected for testing

DOC #	Vehicle Unit #	Vehicle Description	Service	DOC Make	DOC Model	Engine Make	Engine Model	Engine kW (HP)	Hours on unit	Vehicle Supplier	Test comments
Glencore-Sudbury											
	LHD107	JCI-1.25ch	Moderate	DCL	D07RSAM	Deutz	F4L912W	41 (55)	3859	MTI	many Deutzs
	ML098	Fraser mine		CEP	1378	Holand					limited info
	MC204	Toyota	Light	ECS		Toyota	1HZ6	100 (134)	3197	Mobile Parts	broken
	6460	MC100F	Moderate	CEP	IFI00947	Iveco T3	N45	74 (99)	2191	Industrial Fabrication	duplicate
Glencore-Timmins											
	33983	Wet Hauler	Moderate	ECS	AZ-29M-4S	Cummins	QSB 5.9L	179 (240)	14,121	Marcotte	core shifted
	TW	M5400	Moderate	CEP	SX-M009	Kubota	F2803A	40 (54)	1,468	Track & Wheels	duplicate
Vale-Sudbury											
C1	37-315	ST14 Scooptram	Heavy	FinKatalyt	FK26D	Cummins	QSM 11	250 (335)	2600	Atlas Copco	LHD-H
C4	22-103	Boom truck	Moderate	ECS	A20-0044	Mercedes	OM 906	151 (202)	800	Marcotte	Utility
C7	22-622	LT-350 3.5yd	Moderate	DCL	DQ7R-SAM	Mercedes	OM 904	100 (134)	290	MTI	LHD-M
C10	17-726	Bolter	Very Light	ECS	6DZ	Deutz	F6L912W	69 (93)	2770	Maclean	Utility
Vale Creighton											
C23	127	R410		DCL	2203ID	Kubota	V-1902-BDW-3	30 (40)	4400	Kubota	too small
	803	R310		CEP	3SX-KH41	Kubota	V1305-RP	20 (270		Kubota	limited info
	5087	RTV 900		?	?	Kubota	D902-E-UV	16 (22)	2724	Kubota	limited info
	499	MTI Jumbo		DCL	DC6	Deutz	F6L912W	56 (75)		MTI	limited info
C24	758	R520		CEP	4SX-R400	Kubota	V2203-RP	37 (49)	7688	Kubota	too small
		R520S		CEP	T041048	Kubota	V2203-RP	37 (49)		Kubota	limited info

CAMIRO - New DOCs for Laboratory Testing					
DOC #	DOC Make	DOC Model	DOC SN.	Test cycle	Group Type
C31	Catalytic Exhaust Products Limited	12SC-5.0" F	88586	LHD	3
C32	Nett Technologies Inc.	DH522W-5.0" D series		LHD	3
C33	CDTi	Y13-0002	B184602	LHD	3
C34	DCL International Inc.	RD2L-01-1X14-22	662204	LHD	1
C35	Airflow Catalyst Systems Inc.	MinNoDoc-S12000MM16P4P4	46"x19"x23"-10561	LHD	3

APPENDIX C

CAMIRO DOC Evaluation – Test Sheet

CAMIRO DOC Evaluation – Test Sheet

SAP #P-002249.001 File ID: CAMIRO DOC_P2249

Purpose: Laboratory Evaluation of in-use and advanced DOCs for NO_2 Formation

Test Protocol: Progressive load testing and various mine transient test cycles

Engine: DDEC series 60, 11.1L (6063-WK32), Tier 1, rated at 325 hp @ 2100 rpm, 6 cylinder, turbo, charge air cooling

General Engine Test Conditions:
Low idling speed: 600 rpm, high idling speed: 2225 rpm

Rated power: 2100 rpm, 813 lb-ft torque, 325 hp, 117.7 lb/h fuel, exhaust Temp 740ºF
Peak torque: 1200 rpm, 1150 lb-ft torque, 263 hp, 87.0 lb/h fuel, exhaust temp 945ºF

Maximum intake air is 4000 lb/hr Max manifold intake temperature = 150°F

Max intake air restriction, clean filter = 12 in. H2O (± 10%)
Max exhaust manifold pressure = 40 in. H_2O (± 10%)

Test Fuel: Mining Diesel Fuel, C=86.1%wt, H=13.9%wt, S=6.9 mg/kg, SG=0.8156

BASELINE TEST

Test #1 Base Line Engine Testing

Emission measurements: gases (CO, CO_2, NO, NO_x, O_2, THC) and DPM (BG2) sampling for 5 minutes

rpm	Load →	100%	75%	50%	10%
2100 (rated)		Y	Y	Y	Y
1260 (intermediate)		Y	Y	Y	
600 rpm (Low idling)		minimum load			

Test #2 Baseline Progressive testing at 1260 rpm, vary temperature from no load to maximum load in steps of about 20 - 25°F (10 °C), record gaseous data at each point.

Test #3 Progressive load test with DOC #3 at 1260 rpm, insulate exhaust pipes, vary temperature from no load to maximum load in steps of about 20 - 25°F (10 °C), record gaseous data before and after the DOC. Then analyse data and select the required number of load points for further progressive load tests.

Test #4 Baseline LHD-H transient test, record gaseous data every 1 second (repeat 4 cycles)
Test #5 Baseline Utility transient test, record gaseous data every 1 second (repeat 3 cycles)
Test #6 Baseline Tractor transient test, record gaseous data every 1 second (repeat 4 cycles)
Test #7 Baseline Pickup transient test, record gaseous data every 1 second (repeat 4 cycles)

DOC TEST

Test #8 DOC-C2 Progressive load test, record gas data before and after the DOC
Test #9 DOC-C2 LHD transient test, gaseous data every second (repeat 4 cycles)

Test #10 DOC-C3 Progressive load test, record gas data before and after the DOC
Test #11 DOC-C3 LHD transient test, gaseous data every second (repeat 4 cycles)

Test #12 DOC-C15 Progressive load test, record gas data
Test #13 DOC-C15 LHD transient test, gaseous data every second (repeat 4 cycles)

Test #14 DOC-C19 Progressive load test, record gas data
Test #15 DOC-C19 LHD transient test, gaseous data every second (repeat 4 cycles)

Test #16 DOC-C20 Progressive load test, record gas data
Test #17 DOC-C20 LHD transient test, gaseous data every second (repeat 4 cycles)

Test #18 DOC-C31 Progressive load test, record gas data (new DOC from CEP)
Test #19 DOC-C31 LHD transient test, gaseous data every second (repeat 4 cycles)

Test #20 DOC-C32 Progressive load test, record gas data (new DOC from Nett)
Test #21 DOC-C32 LHD transient test, gaseous data every second (repeat 4 cycles)

Test #22 DOC-C33 Progressive load test, record gas data (new DOC from CDTi)
Test #23 DOC-C33 LHD transient test, gaseous data every second (repeat 4 cycles)

Test #24 DOC-C34 Progressive load test, record gas data (new DOC from DCL)
Test #25 DOC-C34 LHD transient test, gaseous data every second (repeat 4 cycles)

Test #26 DOC-C35 Progressive load test, record gas data (new DOC from Airflow Catalysts)
Test #27 DOC-C35 LHD transient test, gaseous data every second (repeat 4 cycles)
…………………………………………
Following tests are done using the exhaust splitter bypass system

Test #28 DOC-C17 Progressive load test, record gas data
Test #29 DOC-C17 Utility transient test, gaseous data every second (repeat 3 cycles)

Test #30 DOC-C18 Progressive load test, record gas data
Test #31 DOC-C18 Utility transient test, gaseous data every second (repeat 3 cycles)

Test #32 DOC-C5 Progressive load test, record gas data
Test #33 DOC-C5 Utility transient test, gaseous data every second (repeat 3 cycles)

Test #34 DOC-C6 Progressive load test, record gas data
Test #35 DOC-C6 Pickup transient test, gaseous data every second (repeat 4 cycles)

Test #36 DOC-C21 Progressive load test, record gas data
Test #37 DOC-C21 Pickup transient test, gaseous data every second (repeat 4 cycles)

Test #38 DOC-C8 Progressive load test, record gas data
Test #39 DOC-C8 LHD transient test, gaseous data every second (repeat 4 cycles)

Test #40 DOC-C12 Progressive load test, record gas data
Test #41 DOC-C12 Tractor transient test, gaseous data every second (repeat 4 cycles)

Test #42 DOC-C16 Progressive load test, record gas data
Test #43 DOC-C16 Utility transient test, gaseous data every second (repeat 3 cycles)

Test #44 DOC-C22 Progressive load test, record gas data
Test #45 DOC-C22 Utility transient test, gaseous data every second (repeat 3 cycles)

Test #46 DOC-C13 Progressive load test, record gas data
Test #47 DOC-C13 Utility transient test, gaseous data every second (repeat 3 cycles)

Test #48 DOC-C14 Progressive load test, record gas data
Test #49 DOC-C14 Utility transient test, gaseous data every second (repeat 3 cycles)

** Record data before and after DOCs for all progressive load testing.

APPENDIX D

Progressive Load Test Emission Data Summary

(For each numbered mode in these tables, the first column contains data taken before DOC, and the second column contains data taken after DOC)

					Summary Progressive Load Test Data- Before and after DOC C2										
Test Points->		1	1	2	2	3	3	4	4	5	5	6	6	7	7
Speed	rpm	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260
Torque	N.m	20	21	102	102	183	183	264	265	319	319	373	373	427	427
Power	kW	2.7	2.7	13.4	13.4	24.2	24.2	34.9	34.9	42.1	42.1	49.3	49.2	56.4	56.3
Engine Exhaust temperature	^oC	123	123	160	161	197	199	237	238	266	267	290	292	313	313
DOC inlet temperature	^oC	116	47	39	60	45	71	51	81	59	93	67	101	72	106
Exhaust gas concentration -wet															
CO_2	%	1.1	1.1	1.9	1.9	2.6	2.6	3.4	3.4	3.8	3.8	4.2	4.3	4.6	4.6
CO	ppm	242	241	207	204	154	151	91	62	73	23	62	14	58	13
NO_2	ppm	35	34	40	38	40	35	36	20	32	15	29	20	27	26
NO	ppm	142	140	236	238	325	331	383	401	425	448	467	484	505	507
THC	ppm	141	129	95	90	68	63	51	42	45	30	42	25	42	23
Specific emission -wet															
CO_2	g/kWh	2956	2917	1007	1010	813	810	714	715	683	697	670	676	654	663
CO	g/kWh	40.6	39.7	7.1	7.0	3.0	2.9	1.2	0.8	0.8	0.3	0.6	0.1	0.5	0.1
NO_2	g/kWh	8.5	8.2	2.0	1.9	1.2	1.0	0.7	0.4	0.5	0.2	0.4	0.3	0.4	0.4
NO	g/kWh	25.5	24.8	8.7	8.7	6.8	6.9	5.6	5.8	5.2	5.6	5.1	5.2	4.9	4.9
THC	g/kWh	12.0	10.8	1.7	1.6	0.7	0.6	0.4	0.3	0.3	0.2	0.2	0.1	0.2	0.1
Test Points->		8	8	9	9	10	10	11	11	12	12	13	13		
Speed	rpm	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1259		
Torque	N.m	481	481	570	570	719	719	929	929	1133	1133	1468	1468		
Power	kW	63.5	63.5	75.2	75.2	94.9	94.9	122.6	122.6	149.4	149.4	193.8	193.6		
Engine Exhaust temperature	^oC	332	333	360	360	398	398	437	437	462	462	490	491		
DOC inlet temperature	^oC	72	112	76	119	82	131	88	140	95	154	106	165		
Exhaust gas concentration -wet															
CO_2	%	4.9	5.0	5.4	5.4	6.1	6.1	6.7	6.8	7.2	7.3	7.7	7.8		
CO	ppm	54.4	10.3	53.1	9.1	64.9	12.5	99.2	24.1	124.6	36.7	117.4	37.2		
NO_2	ppm	25.9	28.8	22.2	32.2	18.1	35.9	15.2	38.8	13.0	40.3	11.6	42.6		
NO	ppm	537.5	537.9	584.0	582.2	673.4	654.9	785.2	762.6	879.4	856.9	952.8	933.1		
THC	ppm	39	20	35	18	30	17	27	18	25	17	25	17		
Specific emission -wet															
CO_2	g/kWh	643	650	632	631	627	632	610	619	602	612	605	604		
CO	g/kWh	0.45	0.09	0.39	0.07	0.43	0.08	0.57	0.14	0.66	0.20	0.58	0.18		
NO_2	g/kWh	0.32	0.36	0.25	0.36	0.18	0.36	0.13	0.34	0.11	0.33	0.09	0.32		
NO	g/kWh	4.77	4.81	4.66	4.61	4.75	4.63	4.84	4.73	5.03	4.92	5.09	4.95		
THC	g/kWh	0.17	0.09	0.14	0.07	0.11	0.06	0.08	0.05	0.07	0.05	0.07	0.05		

Summary Progressive Load Test Data- Before and after DOC C3

Test Points->		1	1	2	2	3	3	4	4	5	5	6	6	7	7
Speed	rpm	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260
Torque	N.m	20	20	102	102	183	183	265	264	319	319	373	373	427	428
Power	kW	2.7	2.7	13.4	13.4	24.2	24.2	34.9	34.9	42.1	42.1	49.2	49.2	56.4	56.4
Engine Exhaust temperature	^oC	124	124	161	162	199	201	239	241	268	270	293	293	314	314
DOC inlet temperature	^oC	117	117	148	150	182	185	218	221	245	246	267	268	287	288
Exhaust gas concentration -wet															
CO_2	%	1.1	1.1	1.9	1.9	2.7	2.7	3.4	3.4	3.9	3.9	4.3	4.2	4.6	4.6
CO	ppm	260	256	222	221	166	164	96	16	76	4	65	2	60	2
NO_2	ppm	35	33	41	35	41	27	37	17	33	35	30	47	28	50
NO	ppm	135	136	235	241	330	344	387	405	429	423	468	441	499	468
THC	ppm	154	134	102	96	72	70	55	34	49	21	46	17	44	16
Specific emission -wet															
CO_2	g/kWh	2873	2858	978	985	791	797	701	705	683	681	666	658	638	646
CO	g/kWh	42.4	41.4	7.3	7.3	3.1	3.1	1.3	0.2	0.9	0.1	0.6	0.0	0.5	0.0
NO_2	g/kWh	8.7	8.1	2.1	1.8	1.2	0.8	0.7	0.4	0.6	0.6	0.5	0.7	0.4	0.7
NO	g/kWh	23.5	23.6	8.3	8.5	6.7	7.0	5.5	5.7	5.2	5.1	5.0	4.7	4.7	4.5
THC	g/kWh	12.8	11.0	1.7	1.6	0.7	0.7	0.4	0.2	0.3	0.1	0.2	0.1	0.2	0.1

Test Points->		8	8	9	9	10	10	11	11	12	12	13	13		
Speed	rpm	1260	1261	1260	1260	1260	1260	1260	1260	1260	1260	1260	1261		
Torque	N.m	481	482	570	570	719	719	929	929	1132	1132	1467	1466		
Power	kW	63.5	63.6	75.2	75.2	94.8	94.8	122.6	122.6	149.4	149.5	193.6	193.5		
Engine Exhaust temperature	^oC	334	334	363	362	400	401	440	441	465	465	492	493		
DOC inlet temperature	^oC	306	307	333	334	370	371	410	411	437	437	465	466		
Exhaust gas concentration -wet															
CO_2	%	5.0	4.9	5.5	5.4	6.1	6.1	6.8	6.9	7.2	7.3	7.7	7.8		
CO	ppm	58.0	1.0	56.2	1.0	69.2	3.2	110.9	7.5	143.6	13.3	129.0	15.1		
NO_2	ppm	27.0	54.8	23.5	63.9	19.3	70.8	17.3	72.9	16.3	70.5	13.4	68.9		
NO	ppm	527.7	492.2	577.8	537.4	655.0	595.7	777.3	701.9	850.2	791.6	923.1	882.6		
THC	ppm	43	15	38	16	33	15	27	15	24	14	26	15		
Specific emission -wet															
CO_2	g/kWh	642	639	625	622	618	618	611	621	605	605	600	604		
CO	g/kWh	0.48	0.01	0.41	0.01	0.44	0.02	0.63	0.04	0.76	0.07	0.64	0.07		
NO_2	g/kWh	0.34	0.70	0.27	0.72	0.19	0.71	0.15	0.65	0.13	0.58	0.10	0.53		
NO	g/kWh	4.63	4.35	4.50	4.21	4.52	4.11	4.77	4.34	4.84	4.49	4.88	4.67		
THC	g/kWh	0.18	0.07	0.15	0.06	0.11	0.05	0.08	0.04	0.07	0.04	0.07	0.04		

Summary Progressive Load Test Data- Before and after DOC C15

Test Points->		1	1	2	2	3	3	4	4	5	5	6	6	7	7
Speed	rpm	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260
Torque	N.m	20	20	102	102	183	183	264	264	319	319	373	373	427	427
Power	kW	2.7	2.7	13.4	13.4	24.1	24.1	34.9	34.9	42.1	42.0	49.2	49.2	56.4	56.4
Engine Exhaust temperature	^oC	124	124	160	161	198	200	239	240	267	268	289	290	310	311
DOC inlet temperature	^oC	116	117	148	150	183	186	221	223	247	249	269	269	289	290
Exhaust gas concentration -wet															
CO_2	%	1.1	1.1	1.9	1.9	2.7	2.7	3.4	3.4	3.8	3.9	4.2	4.2	4.6	4.6
CO	ppm	272	267	225	224	168	165	95	69	76	22	65	15	60	11
NO_2	ppm	35	35	40	40	40	39	35	24	31	17	28	23	25	27
NO	ppm	131	132	229	230	318	322	379	388	414	428	451	465	486	492
THC	ppm	159	152	104	99	74	68	53	42	48	28	44	25	43	24
Specific emission -wet															
CO_2	g/kWh	2923	2924	999	1001	810	799	709	709	683	688	662	662	653	643
CO	g/kWh	44.6	43.9	7.5	7.5	3.2	3.1	1.3	0.9	0.9	0.2	0.6	0.1	0.5	0.1
NO_2	g/kWh	8.9	8.7	2.1	2.1	1.2	1.1	0.7	0.5	0.5	0.3	0.4	0.4	0.3	0.4
NO	g/kWh	23.1	23.3	8.2	8.2	6.6	6.6	5.4	5.5	5.0	5.2	4.8	5.0	4.7	4.7
THC	g/kWh	13.3	12.6	1.8	1.7	0.7	0.7	0.4	0.3	0.3	0.2	0.2	0.1	0.2	0.1
Test Points->		8	8	9	9	10	10	11	11	12	12	13	13		
Speed	rpm	1260	1260	1260	1260	1260	1260	1260	1260	1260	1261	1260	1260		
Torque	N.m	482	481	570	570	719	719	929	929	1132	1132	1467	1468		
Power	kW	63.5	63.5	75.2	75.1	94.9	94.9	122.6	122.6	149.5	149.5	193.6	193.6		
Engine Exhaust temperature	^oC	330	331	359	359	400	401	441	442	468	467	493	493		
DOC inlet temperature	^oC	308	309	336	337	376	378	417	418	446	446	472	473		
Exhaust gas concentration -wet															
CO_2	%	4.9	4.9	5.4	5.4	6.1	6.1	6.8	6.9	7.3	7.3	7.8	7.8		
CO	ppm	56.3	9.1	54.9	7.9	70.8	11.3	112.9	21.9	146.8	31.6	128.9	31.0		
NO_2	ppm	23.0	28.4	19.6	29.0	14.4	30.2	10.6	30.1	8.0	27.8	5.4	28.2		
NO	ppm	516.2	510.6	569.9	559.1	649.4	636.2	775.0	744.2	862.8	835.2	926.7	917.8		
THC	ppm	39	21	35	19	29	17	26	16	24	16	24	16		
Specific emission -wet															
CO_2	g/kWh	639	646	625	636	624	625	610	616	604	608	601	601		
CO	g/kWh	0.47	0.08	0.40	0.06	0.46	0.07	0.64	0.13	0.77	0.17	0.64	0.15		
NO_2	g/kWh	0.29	0.37	0.22	0.33	0.15	0.30	0.09	0.27	0.07	0.23	0.04	0.21		
NO	g/kWh	4.58	4.56	4.49	4.46	4.51	4.42	4.72	4.56	4.89	4.72	4.90	4.83		
THC	g/kWh	0.17	0.09	0.14	0.08	0.10	0.06	0.08	0.05	0.07	0.05	0.06	0.04		

Summary Progressive Load Test Data- Before and after DOC C19

Test Points->		1	1	2	2	3	3	4	4	5	5	6	6	7	7
Speed	rpm	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260
Torque	N.m	20	20	102	102	183	183	264	265	319	319	373	373	427	427
Power	kW	2.7	2.7	13.4	13.4	24.2	24.2	34.9	34.9	42.1	42.1	49.2	49.2	56.4	56.4
Engine Exhaust temperature	^oC	123	123	159	161	197	198	237	239	266	268	292	292	312	313
DOC inlet temperature	^oC	115	115	146	148	180	182	216	219	243	244	266	267	285	286
Exhaust gas concentration -wet															
CO_2	%	1.1	1.1	1.9	1.9	2.6	2.6	3.4	3.4	3.8	3.9	4.3	4.3	4.6	4.6
CO	ppm	249	244	210	208	157	156	92	47	74	14	62	9	57	8
NO_2	ppm	36	34	41	37	42	32	37	20	34	26	31	34	30	35
NO	ppm	137	138	234	241	326	336	384	402	423	440	475	473	514	510
THC	ppm	145	130	96	91	69	66	53	40	47	26	45	21	44	20
Specific emission -wet															
CO_2	g/kWh	2912	2864	983	993	802	808	719	719	687	692	667	668	655	656
CO	g/kWh	41.3	39.9	7.0	7.0	3.0	3.0	1.3	0.6	0.8	0.2	0.6	0.1	0.5	0.1
NO_2	g/kWh	8.7	8.1	2.1	1.9	1.2	0.9	0.8	0.4	0.6	0.4	0.5	0.5	0.4	0.5
NO	g/kWh	24.4	24.3	8.4	8.7	6.8	7.0	5.6	5.8	5.2	5.4	5.1	5.1	5.0	4.9
THC	g/kWh	12.2	10.8	1.6	1.6	0.7	0.7	0.4	0.3	0.3	0.2	0.2	0.1	0.2	0.1

Test Points->		8	8	9	9	10	10	11	11	12	12	13	13		
Speed	rpm	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260		
Torque	N.m	481	482	570	570	719	719	929	929	1132	1132	1469	1469		
Power	kW	63.5	63.5	75.2	75.2	94.9	94.9	122.6	122.6	149.5	149.4	193.8	193.8		
Engine Exhaust temperature	^oC	332	332	360	360	397	398	437	437	461	462	491	492		
DOC inlet temperature	^oC	304	305	331	332	367	368	407	408	434	435	465	466		
Exhaust gas concentration -wet															
CO_2	%	4.9	5.0	5.4	5.4	6.1	6.1	6.8	6.8	7.2	7.3	7.7	7.8		
CO	ppm	53.6	6.8	52.1	6.7	62.5	9.1	100.2	17.7	126.0	27.4	111.5	28.7		
NO_2	ppm	28.0	37.2	25.4	41.7	21.6	48.1	18.3	52.4	17.3	51.5	15.5	52.0		
NO	ppm	552.2	534.4	605.9	577.7	684.0	649.9	786.3	761.1	876.2	861.2	975.0	925.3		
THC	ppm	41	20	38	19	33	19	29	18	27	17	27	18		
Specific emission -wet															
CO_2	g/kWh	644	646	629	631	621	625	620	617	603	612	602	606		
CO	g/kWh	0.44	0.06	0.39	0.05	0.41	0.06	0.58	0.10	0.67	0.15	0.55	0.14		
NO_2	g/kWh	0.35	0.46	0.28	0.46	0.21	0.47	0.16	0.46	0.14	0.42	0.12	0.39		
NO	g/kWh	4.91	4.74	4.81	4.56	4.78	4.55	4.92	4.72	5.02	4.95	5.19	4.92		
THC	g/kWh	0.18	0.09	0.15	0.07	0.12	0.06	0.09	0.05	0.08	0.05	0.07	0.05		

Summary Progressive Load Test Data- Before and after DOC C20

Test Points->		1	1	2	2	3	3	4	4	5	5	6	6	7	7
Speed	rpm	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260
Torque	N.m	20	20	102	102	183	183	264	264	319	319	373	373	427	427
Power	kW	2.7	2.7	13.4	13.4	24.2	24.1	34.9	34.9	42.1	42.1	49.2	49.2	56.4	56.4
Engine Exhaust temperature	^oC	123	123	160	161	198	199	237	239	266	267	290	289	310	311
DOC inlet temperature	^oC	116	116	148	149	182	185	219	221	246	247	269	269	288	289
Exhaust gas concentration -wet															
CO_2	%	1.1	1.1	1.9	1.9	2.7	2.7	3.4	3.4	3.9	3.9	4.2	4.3	4.6	4.6
CO	ppm	270	266	225	225	166	163	95	44	74	8	62	5	57	2
NO_2	ppm	36	35	42	41	41	38	35	19	31	17	28	22	25	23
NO	ppm	136	137	239	240	337	334	389	412	428	443	466	470	501	513
THC	ppm	161	150	105	101	73	69	55	41	49	27	45	24	44	24
Specific emission -wet															
CO_2	g/kWh	2909	2922	1013	1005	800	806	719	721	689	692	662	668	657	658
CO	g/kWh	43.6	43.2	7.6	7.5	3.1	3.1	1.3	0.6	0.8	0.1	0.6	0.0	0.5	0.0
NO_2	g/kWh	8.7	8.7	2.1	2.0	1.2	1.1	0.7	0.4	0.5	0.3	0.4	0.3	0.3	0.3
NO	g/kWh	23.6	23.9	8.6	8.6	6.9	6.8	5.6	5.9	5.2	5.4	5.0	5.0	4.9	5.0
THC	g/kWh	13.1	12.3	1.8	1.7	0.7	0.7	0.4	0.3	0.3	0.2	0.2	0.1	0.2	0.1

Test Points->		8	8	9	9	10	10	11	11	12	12	13	13		
Speed	rpm	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1261		
Torque	N.m	481	481	570	570	719	719	929	929	1132	1133	1467	1467		
Power	kW	63.5	63.5	75.1	75.2	94.9	94.9	122.6	122.6	149.4	149.5	193.6	193.6		
Engine Exhaust temperature	^oC	331	331	359	359	400	401	441	441	466	467	492	493		
DOC inlet temperature	^oC	308	309	335	336	375	376	416	417	443	444	470	472		
Exhaust gas concentration -wet															
CO_2	%	5.0	5.0	5.4	5.5	6.2	6.2	6.9	6.9	7.3	7.3	7.8	7.8		
CO	ppm	53.3	2.2	52.4	2.1	67.1	4.4	111.1	12.5	145.3	20.6	124.5	21.1		
NO_2	ppm	23.3	23.5	19.1	27.2	14.1	32.4	9.3	33.1	8.0	32.5	5.3	33.1		
NO	ppm	544.4	535.3	582.1	576.5	670.8	650.6	786.2	756.6	866.2	848.4	947.7	923.5		
THC	ppm	40	22	37	21	31	18	27	17	25	16	26	17		
Specific emission -wet															
CO_2	g/kWh	643	649	635	640	631	631	618	620	612	614	607	613		
CO	g/kWh	0.44	0.02	0.39	0.02	0.44	0.03	0.64	0.07	0.77	0.11	0.62	0.11		
NO_2	g/kWh	0.29	0.30	0.22	0.31	0.14	0.32	0.08	0.29	0.07	0.26	0.04	0.25		
NO	g/kWh	4.81	4.77	4.64	4.61	4.69	4.53	4.83	4.64	4.95	4.84	5.05	4.94		
THC	g/kWh	0.17	0.10	0.14	0.08	0.11	0.06	0.08	0.05	0.07	0.05	0.07	0.04		

		Summary Progressive Load Test Data- Before and after DOC C31													
Test Points->		1	1	2	2	3	3	4	4	5	5	6	6	7	7
Speed	rpm	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260
Torque	N.m	21	20	102	102	183	183	264	265	319	319	373	373	427	428
Power	kW	2.7	2.7	13.4	13.4	24.2	24.2	34.9	34.9	42.1	42.0	49.2	49.2	56.4	56.4
Engine Exhaust temperature	^oC	123	123	160	161	198	199	238	239	267	268	294	293	314	315
DOC inlet temperature	^oC	115	115	146	148	180	182	216	219	243	245	268	268	288	289
Exhaust gas concentration -wet															
CO_2	%	1.1	1.1	1.9	1.9	2.6	2.7	3.4	3.4	3.8	3.9	4.3	4.3	4.6	4.7
CO	ppm	259	254	218	216	159	159	93	10	77	2	63	2	60	2
NO_2	ppm	36	29	42	30	42	22	38	12	34	19	32	17	30	15
NO	ppm	140	147	241	260	342	362	403	425	435	464	490	502	521	536
THC	ppm	151	130	99	91	69	67	53	36	48	20	45	15	45	14
Specific emission -wet															
CO_2	g/kWh	2886	2906	978	979	796	793	717	722	683	690	666	673	658	654
CO	g/kWh	42.6	42.0	7.3	7.1	3.0	3.0	1.3	0.1	0.9	0.0	0.6	0.0	0.5	0.0
NO_2	g/kWh	8.7	7.1	2.0	1.4	1.2	0.6	0.8	0.2	0.6	0.3	0.5	0.2	0.4	0.2
NO	g/kWh	24.6	26.1	8.6	9.2	7.0	7.4	5.9	6.1	5.3	5.6	5.2	5.4	5.0	5.1
THC	g/kWh	12.5	10.9	1.7	1.5	0.7	0.7	0.4	0.2	0.3	0.1	0.2	0.1	0.2	0.1

Test Points->		8	8	9	9	10	10	11	11	12	12	13	13		
Speed	rpm	1260	1260	1260	1260	1260	1260	1260	1260	1260	1261	1259	1261		
Torque	N.m	482	482	570	570	719	719	929	930	1133	1132	1470	1470		
Power	kW	63.6	63.6	75.2	75.2	94.8	94.9	122.6	122.6	149.5	149.5	193.8	194.0		
Engine Exhaust temperature	^oC	334	335	362	363	400	401	438	439	463	464	491	492		
DOC inlet temperature	^oC	307	308	334	335	370	371	409	410	436	437	466	467		
Exhaust gas concentration -wet															
CO_2	%	5.0	5.0	5.4	5.5	6.1	6.1	6.8	6.8	7.2	7.3	7.7	7.8		
CO	ppm	56.5	1.0	54.9	1.3	65.4	2.1	103.0	6.7	128.2	12.6	114.8	14.8		
NO_2	ppm	27.9	16.1	24.9	24.1	21.1	36.6	18.4	42.0	17.4	41.0	14.5	43.4		
NO	ppm	549.3	569.4	601.0	604.0	685.9	668.3	794.5	790.5	891.2	873.9	991.6	945.6		
THC	ppm	41	13	38	13	34	13	29	13	27	14	27	14		
Specific emission -wet															
CO_2	g/kWh	644	645	633	630	626	627	615	621	601	609	599	604		
CO	g/kWh	0.47	0.01	0.41	0.01	0.43	0.01	0.60	0.04	0.68	0.07	0.57	0.07		
NO_2	g/kWh	0.34	0.20	0.28	0.27	0.21	0.36	0.16	0.36	0.14	0.33	0.11	0.33		
NO	g/kWh	4.85	5.00	4.77	4.74	4.81	4.66	4.93	4.91	5.08	4.99	5.26	5.01		
THC	g/kWh	0.18	0.06	0.15	0.05	0.12	0.04	0.09	0.04	0.08	0.04	0.07	0.04		

Summary Progressive Load Test Data- Before and after DOC C32

Test Points->		1	1	2	2	3	3	4	4	5	5	6	6	7	7
Speed	rpm	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260
Torque	N.m	20	20	102	102	183	183	264	264	319	319	373	373	427	427
Power	kW	2.7	2.7	13.4	13.4	24.2	24.2	34.9	34.9	42.1	42.1	49.2	49.2	56.3	56.4
Engine Exhaust temperature	^oC	124	124	161	162	199	200	240	242	269	270	297	296	317	317
DOC inlet temperature	^oC	115	115	146	148	181	183	218	220	244	246	270	270	290	291
Exhaust gas concentration -wet															
CO_2	%	1.1	1.1	1.9	1.9	2.7	2.7	3.4	3.5	3.9	3.9	4.3	4.4	4.7	4.7
CO	ppm	274	272	236	232	173	168	100	15	78	0	66	0	62	0
NO_2	ppm	36	21	43	13	42	4	37	4	34	4	30	2	28	2
NO	ppm	137	150	237	269	339	378	396	429	435	465	485	505	513	538
THC	ppm	163	103	111	91	76	69	55	37	49	20	45	16	44	14
Specific emission -wet															
CO_2	g/kWh	2885	2846	975	987	793	797	711	724	685	682	662	665	651	656
CO	g/kWh	44.6	43.6	7.8	7.6	3.3	3.2	1.3	0.2	0.9	0.0	0.6	0.0	0.5	0.0
NO_2	g/kWh	8.7	5.0	2.1	0.7	1.2	0.1	0.7	0.1	0.6	0.1	0.4	0.0	0.4	0.0
NO	g/kWh	24.0	25.7	8.4	9.5	6.9	7.6	5.6	6.1	5.2	5.5	5.1	5.3	4.9	5.1
THC	g/kWh	13.4	8.4	1.9	1.5	0.7	0.7	0.4	0.3	0.3	0.1	0.2	0.1	0.2	0.1

Test Points->		8	8	9	9	10	10	11	11	12	12	13	13
Speed	rpm	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260
Torque	N.m	482	482	570	570	719	719	929	929	1132	1132	1467	1466
Power	kW	63.5	63.6	75.2	75.2	94.9	94.8	122.6	122.6	149.4	149.3	193.6	193.5
Engine Exhaust temperature	^oC	338	338	366	366	403	404	442	443	468	468	495	496
DOC inlet temperature	^oC	309	310	335	336	370	371	409	411	437	437	465	466
Exhaust gas concentration -wet													
CO_2	%	5.0	5.1	5.5	5.6	6.2	6.2	6.8	6.9	7.3	7.3	7.8	7.8
CO	ppm	59.3	-0.2	57.4	-0.1	70.9	-0.1	115.3	2.1	147.6	6.6	126.3	10.8
NO_2	ppm	25.8	2.6	22.0	5.7	18.1	24.0	15.2	45.1	13.7	49.0	11.2	48.4
NO	ppm	543.6	578.2	598.2	615.0	682.8	670.5	783.1	754.3	866.4	856.4	960.4	917.7
THC	ppm	42	13	38	12	32	12	29	12	28	13	28	13
Specific emission -wet													
CO_2	g/kWh	641	641	639	643	625	633	616	619	607	615	604	605
CO	g/kWh	0.48	0.00	0.42	0.00	0.46	0.00	0.66	0.01	0.78	0.04	0.62	0.05
NO_2	g/kWh	0.32	0.03	0.25	0.06	0.18	0.24	0.13	0.39	0.11	0.39	0.08	0.36
NO	g/kWh	4.72	4.99	4.72	4.86	4.73	4.67	4.82	4.63	4.94	4.89	5.10	4.85
THC	g/kWh	0.18	0.06	0.15	0.05	0.11	0.04	0.09	0.04	0.08	0.04	0.07	0.04

		Summary Progressive Load Test Data- Before and after DOC C33													
Test Points->		1	1	2	2	3	3	4	4	5	5	6	6	7	7
Speed	rpm	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260
Torque	N.m	20	20	102	102	183	183	264	265	319	319	373	373	428	427
Power	kW	2.7	2.7	13.4	13.5	24.1	24.2	34.9	34.9	42.0	42.0	49.3	49.2	56.4	56.4
Engine Exhaust temperature	^oC	122	122	159	160	196	197	236	237	264	266	291	292	314	314
DOC inlet temperature	^oC	111	111	141	144	175	178	212	214	238	240	263	264	285	285
Exhaust gas concentration -wet															
CO_2	%	1.1	1.1	1.9	1.9	2.6	2.7	3.4	3.4	3.8	3.8	4.2	4.3	4.6	4.7
CO	ppm	274	270	232	236	175	177	100	104	81	89	67	75	63	68
NO_2	ppm	36	23	41	15	42	2	37	1	33	0	29	0	27	1
NO	ppm	139	151	239	267	335	376	392	439	431	463	480	511	520	545
THC	ppm	158	92	105	83	74	67	54	55	47	36	44	23	44	16
Specific emission -wet															
CO_2	g/kWh	2886	2916	985	1000	799	791	712	715	675	688	656	664	663	670
CO	g/kWh	45.2	44.6	7.8	8.0	3.4	3.3	1.4	1.4	0.9	1.0	0.7	0.7	0.6	0.6
NO_2	g/kWh	8.8	5.6	2.1	0.7	1.2	0.0	0.7	0.0	0.5	0.0	0.4	0.0	0.4	0.0
NO	g/kWh	24.6	26.7	8.6	9.7	6.9	7.7	5.7	6.3	5.2	5.7	5.1	5.4	5.1	5.3
THC	g/kWh	13.2	7.7	1.8	1.4	0.7	0.7	0.4	0.4	0.3	0.2	0.2	0.1	0.2	0.1

Test Points->		8	8	9	9	10	10	11	11	12	12	13	13		
Speed	rpm	1261	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260		
Torque	N.m	482	482	569	569	719	719	929	929	1133	1132	1468	1467		
Power	kW	63.6	63.6	75.1	75.2	94.8	94.9	122.6	122.6	149.5	149.4	193.7	193.6		
Engine Exhaust temperature	^oC	334	335	364	366	406	407	444	444	467	467	494	495		
DOC inlet temperature	^oC	304	305	330	332	369	370	406	406	431	433	460	462		
Exhaust gas concentration -wet															
CO_2	%	5.0	5.0	5.5	5.5	6.2	6.3	6.9	6.9	7.3	7.4	7.8	7.8		
CO	ppm	59.6	59.4	58.0	46.4	75.3	42.9	117.6	50.5	137.7	59.8	126.8	56.3		
NO_2	ppm	24.6	7.7	21.2	35.4	16.6	82.8	13.2	118.4	12.6	128.1	9.9	126.9		
NO	ppm	555.1	570.8	623.1	594.4	697.1	622.9	812.0	691.4	910.6	764.8	979.6	848.8		
THC	ppm	41	13	37	10	33	9	29	9	27	10	27	10		
Specific emission -wet															
CO_2	g/kWh	657	652	640	651	639	647	628	627	614	621	611	611		
CO	g/kWh	0.50	0.49	0.43	0.35	0.49	0.28	0.68	0.29	0.74	0.32	0.63	0.28		
NO_2	g/kWh	0.31	0.10	0.23	0.39	0.16	0.82	0.12	1.03	0.10	1.03	0.07	0.94		
NO	g/kWh	4.99	5.06	4.97	4.76	4.91	4.40	5.06	4.28	5.25	4.40	5.25	4.51		
THC	g/kWh	0.18	0.05	0.14	0.04	0.11	0.03	0.09	0.03	0.08	0.03	0.07	0.03		

				Summary Progressive Load Test Data- Before and after DOC C34											
Test Points->		1	1	2	2	3	3	4	4	5	5	6	6	7	7
Speed	rpm	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260
Torque	N.m	20	20	102	102	183	183	265	265	319	319	373	373	427	427
Power	kW	2.7	2.7	13.4	13.4	24.2	24.1	35.0	34.9	42.0	42.1	49.2	49.2	56.4	56.4
Engine Exhaust temperature	^oC	123	123	160	161	198	200	238	241	268	267	291	291	314	314
DOC inlet temperature	^oC	115	115	145	147	180	182	217	220	245	245	266	267	288	289
Exhaust gas concentration -wet															
CO_2	%	1.1	1.1	1.9	1.9	2.7	2.7	3.4	3.5	3.9	3.9	4.3	4.3	4.7	4.7
CO	ppm	259	247	217	185	163	41	95	3	75	2	67	1	62	1
NO_2	ppm	37	20	41	13	41	5	36	14	32	40	28	64	26	81
NO	ppm	145	154	245	274	339	379	400	416	450	427	478	440	521	456
THC	ppm	154	112	101	81	74	52	57	27	54	21	50	18	48	17
Specific emission -wet															
CO_2	g/kWh	3028	3021	1035	1025	839	833	747	758	718	722	704	709	688	691
CO	g/kWh	44.3	42.0	7.5	6.3	3.2	0.8	1.3	0.0	0.9	0.0	0.7	0.0	0.6	0.0
NO_2	g/kWh	9.0	4.9	2.1	0.6	1.2	0.1	0.7	0.3	0.5	0.7	0.4	1.0	0.4	1.1
NO	g/kWh	26.5	28.0	9.1	10.0	7.2	8.0	6.0	6.2	5.7	5.4	5.4	4.9	5.2	4.6
THC	g/kWh	13.2	9.6	1.8	1.4	0.8	0.5	0.4	0.2	0.3	0.1	0.3	0.1	0.2	0.1
Test Points->		8	8	9	9	10	10	11	11	12	12	13	13		
Speed	rpm	1260	1260	1260	1260	1260	1260	1260	1260	1259	1260	1260	1260		
Torque	N.m	481	482	570	570	719	719	929	929	1133	1133	1469	1470		
Power	kW	63.5	63.5	75.2	75.2	94.8	94.9	122.6	122.6	149.4	149.4	193.7	193.9		
Engine Exhaust temperature	^oC	334	335	364	364	406	406	445	444	467	467	494	494		
DOC inlet temperature	^oC	308	309	336	337	375	377	413	414	438	439	467	467		
Exhaust gas concentration -wet															
CO_2	%	5.0	5.0	5.5	5.5	6.2	6.3	6.9	6.9	7.3	7.3	7.8	7.8		
CO	ppm	57.6	1.1	57.3	0.0	76.3	1.0	115.5	1.0	143.2	1.0	127.2	1.0		
NO_2	ppm	23.9	100.2	20.2	128.3	14.6	156.1	10.4	181.5	9.3	183.9	6.7	164.6		
NO	ppm	564.1	464.8	610.7	490.1	690.1	533.1	821.4	600.0	890.8	681.3	971.1	784.1		
THC	ppm	42	16	39	16	34	16	31	17	29	17	28	15		
Specific emission -wet															
CO_2	g/kWh	658	662	645	645	637	642	622	628	617	614	606	607		
CO	g/kWh	0.48	0.01	0.42	0.00	0.50	0.01	0.66	0.01	0.77	0.01	0.63	0.00		
NO_2	g/kWh	0.29	1.24	0.22	1.41	0.14	1.52	0.09	1.57	0.08	1.48	0.05	1.23		
NO	g/kWh	5.06	4.16	4.86	3.89	4.81	3.73	5.04	3.71	5.13	3.88	5.14	4.15		
THC	g/kWh	0.19	0.07	0.15	0.06	0.12	0.06	0.09	0.05	0.08	0.05	0.07	0.04		

				Summary Progressive Load Test Data- Before and after DOC C35											
Test Points->		1	1	2	2	3	3	4	4	5	5	6	6	7	7
Speed	rpm	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260
Torque	N.m	20	20	102	102	183	183	265	264	319	319	373	373	427	427
Power	kW	2.7	2.7	13.4	13.4	24.2	24.2	34.9	34.9	42.1	42.1	49.2	49.2	56.4	56.4
Engine Exhaust temperature	^oC	125	125	161	162	199	200	239	241	265	266	288	288	309	310
DOC inlet temperature	^oC	112	112	140	142	174	177	208	211	232	234	253	254	273	275
Exhaust gas concentration -wet															
CO_2	%	1.1	1.1	1.9	1.9	2.6	2.7	3.4	3.4	3.8	3.8	4.2	4.2	4.6	4.6
CO	ppm	237	234	198	198	150	146	89	85	76	62	64	20	59	1
NO_2	ppm	35	31	41	31	40	19	36	4	32	1	30	0	27	0
NO	ppm	143	145	243	251	326	356	385	417	420	456	464	501	504	531
THC	ppm	137	123	91	86	66	61	50	46	46	36	44	27	43	21
Specific emission -wet															
CO_2	g/kWh	3034	3074	1039	1041	832	846	746	747	716	717	695	696	678	684
CO	g/kWh	40.4	40.4	6.9	6.9	3.0	3.0	1.3	1.2	0.9	0.7	0.7	0.2	0.6	0.0
NO_2	g/kWh	8.7	7.8	2.0	1.6	1.2	0.6	0.7	0.1	0.6	0.0	0.5	0.0	0.4	0.0
NO	g/kWh	26.2	26.9	9.1	9.4	7.0	7.7	5.8	6.3	5.4	5.8	5.2	5.6	5.1	5.4
THC	g/kWh	11.8	10.7	1.6	1.5	0.7	0.6	0.4	0.3	0.3	0.2	0.2	0.1	0.2	0.1

Test Points->		8	8	9	9	10	10	11	11	12	12	13	13		
Speed	rpm	1260	1260	1260	1261	1259	1260	1260	1261	1260	1260	1260	1260		
Torque	N.m	482	482	570	570	719	719	929	929	1132	1133	1466	1465		
Power	kW	63.6	63.5	75.1	75.2	94.8	94.9	122.5	122.7	149.4	149.5	193.5	193.4		
Engine Exhaust temperature	^oC	330	331	359	360	401	402	444	444	470	470	498	498		
DOC inlet temperature	^oC	293	294	320	322	359	361	400	402	426	428	454	456		
Exhaust gas concentration -wet															
CO_2	%	4.9	4.9	5.4	5.4	6.1	6.2	6.9	6.9	7.3	7.4	7.8	7.9		
CO	ppm	54.3	0.0	54.2	0.0	66.3	0.0	109.1	0.0	143.1	0.0	129.7	0.0		
NO_2	ppm	25.1	0.9	21.9	2.6	17.3	8.8	13.0	16.8	11.3	20.7	9.0	23.7		
NO	ppm	542.2	570.1	595.0	617.0	695.8	695.2	800.4	808.6	891.4	889.6	971.8	951.3		
THC	ppm	39	15	36	12	30	10	27	9	24	9	25	9		
Specific emission -wet															
CO_2	g/kWh	669	669	657	651	642	648	630	638	618	624	615	619		
CO	g/kWh	0.47	0.00	0.42	0.00	0.44	0.00	0.64	0.00	0.77	0.00	0.65	0.00		
NO_2	g/kWh	0.32	0.01	0.25	0.03	0.17	0.09	0.11	0.15	0.09	0.17	0.07	0.18		
NO	g/kWh	5.03	5.26	4.91	5.03	4.97	4.98	5.01	5.09	5.13	5.13	5.20	5.09		
THC	g/kWh	0.18	0.07	0.15	0.05	0.11	0.04	0.08	0.03	0.07	0.03	0.07	0.02		

		Summary Progressive Load Test Data- Before and after DOC C17													
Test Points->		1	1	2	2	3	3	4	4	5	5	6	6	7	7
Speed	rpm	1260	1260	1260	1260	1260	1259	1260	1260	1260	1259	1260	1260	1260	1260
Torque	N.m	20	20	102	102	183	183	264	265	319	319	373	373	427	427
Power	kW	2.7	2.7	13.4	13.4	24.2	24.2	34.9	34.9	42.0	42.1	49.2	49.2	56.3	56.4
Engine Exhaust temperature	^oC	125	125	162	163	199	201	240	242	269	268	292	292	313	313
DOC inlet temperature	^oC	116	116	147	149	183	186	220	222	246	247	267	268	287	288
Exhaust gas concentration -wet															
CO_2	%	1.2	1.2	2.0	2.0	2.7	2.7	3.5	3.5	3.9	3.9	4.3	4.3	4.7	4.7
CO	ppm	278	274	236	231	170	170	102	69	77	40	68	31	63	28
NO_2	ppm	36	35	42	41	41	40	37	27	32	23	30	24	28	24
NO	ppm	132	131	229	234	330	330	380	393	422	427	452	462	485	488
THC	ppm	167	157	117	106	73	69	55	45	49	37	46	34	45	33
Specific emission -wet															
CO_2	g/kWh	2945	2897	981	998	799	804	717	713	683	686	659	663	642	642
CO	g/kWh	44.3	43.1	7.5	7.5	3.1	3.2	1.3	0.9	0.9	0.4	0.7	0.3	0.6	0.2
NO_2	g/kWh	8.9	8.7	2.1	2.1	1.2	1.2	0.8	0.6	0.6	0.4	0.5	0.4	0.4	0.3
NO	g/kWh	22.6	22.2	7.8	8.1	6.5	6.6	5.4	5.5	5.0	5.1	4.7	4.8	4.5	4.5
THC	g/kWh	13.5	12.6	1.9	1.8	0.7	0.7	0.4	0.3	0.3	0.2	0.2	0.2	0.2	0.2
Test Points->		8	8	9	9	10	10	11	11	12	12	13	13		
Speed	rpm	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1259	1259		
Torque	N.m	482	482	570	570	719	719	929	929	1133	1132	1468	1468		
Power	kW	63.5	63.5	75.2	75.2	94.9	94.8	122.6	122.5	149.4	149.4	193.6	193.6		
Engine Exhaust temperature	^oC	333	333	360	361	400	400	439	440	465	465	490	491		
DOC inlet temperature	^oC	306	307	333	334	372	373	411	412	439	439	465	466		
Exhaust gas concentration -wet															
CO_2	%	5.0	5.0	5.5	5.5	6.1	6.2	6.8	6.9	7.3	7.3	7.8	7.8		
CO	ppm	59.2	25.1	57.5	22.8	73.6	28.2	116.4	47.2	155.2	67.5	127.2	62.8		
NO_2	ppm	26.5	23.5	23.8	24.2	19.8	24.3	17.3	23.8	16.1	23.4	14.5	24.2		
NO	ppm	515.7	519.4	561.7	562.3	638.4	632.1	736.9	741.4	823.4	824.0	906.2	893.3		
THC	ppm	42	31	38	27	33	24	28	21	27	20	26	21		
Specific emission -wet															
CO_2	g/kWh	635	634	629	631	617	619	609	617	611	612	606	605		
CO	g/kWh	0.48	0.20	0.42	0.17	0.47	0.18	0.66	0.27	0.83	0.36	0.63	0.31		
NO_2	g/kWh	0.34	0.30	0.27	0.28	0.20	0.24	0.16	0.21	0.14	0.20	0.11	0.19		
NO	g/kWh	4.44	4.47	4.40	4.40	4.37	4.32	4.47	4.53	4.70	4.68	4.82	4.72		
THC	g/kWh	0.18	0.13	0.15	0.11	0.11	0.08	0.09	0.06	0.08	0.06	0.07	0.06		

				Summary Progressive Load Test Data- Before and after DOC C18											
Test Points->		1	1	2	2	3	3	4	4	5	5	6	6	7	7
Speed	rpm	1260	1260	1259	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260
Torque	N.m	20	20	102	102	183	183	265	265	319	319	373	373	427	427
Power	kW	2.7	2.7	13.4	13.5	24.2	24.1	34.9	34.9	42.0	42.1	49.2	49.2	56.4	56.4
Engine Exhaust temperature	^oC	124	124	161	162	199	200	239	240	268	269	291	291	312	312
DOC inlet temperature	^oC	115	115	147	149	182	185	218	220	245	246	267	268	287	287
Exhaust gas concentration -wet															
CO_2	%	1.2	1.2	1.9	1.9	2.7	2.7	3.4	3.5	3.9	3.9	4.3	4.3	4.7	4.6
CO	ppm	276	271	227	223	165	162	96	48	77	15	67	8	62	6
NO_2	ppm	38	36	43	42	42	40	38	24	34	27	31	34	30	39
NO	ppm	144	143	247	252	344	353	408	419	440	449	477	478	517	500
THC	ppm	162	149	103	96	71	66	57	44	50	34	45	28	44	24
Specific emission -wet															
CO_2	g/kWh	2999	2980	1005	1005	801	806	723	729	689	693	667	671	653	652
CO	g/kWh	45.3	44.3	7.5	7.4	3.1	3.1	1.3	0.6	0.9	0.2	0.7	0.1	0.6	0.1
NO_2	g/kWh	9.0	8.7	2.1	2.0	1.2	1.1	0.7	0.5	0.6	0.4	0.5	0.5	0.4	0.5
NO	g/kWh	25.3	25.1	8.8	9.0	6.9	7.1	5.9	6.0	5.3	5.4	5.1	5.1	4.9	4.8
THC	g/kwh	13.4	12.3	1.7	1.6	0.7	0.6	0.4	0.3	0.3	0.2	0.2	0.1	0.2	0.1
Test Points->		8	8	9	9	10	10	11	11	12	12	13	13		
Speed	rpm	1260	1259	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260		
Torque	N.m	481	481	570	570	719	719	929	929	1132	1133	1473	1472		
Power	kW	63.5	63.5	75.2	75.2	94.8	94.9	122.6	122.5	149.4	149.4	194.4	194.2		
Engine Exhaust temperature	^oC	332	332	359	359	398	399	438	438	462	463	489	490		
DOC inlet temperature	^oC	306	307	334	334	372	373	412	413	439	439	466	467		
Exhaust gas concentration -wet															
CO_2	%	5.0	5.0	5.5	5.5	6.1	6.1	6.8	6.8	7.3	7.3	7.7	7.8		
CO	ppm	57.5	4.5	55.2	4.4	66.3	6.2	106.6	12.7	139.0	20.8	119.0	23.1		
NO_2	ppm	27.9	42.5	25.3	48.2	21.9	50.2	19.6	48.0	19.0	47.4	17.5	47.7		
NO	ppm	549.5	529.3	602.0	575.1	682.3	646.7	796.6	760.4	891.5	856.6	958.2	943.7		
THC	ppm	40	21	36	19	30	17	26	15	24	14	25	15		
Specific emission -wet															
CO_2	g/kWh	640	643	638	629	625	625	611	615	604	609	604	605		
CO	g/kWh	0.47	0.04	0.41	0.03	0.43	0.04	0.61	0.07	0.73	0.11	0.59	0.11		
NO_2	g/kWh	0.34	0.52	0.28	0.53	0.21	0.49	0.17	0.42	0.15	0.38	0.13	0.36		
NO	g/kWh	4.80	4.66	4.79	4.53	4.76	4.50	4.87	4.68	5.06	4.88	5.10	5.01		
THC	g/kWh	0.17	0.09	0.14	0.07	0.11	0.06	0.08	0.05	0.07	0.04	0.07	0.04		

Summary Progressive Load Test Data- Before and after DOC C5

Test Points->		1	1	2	2	3	3	4	4	5	5	6	6	7	7
Speed	rpm	1260	1260	1260	1260	1259	1260	1260	1260	1260	1260	1260	1260	1260	1260
Torque	N.m	20	20	102	102	183	183	264	265	319	319	373	373	427	427
Power	kW	2.7	2.7	13.4	13.4	24.2	24.1	34.9	34.9	42.1	42.1	49.2	49.2	56.4	56.4
Engine Exhaust temperature	^oC	124	124	161	162	198	200	239	240	267	266	288	289	309	310
DOC inlet temperature	^oC	116	116	146	149	184	186	221	223	247	248	268	269	288	289
Exhaust gas concentration -wet															
CO_2	%	1.2	1.2	1.9	1.9	2.7	2.7	3.4	3.5	3.9	3.9	4.2	4.3	4.6	4.6
CO	ppm	260	257	217	214	160	154	96	0	77	0	68	0	62	0
NO_2	ppm	36	36	41	37	41	27	38	26	34	61	32	87	29	96
NO	ppm	133	132	228	234	318	334	374	383	413	378	447	384	482	400
THC	ppm	172	169	104	105	72	78	59	35	56	29	54	29	52	24
Specific emission -wet															
CO_2	g/kWh	3013	2995	1012	1007	814	805	712	726	684	692	658	670	657	652
CO	g/kWh	42.6	41.9	7.2	7.1	3.1	2.9	1.3	0.0	0.9	0.0	0.7	0.0	0.6	0.0
NO_2	g/kWh	9.2	9.0	2.1	1.9	1.2	0.8	0.8	0.5	0.6	1.1	0.5	1.3	0.4	1.3
NO	g/kWh	23.4	23.0	8.1	8.3	6.5	6.8	5.3	5.5	5.0	4.6	4.7	4.1	4.7	3.9
THC	g/kWh	14.3	14.0	1.8	1.8	0.7	0.8	0.4	0.2	0.3	0.2	0.3	0.2	0.2	0.1
Test Points->		8	8	9	9	10	10	11	11	12	12	13	13		
Speed	rpm	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1259	1259		
Torque	N.m	482	481	570	570	719	719	929	929	1133	1133	1471	1472		
Power	kW	63.6	63.5	75.2	75.1	94.9	94.8	122.5	122.5	149.4	149.4	194.1	194.0		
Engine Exhaust temperature	^oC	328	328	355	356	395	396	436	437	462	462	489	490		
DOC inlet temperature	^oC	307	307	333	334	372	373	412	414	440	441	467	469		
Exhaust gas concentration -wet															
CO_2	%	4.9	4.9	5.4	5.4	6.1	6.1	6.8	6.8	7.2	7.3	7.7	7.8		
CO	ppm	56.9	0.0	53.1	0.0	65.1	0.0	105.7	0.0	141.3	0.0	120.6	0.5		
NO_2	ppm	27.2	102.8	24.0	114.4	20.5	126.1	18.6	130.1	17.0	125.7	15.1	116.8		
NO	ppm	513.4	416.9	560.6	458.0	638.4	516.3	757.1	620.6	840.4	709.7	916.3	810.9		
THC	ppm	46	18	42	16	36	14	32	15	30	15	30	15		
Specific emission -wet															
CO_2	g/kWh	637	639	625	634	624	623	617	618	606	613	605	607		
CO	g/kWh	0.47	0.00	0.39	0.00	0.43	0.00	0.61	0.00	0.75	0.00	0.60	0.00		
NO_2	g/kWh	0.35	1.32	0.28	1.33	0.21	1.29	0.17	1.17	0.14	1.05	0.12	0.91		
NO	g/kWh	4.53	3.69	4.44	3.67	4.48	3.61	4.71	3.83	4.81	4.07	4.89	4.31		
THC	g/kWh	0.20	0.08	0.16	0.06	0.12	0.05	0.10	0.05	0.09	0.04	0.08	0.04		

Summary Progressive Load Test Data- Before and after DOC C6

Test Points->		1	1	2	2	3	3	4	4	5	5	6	6	7	7
Speed	rpm	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260
Torque	N.m	21	20	102	102	183	183	265	264	319	319	373	373	427	427
Power	kW	2.7	2.7	13.4	13.4	24.2	24.2	34.9	34.8	42.1	42.1	49.2	49.2	56.4	56.4
Engine Exhaust temperature	^oC	123	123	160	161	198	199	238	240	266	266	289	289	310	310
DOC inlet temperature	^oC	114	114	145	147	180	183	216	219	242	244	264	265	284	285
Exhaust gas concentration -wet															
CO_2	%	1.1	1.1	1.9	1.9	2.7	2.7	3.4	3.4	3.9	3.9	4.3	4.3	4.6	4.6
CO	ppm	259	256	218	215	162	155	94	37	74	17	66	12	60	10
NO_2	ppm	37	36	44	42	44	38	39	26	36	37	33	53	31	61
NO	ppm	142	143	243	247	338	345	397	412	444	438	476	457	515	485
THC	ppm	153	137	101	94	72	66	56	41	51	34	46	30	44	28
Specific emission -wet															
CO_2	g/kWh	2986	2995	1025	1030	821	828	737	743	709	713	684	688	668	674
CO	g/kWh	43.1	42.4	7.4	7.4	3.1	3.0	1.3	0.5	0.9	0.2	0.7	0.1	0.6	0.1
NO_2	g/kWh	9.0	8.7	2.2	2.1	1.3	1.1	0.8	0.5	0.6	0.6	0.5	0.8	0.4	0.8
NO	g/kWh	25.4	25.4	8.9	9.0	7.0	7.2	5.9	6.1	5.5	5.5	5.2	5.0	5.1	4.8
THC	g/kWh	12.8	11.5	1.7	1.6	0.7	0.7	0.4	0.3	0.3	0.2	0.2	0.2	0.2	0.1
Test Points->		8	8	9	9	10	10	11	11	12	12	13	13		
Speed	rpm	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260		
Torque	N.m	481	481	570	570	719	719	930	929	1133	1133	1473	1473		
Power	kW	63.5	63.5	75.2	75.2	94.8	94.9	122.6	122.6	149.4	149.4	194.3	194.4		
Engine Exhaust temperature	^oC	330	330	358	358	397	398	438	438	463	464	490	489		
DOC inlet temperature	^oC	304	305	331	332	369	371	411	412	438	439	466	466		
Exhaust gas concentration -wet															
CO_2	%	5.0	5.0	5.4	5.5	6.1	6.1	6.8	6.9	7.3	7.3	7.8	7.8		
CO	ppm	57.7	10.2	54.8	9.2	65.3	12.5	106.7	23.4	143.8	34.9	121.4	33.9		
NO_2	ppm	29.8	67.6	26.9	73.0	23.8	77.1	21.5	70.0	20.2	63.8	18.9	60.6		
NO	ppm	559.5	507.3	597.8	548.0	683.6	635.7	794.6	744.1	886.7	842.2	974.7	930.1		
THC	ppm	42	25	36	23	30	20	27	19	25	17	25	17		
Specific emission -wet															
CO_2	g/kWh	662	666	646	652	643	645	626	633	621	625	611	613		
CO	g/kWh	0.49	0.09	0.41	0.07	0.44	0.08	0.62	0.14	0.78	0.19	0.61	0.17		
NO_2	g/kWh	0.37	0.85	0.30	0.82	0.24	0.76	0.19	0.62	0.16	0.52	0.14	0.45		
NO	g/kWh	5.09	4.63	4.84	4.47	4.90	4.57	4.96	4.69	5.16	4.89	5.23	4.97		
THC	g/kWh	0.18	0.11	0.14	0.09	0.11	0.07	0.08	0.06	0.07	0.05	0.07	0.05		

Summary Progressive Load Test Data- Before and after DOC C21

Test Points->		1	1	2	2	3	3	4	4	5	5	6	6	7	7
Speed	rpm	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260
Torque	N.m	20	20	102	102	183	183	265	265	319	319	373	373	427	428
Power	kW	2.7	2.7	13.4	13.4	24.2	24.2	34.9	34.9	42.0	42.1	49.2	49.2	56.4	56.4
Engine Exhaust temperature	^oC	124	124	160	161	196	198	238	240	267	268	290	290	312	312
DOC inlet temperature	^oC	115	114	145	147	176	179	214	217	240	242	263	263	283	283
Exhaust gas concentration -wet															
CO_2	%	1.2	1.1	1.9	1.9	2.7	2.7	3.4	3.5	3.9	3.9	4.3	4.3	4.7	4.7
CO	ppm	271	264	228	223	168	157	94	20	75	9	62	7	58	6
NO_2	ppm	37	36	44	41	46	36	40	32	37	61	34	86	32	103
NO	ppm	142	145	246	249	345	353	401	409	446	418	488	424	518	444
THC	ppm	159	140	103	98	72	69	55	37	51	30	45	27	43	24
Specific emission -wet															
CO_2	g/kWh	2946	2931	988	1003	805	812	728	727	688	701	665	670	651	657
CO	g/kWh	44.0	42.8	7.4	7.4	3.2	3.0	1.3	0.3	0.8	0.1	0.6	0.1	0.5	0.1
NO_2	g/kWh	8.9	8.5	2.1	2.0	1.3	1.0	0.8	0.6	0.6	1.0	0.5	1.3	0.4	1.4
NO	g/kWh	24.8	25.4	8.6	8.8	7.0	7.2	5.8	5.9	5.4	5.1	5.2	4.5	4.9	4.3
THC	g/kWh	13.1	11.5	1.7	1.6	0.7	0.7	0.4	0.3	0.3	0.2	0.2	0.1	0.2	0.1

Test Points->		8	8	9	9	10	10	11	11	12	12	13	13
Speed	rpm	1259	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260
Torque	N.m	482	481	570	570	719	719	929	929	1133	1132	1473	1472
Power	kW	63.6	63.5	75.2	75.2	94.9	94.8	122.6	122.6	149.4	149.4	194.5	194.2
Engine Exhaust temperature	^oC	331	332	359	360	398	399	438	438	462	463	488	489
DOC inlet temperature	^oC	302	303	329	330	367	368	406	408	434	435	460	461
Exhaust gas concentration -wet													
CO_2	%	5.0	5.0	5.5	5.5	6.1	6.1	6.8	6.8	7.3	7.3	7.7	7.8
CO	ppm	55.4	5.6	53.0	5.6	63.5	7.8	108.1	16.6	142.4	26.2	117.2	27.5
NO_2	ppm	30.8	109.4	28.3	110.8	24.3	111.5	22.6	101.0	21.8	89.9	19.7	81.1
NO	ppm	544.0	462.6	596.4	503.3	677.2	585.5	794.0	708.3	879.7	806.1	960.9	896.0
THC	ppm	40	22	37	21	31	18	27	17	25	15	25	15
Specific emission -wet													
CO_2	g/kWh	643	643	631	636	622	627	614	616	604	609	602	604
CO	g/kWh	0.46	0.05	0.39	0.04	0.41	0.05	0.62	0.09	0.75	0.14	0.58	0.14
NO_2	g/kWh	0.38	1.34	0.31	1.23	0.24	1.09	0.20	0.87	0.18	0.72	0.15	0.61
NO	g/kWh	4.80	4.06	4.71	4.00	4.70	4.08	4.88	4.35	4.99	4.59	5.10	4.74
THC	g/kWh	0.17	0.09	0.14	0.08	0.11	0.06	0.08	0.05	0.07	0.04	0.07	0.04

Summary Progressive Load Test Data- Before and after DOC C8															
Test Points->		1	1	2	2	3	3	4	4	5	5	6	6	7	7
Speed	rpm	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260
Torque	N.m	20	20	102	102	183	183	265	264	319	319	373	373	427	428
Power	kW	2.7	2.7	13.4	13.4	24.1	24.2	34.9	34.9	42.1	42.1	49.2	49.2	56.4	56.4
Engine Exhaust temperature	^oC	123	123	159	160	197	198	237	238	265	267	289	289	309	309
DOC inlet temperature	^oC	115	115	146	148	182	185	219	221	246	248	269	269	289	289
Exhaust gas concentration -wet															
CO_2	%	1.1	1.1	1.9	1.9	2.6	2.7	3.4	3.4	3.8	3.9	4.2	4.3	4.6	4.6
CO	ppm	259	254	213	213	159	158	92	56	74	15	63	10	58	8
NO_2	ppm	36	35	41	38	41	34	37	21	33	20	30	26	28	29
NO	ppm	138	139	238	241	331	337	389	407	428	444	468	471	506	503
THC	ppm	168	149	98	92	70	67	54	45	49	33	44	30	43	28
Specific emission -wet															
CO_2	g/kWh	2972	2955	1004	1011	809	811	719	723	694	695	674	680	653	659
CO	g/kWh	43.4	42.2	7.2	7.2	3.1	3.1	1.3	0.8	0.9	0.2	0.6	0.1	0.5	0.1
NO_2	g/kWh	9.0	8.5	2.0	1.9	1.2	1.0	0.7	0.4	0.6	0.3	0.5	0.4	0.4	0.4
NO	g/kWh	24.7	24.7	8.7	8.8	6.9	7.0	5.7	5.9	5.3	5.5	5.1	5.1	4.9	4.9
THC	g/kWh	14.2	12.6	1.7	1.6	0.7	0.7	0.4	0.3	0.3	0.2	0.2	0.2	0.2	0.1
Test Points->		8	8	9	9	10	10	11	11	12	12	13	13		
Speed	rpm	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1261	1260		
Torque	N.m	482	481	570	570	719	719	929	929	1133	1133	1475	1475		
Power	kW	63.6	63.6	75.2	75.2	94.9	94.9	122.6	122.6	149.4	149.5	194.7	194.7		
Engine Exhaust temperature	^oC	328	328	355	356	395	396	435	435	460	461	488	489		
DOC inlet temperature	^oC	307	308	333	334	372	374	413	414	440	441	468	469		
Exhaust gas concentration -wet															
CO_2	%	4.9	4.9	5.3	5.4	6.0	6.1	6.7	6.8	7.2	7.2	7.7	7.8		
CO	ppm	53.7	6.8	51.3	6.7	62.3	10.6	97.5	21.1	129.9	32.2	111.3	32.8		
NO_2	ppm	26.5	31.5	23.3	36.0	20.1	38.9	16.6	38.4	15.4	37.0	12.1	36.7		
NO	ppm	532.3	531.7	581.7	584.7	671.4	655.3	804.0	768.0	897.8	863.1	964.1	946.1		
THC	ppm	39	24	34	22	30	20	26	19	25	18	25	18		
Specific emission -wet															
CO_2	g/kWh	647	648	632	631	623	625	611	618	610	611	603	609		
CO	g/kWh	0.45	0.06	0.39	0.05	0.41	0.07	0.56	0.12	0.70	0.17	0.56	0.16		
NO_2	g/kWh	0.33	0.39	0.26	0.40	0.20	0.38	0.14	0.34	0.12	0.30	0.09	0.28		
NO	g/kWh	4.80	4.78	4.69	4.68	4.73	4.61	4.98	4.78	5.19	4.97	5.17	5.07		
THC	g/kWh	0.17	0.11	0.14	0.09	0.10	0.07	0.08	0.06	0.07	0.05	0.07	0.05		

Summary Progressive Load Test Data- Before and after DOC C12

Test Points->		1	1	2	2	3	3	4	4	5	5	6	6	7	7
Speed	rpm	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260
Torque	N.m	20	21	102	102	183	183	265	265	319	319	373	373	427	427
Power	kW	2.7	2.7	13.5	13.4	24.2	24.2	34.9	34.9	42.1	42.1	49.2	49.2	56.4	56.4
Engine Exhaust temperature	^oC	124	124	161	162	198	200	238	240	266	268	289	290	312	312
DOC inlet temperature	^oC	116	116	147	149	184	186	220	223	247	249	269	270	290	291
Exhaust gas concentration -wet															
CO_2	%	1.1	1.1	1.9	1.9	2.7	2.7	3.4	3.4	3.9	3.9	4.2	4.3	4.6	4.6
CO	ppm	258	254	215	213	159	157	94	26	75	6	64	3	60	3
NO_2	ppm	36	36	42	39	41	33	37	17	33	33	30	50	28	56
NO	ppm	141	140	242	242	338	341	391	406	429	429	469	447	503	477
THC	ppm	153	160	102	106	73	76	58	45	53	33	48	29	45	26
Specific emission -wet															
CO_2	g/kWh	2974	2931	1002	990	802	805	715	731	687	687	675	674	649	657
CO	g/kWh	42.6	41.5	7.2	7.0	3.0	3.0	1.3	0.4	0.8	0.1	0.6	0.0	0.5	0.0
NO_2	g/kWh	8.8	8.6	2.1	1.9	1.2	1.0	0.7	0.3	0.6	0.6	0.5	0.8	0.4	0.8
NO	g/kWh	25.0	24.6	8.7	8.6	6.9	7.0	5.6	5.9	5.2	5.2	5.1	4.8	4.8	4.6
THC	g/kWh	12.8	13.3	1.7	1.8	0.7	0.8	0.4	0.3	0.3	0.2	0.3	0.2	0.2	0.1

Test Points->		8	8	9	9	10	10	11	11	12	12	13	13		
Speed	rpm	1260	1260	1260	1260	1260	1260	1260	1260	1260	1259	1260	1260		
Torque	N.m	482	482	569	570	719	719	929	929	1132	1133	1476	1475		
Power	kW	63.5	63.5	75.2	75.2	94.9	94.9	122.6	122.6	149.4	149.4	194.8	194.6		
Engine Exhaust temperature	^oC	332	332	360	361	400	400	438	439	463	463	488	490		
DOC inlet temperature	^oC	309	310	337	337	375	376	414	415	440	440	466	468		
Exhaust gas concentration -wet															
CO_2	%	5.0	5.0	5.5	5.5	6.1	6.1	6.8	6.8	7.2	7.3	7.7	7.8		
CO	ppm	55.9	2.1	53.8	3.3	67.0	4.7	108.4	10.1	137.2	16.0	116.2	17.7		
NO_2	ppm	27.1	59.0	24.0	65.4	19.7	73.1	17.6	74.9	15.4	68.8	13.5	64.2		
NO	ppm	536.5	504.8	597.0	546.1	681.1	617.6	783.3	734.9	879.5	820.7	952.9	902.7		
THC	ppm	42	23	39	21	33	18	28	16	27	16	27	16		
Specific emission -wet															
CO_2	g/kWh	645	641	632	636	622	628	608	617	604	605	594	604		
CO	g/kWh	0.46	0.02	0.40	0.02	0.43	0.03	0.62	0.06	0.73	0.08	0.57	0.09		
NO_2	g/kWh	0.34	0.73	0.27	0.73	0.19	0.72	0.15	0.65	0.12	0.56	0.10	0.49		
NO	g/kWh	4.75	4.44	4.73	4.33	4.73	4.31	4.79	4.53	5.01	4.66	5.02	4.80		
THC	g/kWh	0.18	0.10	0.15	0.08	0.11	0.06	0.09	0.05	0.08	0.05	0.07	0.04		

Summary Progressive Load Test Data- Before and after DOC C16															
Test Points->		1	1	2	2	3	3	4	4	5	5	6	6	7	7
Speed	rpm	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260
Torque	N.m	20	20	102	102	183	183	264	264	319	319	373	373	427	427
Power	kW	2.7	2.7	13.4	13.4	24.2	24.2	34.9	34.9	42.1	42.1	49.2	49.2	56.4	56.4
Engine Exhaust temperature	^oC	124	124	160	161	198	199	238	239	266	267	289	290	310	312
DOC inlet temperature	^oC	113	113	142	145	174	177	208	210	233	236	256	257	276	277
Exhaust gas concentration -wet															
CO_2	%	1.1	1.1	1.9	1.9	2.7	2.7	3.4	3.4	3.9	3.9	4.3	4.3	4.6	4.7
CO	ppm	271	264	228	215	169	128	98	2	76	0	64	0	59	0
NO_2	ppm	34	31	39	29	40	15	35	31	31	90	28	149	26	190
NO	ppm	142	145	244	255	340	364	402	405	439	370	481	332	513	310
THC	ppm	158	139	104	95	73	66	56	28	50	21	44	18	41	15
Specific emission -wet															
CO_2	g/kWh	2945	2877	999	1001	802	812	708	717	689	692	672	667	653	654
CO	g/kWh	44.3	42.3	7.6	7.2	3.2	2.5	1.3	0.0	0.9	0.0	0.6	0.0	0.5	0.0
NO_2	g/kWh	8.2	7.3	1.9	1.5	1.1	0.4	0.7	0.6	0.5	1.5	0.4	2.2	0.3	2.6
NO	g/kWh	25.0	24.9	8.7	9.1	6.9	7.5	5.7	5.8	5.3	4.5	5.2	3.5	4.9	3.0
THC	g/kWh	13.1	11.3	1.8	1.6	0.7	0.6	0.4	0.2	0.3	0.1	0.2	0.1	0.2	0.1
Test Points->		8	8	9	9	10	10	11	11	12	12	13	13		
Speed	rpm	1260	1260	1260	1260	1260	1260	1259	1260	1260	1260	1260	1259		
Torque	N.m	482	481	570	570	719	719	929	929	1132	1133	1474	1474		
Power	kW	63.6	63.5	75.2	75.2	94.9	94.9	122.6	122.6	149.4	149.4	194.5	194.4		
Engine Exhaust temperature	^oC	331	331	360	360	399	400	439	440	463	464	489	489		
DOC inlet temperature	^oC	295	296	323	324	363	365	405	407	432	433	459	460		
Exhaust gas concentration -wet															
CO_2	%	5.0	5.0	5.5	5.5	6.1	6.1	6.8	6.9	7.3	7.3	7.7	7.8		
CO	ppm	56.1	0.0	54.7	0.0	67.1	0.0	108.1	2.1	141.5	3.2	123.7	4.3		
NO_2	ppm	24.2	220.1	21.0	244.5	17.6	249.9	14.6	230.2	12.9	205.0	10.8	172.4		
NO	ppm	542.0	301.5	597.2	318.2	675.2	385.6	797.3	523.6	876.6	645.0	952.1	773.6		
THC	ppm	37	13	36	13	30	13	26	12	24	12	25	12		
Specific emission -wet															
CO_2	g/kWh	643	647	638	638	623	625	612	620	610	609	598	604		
CO	g/kWh	0.46	0.00	0.41	0.00	0.43	0.00	0.62	0.01	0.76	0.02	0.61	0.02		
NO_2	g/kWh	0.30	2.72	0.23	2.73	0.17	2.45	0.13	2.00	0.10	1.64	0.08	1.29		
NO	g/kWh	4.79	2.67	4.76	2.53	4.69	2.68	4.89	3.22	5.03	3.67	5.02	4.10		
THC	g/kWh	0.16	0.06	0.14	0.05	0.10	0.04	0.08	0.04	0.07	0.03	0.07	0.03		

Summary Progressive Load Test Data- Before and after DOC C22

Test Points->		1	1	2	2	3	3	4	4	5	5	6	6	7	7
Speed	rpm	1259	1260	1260	1260	1259	1260	1260	1260	1260	1260	1260	1260	1260	1260
Torque	N.m	20	20	102	102	183	183	264	265	319	319	373	373	427	427
Power	kW	2.7	2.7	13.4	13.4	24.2	24.2	34.9	34.9	42.1	42.1	49.2	49.2	56.4	56.4
Engine Exhaust temperature	^oC	124	124	160	161	198	199	238	239	266	267	288	288	309	309
DOC inlet temperature	^oC	108	108	130	133	162	165	193	197	217	219	236	238	255	257
Exhaust gas concentration -wet															
CO_2	%	1.1	1.1	1.8	1.9	2.6	2.6	3.3	3.3	3.8	3.8	4.2	4.2	4.5	4.5
CO	ppm	261	257	220	217	162	161	94	91	74	70	62	32	58	15
NO_2	ppm	35	34	41	40	41	40	36	34	33	26	30	15	28	15
NO	ppm	131	132	226	231	318	319	370	378	411	420	450	466	478	500
THC	ppm	157	146	103	98	71	67	52	48	46	41	43	34	43	30
Specific emission -wet															
CO_2	g/kWh	2795	2781	946	944	779	773	692	683	662	667	646	648	631	635
CO	g/kWh	42.7	41.7	7.2	7.0	3.1	3.0	1.2	1.2	0.8	0.8	0.6	0.3	0.5	0.1
NO_2	g/kWh	8.8	8.5	2.0	2.0	1.2	1.1	0.7	0.7	0.6	0.5	0.5	0.2	0.4	0.2
NO	g/kWh	23.0	22.9	7.9	8.0	6.5	6.4	5.2	5.3	4.9	5.0	4.8	4.9	4.6	4.8
THC	g/kWh	13.0	12.1	1.7	1.6	0.7	0.6	0.4	0.3	0.3	0.2	0.2	0.2	0.2	0.1

Test Points->		8	8	9	9	10	10	11	11	12	12	13	13		
Speed	rpm	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260		
Torque	N.m	482	482	570	570	719	719	929	930	1133	1132	1473	1472		
Power	kW	63.5	63.5	75.2	75.2	94.9	94.9	122.6	122.7	149.5	149.4	194.4	194.2		
Engine Exhaust temperature	^oC	329	330	358	359	399	399	439	440	464	464	491	491		
DOC inlet temperature	^oC	272	274	298	300	336	339	376	378	404	405	433	434		
Exhaust gas concentration -wet															
CO_2	%	4.9	4.9	5.3	5.4	6.0	6.1	6.7	6.8	7.2	7.2	7.6	7.7		
CO	ppm	53.9	11.3	53.6	11.3	66.1	15.5	109.2	29.3	147.9	40.1	118.8	39.6		
NO_2	ppm	26.6	18.9	24.1	25.8	20.5	34.0	17.9	38.2	17.2	40.2	15.7	44.0		
NO	ppm	513.5	523.3	562.5	567.3	638.7	631.1	756.3	735.6	837.4	810.2	913.0	888.0		
THC	ppm	39	26	36	23	33	22	30	21	29	20	29	20		
Specific emission -wet															
CO_2	g/kWh	623	623	612	616	611	615	600	611	595	607	590	594		
CO	g/kWh	0.44	0.09	0.39	0.08	0.43	0.10	0.62	0.17	0.78	0.21	0.58	0.19		
NO_2	g/kWh	0.34	0.24	0.27	0.29	0.21	0.34	0.16	0.34	0.14	0.33	0.12	0.34		
NO	g/kWh	4.50	4.55	4.40	4.42	4.42	4.37	4.59	4.50	4.73	4.64	4.81	4.68		
THC	g/kWh	0.17	0.11	0.14	0.09	0.11	0.07	0.09	0.06	0.08	0.06	0.08	0.05		

				Summary Progressive Load Test Data- Before and after DOC C13											
Test Points->		1	1	2	2	3	3	4	4	5	5	6	6	7	7
Speed	rpm	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260
Torque	N.m	20	20	102	102	183	183	264	265	319	319	373	373	428	427
Power	kW	2.7	2.7	13.4	13.4	24.2	24.2	34.9	34.9	42.1	42.0	49.2	49.2	56.4	56.4
Engine Exhaust temperature	^oC	124	124	160	161	196	198	236	238	265	266	289	289	310	311
DOC inlet temperature	^oC	107	107	129	132	158	162	190	193	213	217	235	237	253	255
Exhaust gas concentration -wet															
CO_2	%	1.2	1.2	1.9	1.9	2.7	2.7	3.4	3.4	3.8	3.9	4.2	4.2	4.6	4.6
CO	ppm	272	269	231	232	172	172	98	96	74	72	63	52	58	36
NO_2	ppm	36	35	42	42	41	40	37	32	33	26	30	19	28	14
NO	ppm	134	134	232	232	332	338	397	407	449	460	498	508	532	554
THC	ppm	166	154	123	119	75	72	56	53	51	47	50	42	50	38
Specific emission -wet															
CO_2	g/kWh	2906	2894	983	981	785	776	686	693	654	660	637	641	628	628
CO	g/kWh	43.5	43.0	7.5	7.6	3.2	3.2	1.3	1.3	0.8	0.8	0.6	0.5	0.5	0.3
NO_2	g/kWh	8.7	8.6	2.1	2.1	1.2	1.1	0.7	0.6	0.5	0.4	0.4	0.3	0.3	0.2
NO	g/kWh	23.1	22.9	8.1	8.1	6.7	6.7	5.5	5.7	5.2	5.4	5.1	5.2	5.0	5.1
THC	g/kWh	13.5	12.5	2.1	2.0	0.7	0.7	0.4	0.4	0.3	0.3	0.2	0.2	0.2	0.2
Test Points->		8	8	9	9	10	10	11	11	12	12	13	13		
Speed	rpm	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1259	1259		
Torque	N.m	481	482	570	570	719	719	929	929	1132	1132	1471	1471		
Power	kW	63.5	63.5	75.2	75.2	94.9	94.9	122.6	122.6	149.4	149.4	194.0	194.0		
Engine Exhaust temperature	^oC	330	331	359	360	400	400	440	440	465	465	492	492		
DOC inlet temperature	^oC	271	273	295	298	333	337	375	378	404	405	434	435		
Exhaust gas concentration -wet															
CO_2	%	4.9	5.0	5.5	5.5	6.1	6.1	6.8	6.9	7.3	7.3	7.7	7.8		
CO	ppm	55.2	26.5	52.9	18.3	64.7	17.0	107.6	25.0	139.1	32.5	109.7	31.9		
NO_2	ppm	25.6	11.8	22.9	10.2	18.9	10.9	16.3	13.3	15.9	14.9	41.4	43.0		
NO	ppm	569.5	588.1	627.4	642.4	713.2	723.5	832.6	841.8	926.6	927.1	962.0	970.9		
THC	ppm	48	34	43	27	39	24	35	25	32	24	27	18		
Specific emission -wet															
CO_2	g/kWh	622	626	614	618	612	612	608	608	601	600	592	598		
CO	g/kWh	0.44	0.21	0.38	0.13	0.41	0.11	0.61	0.14	0.73	0.17	0.53	0.16		
NO_2	g/kWh	0.30	0.14	0.24	0.11	0.18	0.10	0.13	0.11	0.12	0.11	0.30	0.31		
NO	g/kWh	4.88	5.04	4.82	4.95	4.86	4.91	5.05	5.07	5.23	5.20	5.03	5.08		
THC	g/kWh	0.20	0.14	0.16	0.10	0.13	0.08	0.11	0.07	0.09	0.07	0.07	0.05		

Summary Progressive Load Test Data- Before and after DOC C14

Test Points->		1	1	2	2	3	3	4	4	5	5	6	6	7	7
Speed	rpm	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260	1260
Torque	N.m	20	20	102	102	183	183	265	265	319	319	373	373	428	427
Power	kW	2.7	2.7	13.4	13.4	24.2	24.1	34.9	34.9	42.1	42.0	49.2	49.2	56.4	56.4
Engine Exhaust temperature	^oC	124	124	160	161	198	199	237	239	265	266	287	287	307	308
DOC inlet temperature	^oC	105	105	127	131	154	158	184	189	208	212	228	230	246	249
Exhaust gas concentration -wet															
CO_2	%	1.1	1.1	1.9	1.9	2.7	2.7	3.4	3.4	3.8	3.8	4.2	4.2	4.6	4.6
CO	ppm	251	246	211	208	154	153	92	89	74	61	62	31	58	18
NO_2	ppm	35	33	41	36	41	30	37	16	34	11	31	10	29	13
NO	ppm	138	138	235	240	324	337	376	399	420	441	458	478	494	509
THC	ppm	150	123	102	88	74	66	61	57	53	52	46	41	45	34
Specific emission -wet															
CO_2	g/kWh	3037	2995	1035	1022	820	823	735	735	703	705	680	680	663	666
CO	g/kWh	42.6	41.3	7.3	7.1	3.0	3.0	1.3	1.2	0.9	0.7	0.6	0.3	0.5	0.2
NO_2	g/kWh	8.8	8.2	2.1	1.8	1.2	0.9	0.8	0.3	0.6	0.2	0.5	0.2	0.4	0.2
NO	g/kWh	25.3	24.9	8.8	8.8	6.8	7.1	5.6	5.9	5.3	5.6	5.1	5.3	4.9	5.1
THC	g/kWh	12.9	10.5	1.8	1.5	0.7	0.7	0.4	0.4	0.3	0.3	0.2	0.2	0.2	0.2
Test Points->		8	8	9	9	10	10	11	11	12	12	13	13		
Speed	rpm	1260	1260	1260	1260	1260	1260	1260	1260	1261	1260	1260	1260		
Torque	N.m	482	481	570	570	719	719	929	929	1133	1133	1476	1475		
Power	kW	63.5	63.5	75.2	75.1	94.9	94.9	122.6	122.6	149.5	149.5	194.7	194.7		
Engine Exhaust temperature	^oC	327	328	356	357	396	397	438	438	462	463	489	489		
DOC inlet temperature	^oC	264	266	288	291	324	328	367	371	400	402	431	433		
Exhaust gas concentration -wet															
CO_2	%	4.9	4.9	5.4	5.4	6.1	6.1	6.8	6.8	7.2	7.3	7.7	7.7		
CO	ppm	55.3	12.5	52.0	10.2	61.9	13.6	105.2	24.5	136.8	35.8	107.6	32.8		
NO_2	ppm	27.0	17.1	23.7	21.4	19.5	25.5	16.6	26.6	16.3	27.8	13.4	31.4		
NO	ppm	525.3	530.9	579.8	579.3	664.2	664.3	783.3	778.4	875.1	856.0	960.1	927.7		
THC	ppm	41	28	36	23	30	19	26	17	24	16	23	15		
Specific emission -wet															
CO_2	g/kWh	656	655	647	645	636	637	623	622	614	617	598	611		
CO	g/kWh	0.47	0.11	0.40	0.08	0.41	0.09	0.61	0.14	0.74	0.19	0.53	0.16		
NO_2	g/kWh	0.35	0.22	0.27	0.25	0.20	0.25	0.15	0.23	0.13	0.23	0.10	0.24		
NO	g/kWh	4.82	4.83	4.76	4.72	4.75	4.74	4.89	4.84	5.07	4.96	5.10	5.01		
THC	g/kWh	0.18	0.12	0.15	0.09	0.11	0.07	0.08	0.05	0.07	0.05	0.06	0.04		

APPENDIX E

Transient Mine Vehicle Load Cycle Emission Data Summary

Transient LHD Cycle Average for DOC C2	Unit	Basseline Test 4	DOC Test 9	Percentage Change
Speed	rpm	1586.9	1584.0	-0.2%
Torque	N.m	523.5	528.4	0.9%
Power	kW	87.0	87.7	0.8%
Exhaust Temperature	^oC	309	307	-0.6%
Exhaust Specific Emission				
CO_2	g/kWh	706.2	704.0	-0.3%
CO	g/kWh	1.1	0.4	-60.4%
NO_2	g/kWh	0.4	0.3	-18.4%
NO	g/kWh	3.9	3.9	0.2%
THC	g/kWh	0.2	0.1	-44.6%

Transient LHD Cycle Average for DOC C3	Unit	Baseline Test 4	Doc Test 11	Percent Change
Speed	rpm	1586.9	1584.6	-0.1%
Torque	N.m	523.6	526.7	0.6%
Power	kW	87.0	87.4	0.5%
Exhaust Temperature	^oC	310	311	0.3%
Exhaust Specific Emission				
CO_2	g/kWh	706.1	685.8	-2.9%
CO	g/kWh	1.1	0.3	-69.5%
NO_2	g/kWh	0.4	0.5	32.1%
NO	g/kWh	3.9	3.7	-5.5%
THC	g/kWh	0.2	0.1	-58.7%

Transient LHD Cycle Average for DOC C15	Unit	Baseline Test 4	DOC Test13	Percentage Change
Speed	rpm	1585.9	1585.2	0.0%
Torque	N.m	523.6	521.2	-0.5%
Power	kW	87.0	86.5	-0.5%
Exhaust Temperature	^oC	310	311	0.4%
Exhaust Specific Emission				
CO_2	g/kWh	706.6	727.1	2.9%
CO	g/kWh	1.1	0.6	-48.6%
NO_2	g/kWh	0.4	0.4	-5.3%
NO	g/kWh	3.9	3.9	-0.2%
THC	g/kWh	0.2	0.1	-50.9%

Transient LHD Cycle Average for DOC C19	Unit	Baseline Test 4	DOC Test 15	Percent Change
Speed	rpm	1585.9	1585.7	0.0%
Torque	N.m	523.6	525.2	0.3%
Power	kW	87.0	87.2	0.3%
Exhaust Temperature	^oC	310	309	-0.2%
Exhaust Specific Emission				
CO_2	g/kWh	706.6	714.7	1.1%
CO	g/kWh	1.1	0.5	-57.5%
NO_2	g/kWh	0.4	0.4	1.5%
NO	g/kWh	3.9	3.8	-1.6%
THC	g/kWh	0.2	0.1	-48.6%

Transient LHD Cycle Average for DOC C20	Unit	Baseline Test 4	DOC Test 17	Percent Change
Speed	rpm	1585.9	1587.3	0.1%
Torque	N.m	523.6	525.3	0.3%
Power	kW	87.0	87.3	0.4%
Exhaust Temperature	^oC	310	311	0.5%
Exhaust Specific Emission				
CO_2	g/kWh	706.6	719.3	1.8%
CO	g/kWh	1.1	0.5	-52.9%
NO_2	g/kWh	0.4	0.3	-17.2%
NO	g/kWh	3.9	3.8	-0.8%
THC	g/kWh	0.2	0.1	-51.2%

Transient LHD Cycle Average for DOC C31	Unit	Baseline Test 4	DOC Test 19	Percent Change
Speed	rpm	1585.9	1581.6	-0.3%
Torque	N.m	523.6	519.1	-0.9%
Power	kW	87.0	86.0	-1.1%
Exhaust Temperature	^oC	310	310	0.2%
Exhaust Specific Emission				
CO_2	g/kWh	706.6	709.1	0.3%
CO	g/kWh	1.2	0.4	-66.6%
NO_2	g/kWh	0.4	0.1	-70.6%
NO	g/kWh	4.2	4.4	4.8%
THC	g/kWh	0.2	0.1	-61.8%

Transient LHD Cycle Average for DOC C32	Unit	Baseline Test 4	DOC Test 21	Percent Change
Speed	rpm	1585.9	1582.9	-0.2%
Torque	N.m	523.6	525.1	0.3%
Power	kW	87.0	87.0	0.1%
Exhaust Temperature	^oC	310	312	0.8%
Exhaust Specific Emission				
CO_2	g/kWh	706.6	720.2	1.9%
CO	g/kWh	1.1	0.4	-61.4%
NO_2	g/kWh	0.4	0.1	-81.2%
NO	g/kWh	3.9	4.0	4.3%
THC	g/kWh	0.2	0.1	-62.3%

Transient LHD Cycle Average for DOC C33	Unit	Baseline Test 4	DOC Test 23	Percent Change
Speed	rpm	1585.9	1584.9	-0.1%
Torque	N.m	523.6	520.7	-0.6%
Power	kW	87.0	86.4	-0.6%
Exhaust Temperature	^oC	310	311	0.3%
Exhaust Specific Emission				
CO_2	g/kWh	706.6	718.2	1.6%
CO	g/kWh	1.1	1.1	-6.0%
NO_2	g/kWh	0.4	0.2	-47.5%
NO	g/kWh	3.9	4.0	2.5%
THC	g/kWh	0.2	0.1	-72.0%

Transient LHD Cycle Average for DOC 34	Unit	Baseline Test 4	DOC Test 25	Percent Change
Speed	rpm	1585.9	1584.9	-0.1%
Torque	N.m	523.6	523.1	-0.1%
Power	kW	87.0	86.8	-0.2%
Exhaust Temperature	^oC	310	311	0.3%
Exhaust Specific Emission				
CO_2	g/kWh	706.6	710.7	0.6%
CO	g/kWh	1.1	0.0	-99.1%
NO_2	g/kWh	0.4	1.1	183.8%
NO	g/kWh	3.9	3.6	-7.1%
THC	g/kWh	0.2	0.1	-68.1%

Transient LHD Cycle Average for DOC C35	Unit	Baseline Test 4	DOC Test 27	Percent Change
Speed	rpm	1585.9	1582.8	-0.2%
Torque	N.m	523.6	524.1	0.1%
Power	kW	87.0	86.9	-0.1%
Exhaust Temperature	^oC	310	313	0.9%
Exhaust Specific Emission				
CO_2	g/kWh	706.6	716.5	1.4%
CO	g/kWh	1.1	0.0	-97.8%
NO_2	g/kWh	0.4	0.0	-94.1%
NO	g/kWh	3.9	4.1	5.8%
THC	g/kWh	0.2	0.0	-72.3%

Transient Utility Vehicle Cycle Average for DOC 17	Unit	Baseline Test 5	DOC Test 29	Percent Change
Speed	rpm	1667.3	1668.8	0.1%
Torque	N.m	504.1	505.0	0.2%
Power	kW	160.0	160.5	0.3%
Exhaust Temperature	^oC	338	336	-0.5%
Exhaust Specific Emission				
CO_2	g/kWh	747.9	749.5	0.2%
CO	g/kWh	0.5	0.3	-33.8%
NO_2	g/kWh	0.3	0.2	-37.3%
NO	g/kWh	3.8	3.9	0.7%
THC	g/kWh	0.1	0.1	-26.9%

Transient Utility Vehicle Average for DOC C18	Unit	Baseliune Test 5	DOC Test 31	Percent Change
Speed	rpm	1657.7	1658.7	0.1%
Torque	N.m	499.8	499.8	0.0%
Power	kW	157.7	157.9	0.1%
Exhaust Temperature	^oC	337	634	88.1%
Exhaust Specific Emission				
CO_2	g/kWh	752.1	752.6	0.1%
CO	g/kWh	0.5	0.1	-70.1%
NO_2	g/kWh	0.3	0.3	-1.8%
NO	g/kWh	3.9	3.9	0.8%
THC	g/kWh	0.1	0.1	-49.4%

Transient Utility Vehicle Cycle Average for DOC C5	Unit	Baseline Test 5	DOC Test 33	Percent Change
Speed	rpm	1655.2	1658.6	0.2%
Torque	N.m	498.6	500.7	0.4%
Power	kW	157.1	158.1	0.6%
Exhaust Temperature	^oC	337	332	-1.3%
Exhaust Specific Emission				
CO_2	g/kWh	752.7	747.6	-0.7%
CO	g/kWh	0.5	0.0	-98.8%
NO_2	g/kWh	0.3	0.8	153.6%
NO	g/kWh	3.9	3.5	-9.5%
THC	g/kWh	0.1	0.0	-74.1%

Transient Pickup Truck Cycle Average for DOC C6	Unit	Baseline Test 7	DOC Test 35	Percent Change
Speed	rpm	1034.7	1035.9	0.1%
Torque	N.m	312.9	313.5	0.2%
Power	kW	33.9	34.0	0.3%
Exhaust Temperature	^oC	270	270	0.1%
Exhaust Specific Emission				
CO_2	g/kWh	890.8	910.5	2.2%
CO	g/kWh	0.9	0.2	-80.6%
NO_2	g/kWh	0.6	1.3	101.6%
NO	g/kWh	5.8	5.5	-6.6%
THC	g/kWh	0.3	0.1	-53.8%

Transient Pickup Truck Cycle Average for DOC C21	Unit	Baseline Test 7	DOC Test 37	Perecent Change
Speed	rpm	1064.3	1060.5	-0.4%
Torque	N.m	331.8	329.8	-0.6%
Power	kW	37.0	36.6	-1.0%
Exhaust Temperature	^oC	271	271	0.1%
Exhaust Specific Emission				
CO_2	g/kWh	867.5	864.4	-0.4%
CO	g/kWh	0.8	0.1	-84.3%
NO_2	g/kWh	0.6	1.6	178.9%
NO	g/kWh	5.6	4.9	-12.9%
THC	g/kWh	0.2	0.1	-59.3%

Transient LHD Cycle Average for DOC C8	Unit	Baseline Test 4	DOC Test 39	Percent Change
Speed	rpm	1585.9	1586.9	0.1%
Torque	N.m	523.6	520.0	-0.7%
Power	kW	87.0	86.4	-0.6%
Exhaust Temperature	^{o}C	310	308	-0.7%
Exhaust Specific Emission				
CO_2	g/kWh	706.6	711.3	0.7%
CO	g/kWh	1.1	0.5	-55.0%
NO_2	g/kWh	0.4	0.3	-24.2%
NO	g/kWh	3.9	3.9	0.3%
THC	g/kWh	0.2	0.1	-42.7%

Transient Tractor Cycle Average for DOC C12	Unit	Baseline Test 6	DOC Test 41	Percent Change
Speed	rpm	1038.1	1038.1	0.0%
Torque	N.m	246.9	248.4	0.6%
Power	kW	26.8	27.0	0.6%
Exhaust Temperature	^{o}C	239	239	0.1%
Exhaust Specific Emission				
CO_2	g/kWh	904.7	900.6	-0.5%
CO	g/kWh	1.2	0.4	-66.2%
NO_2	g/kWh	0.8	0.9	18.3%
NO	g/kWh	6.1	5.9	-2.3%
THC	g/kWh	0.3	0.2	-50.0%

Transient Utility Vehicle Cycle Average for DOC C16	Unit	Baseline Test 5	DOC Test 43	Percent Change
Speed	rpm	1657.7	1658.9	0.1%
Torque	N.m	499.8	500.1	0.1%
Power	kW	157.7	158.0	0.1%
Exhaust Temperature	^{o}C	337	334	-0.8%
Exhaust Specific Emission				
CO_2	g/kWh	752.1	755.2	0.4%
CO	g/kWh	0.5	0.0	-91.2%
NO_2	g/kWh	0.3	1.8	445.6%
NO	g/kWh	3.9	2.8	-28.8%
THC	g/kWh	0.1	0.0	-70.7%

Transient Utility Vehicle Cycle Average for DOC C22	Unit	Baseline Test 5	DOC Test 45	Percent Change
Speed	rpm	1656.9	1655.1	-0.1%
Torque	N.m	677.1	675.8	-0.2%
Power	kW	117.5	117.1	-0.3%
Exhaust Temperature	^oC	337	334	-0.8%
Exhaust Specific Emission				
CO_2	g/kWh	752.5	723.6	-3.8%
CO	g/kWh	0.5	0.2	-58.1%
NO_2	g/kWh	0.3	0.4	7.9%
NO	g/kWh	3.9	3.8	-2.3%
THC	g/kWh	0.1	0.1	-38.0%

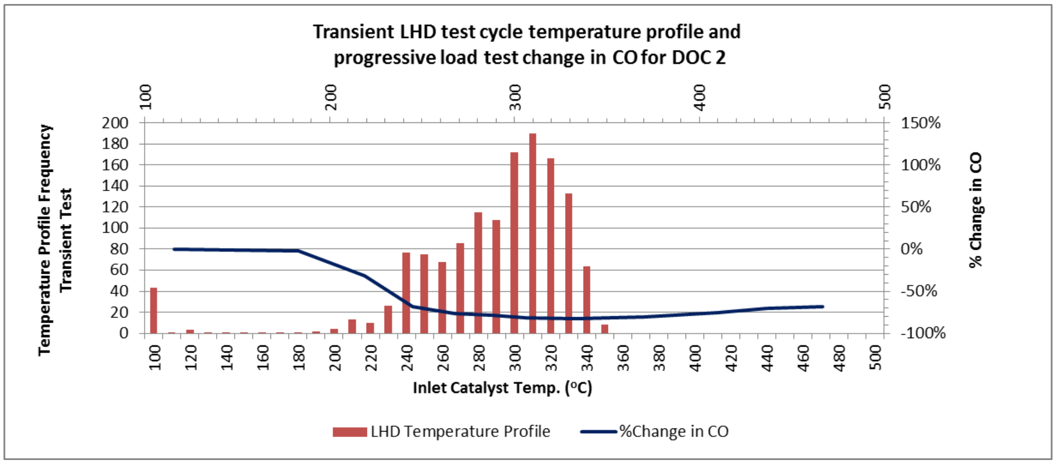
Transient Utility Vehicle Cycle Average for DOC C13	Unit	Baseline Test 5	DOC Test 47	Percent Change
Speed	rpm	1655.2	1661.1	0.4%
Torque	N.m	676.0	678.8	0.4%
Power	kW	117.2	118.1	0.8%
Exhaust Temperature	^oC	337	335	-0.5%
Exhaust Specific Emission				
CO_2	g/kWh	753.3	748.9	-0.6%
CO	g/kWh	0.5	0.2	-46.5%
NO_2	g/kWh	0.3	0.2	-46.6%
NO	g/kWh	3.9	3.9	1.2%
THC	g/kWh	0.1	0.1	-40.8%

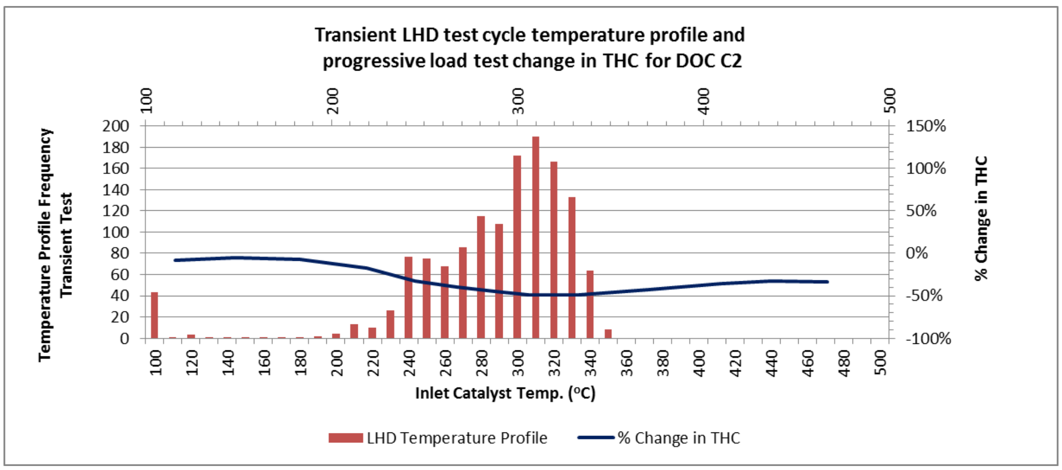
Transient Utility Vehicle Cycle Average for DOC C14	Unit	Baseline Test 5	DOC Test 49	Percent Change
Speed	rpm	1656.0	1657.9	0.1%
Torque	N.m	676.5	677.2	0.1%
Power	kW	117.3	117.6	0.2%
Exhaust Temperature	^oC	337	331	-1.8%
Exhaust Specific Emission				
CO_2	g/kWh	752.9	756.9	0.5%
CO	g/kWh	0.5	0.2	-64.4%
NO_2	g/kWh	0.3	0.4	9.2%
NO	g/kWh	3.9	3.9	0.5%
THC	g/kWh	0.1	0.1	-47.6%

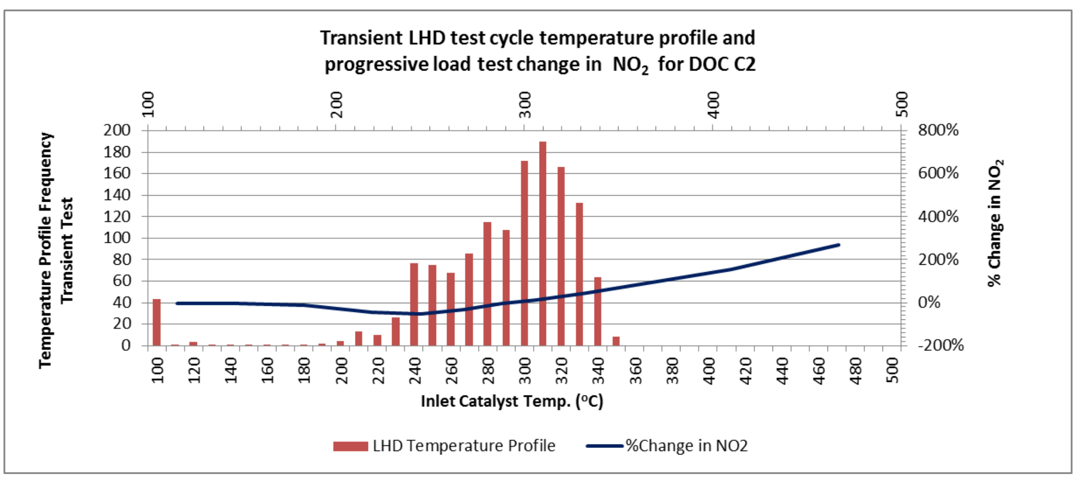
APPENDIX F

Transient Mine Vehicle Temperature Profile and Progressive Load Test Emission

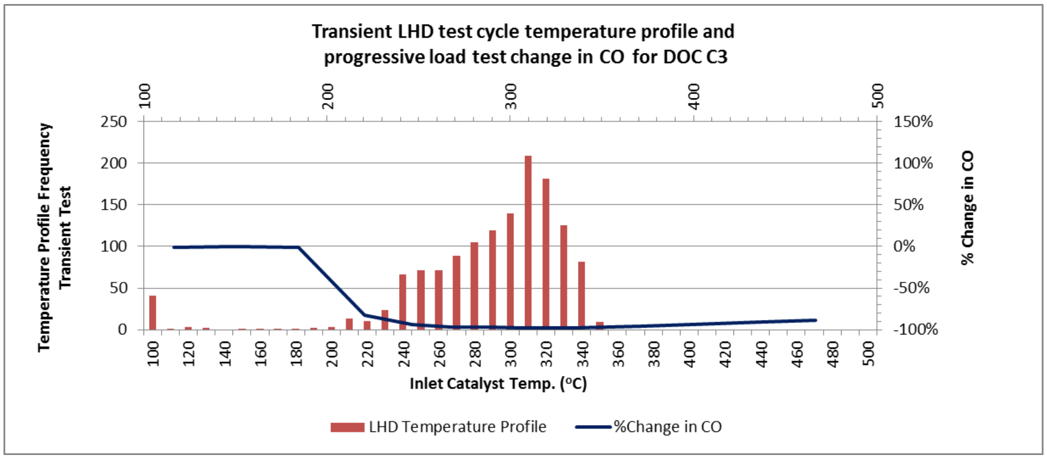
Transient Mine Vehicle Temperature Profile and Change in CO, THC and NO_2 under Progressive Load Testing for DOC C2

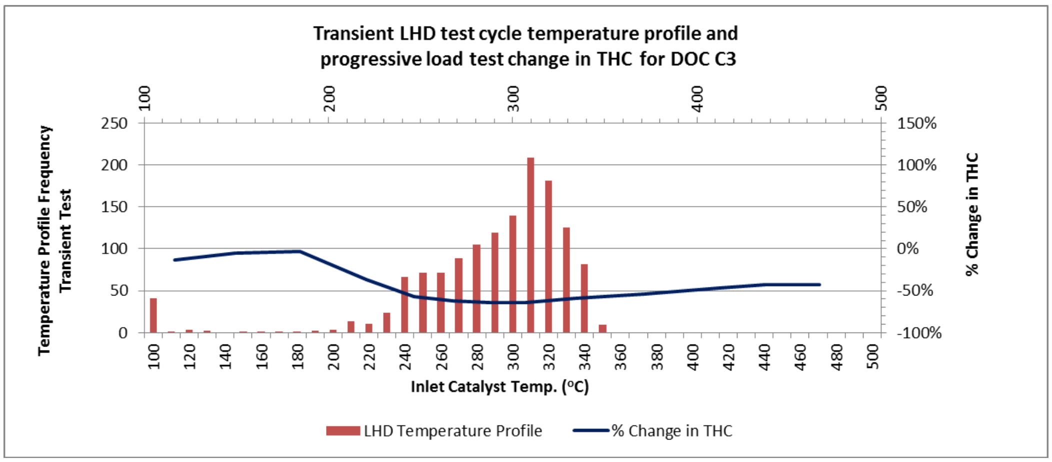


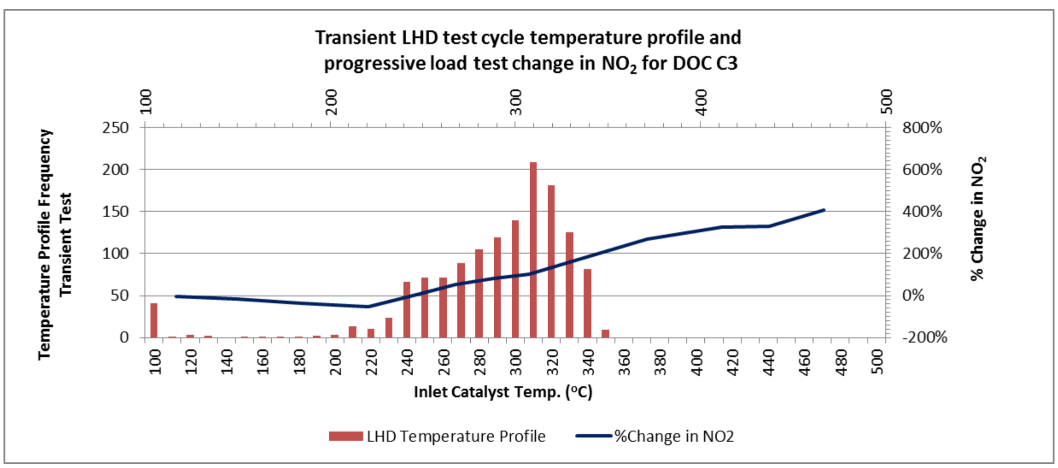




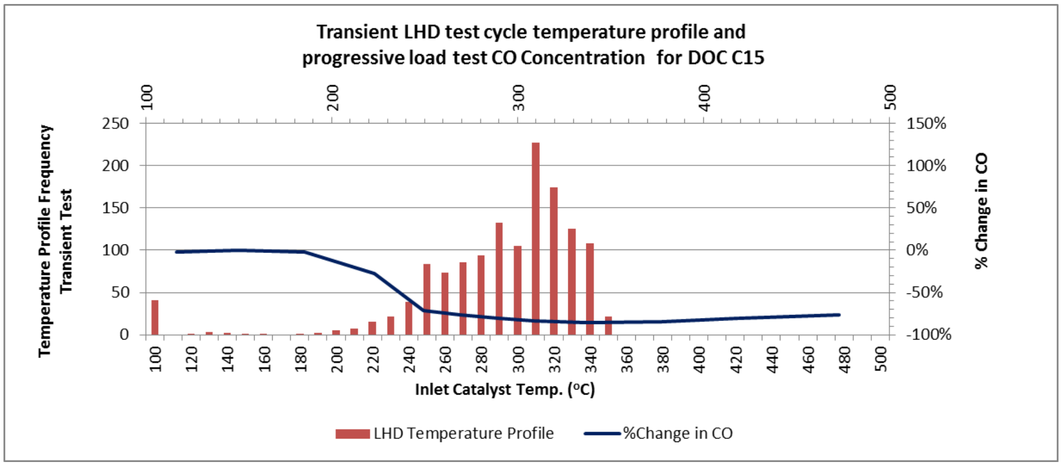
Transient Mine Vehicle Temperature Profile and Change in CO, THC and NO_2 under Progressive Load Testing for DOC C3

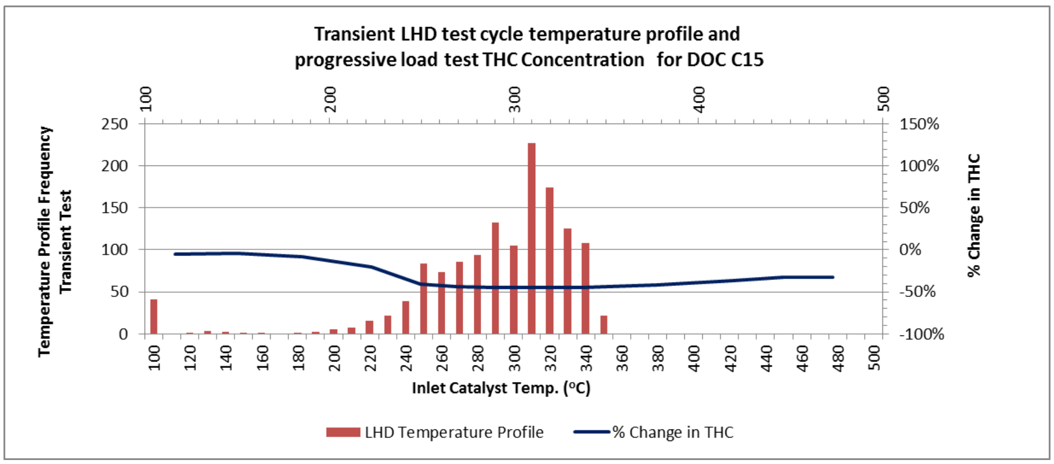


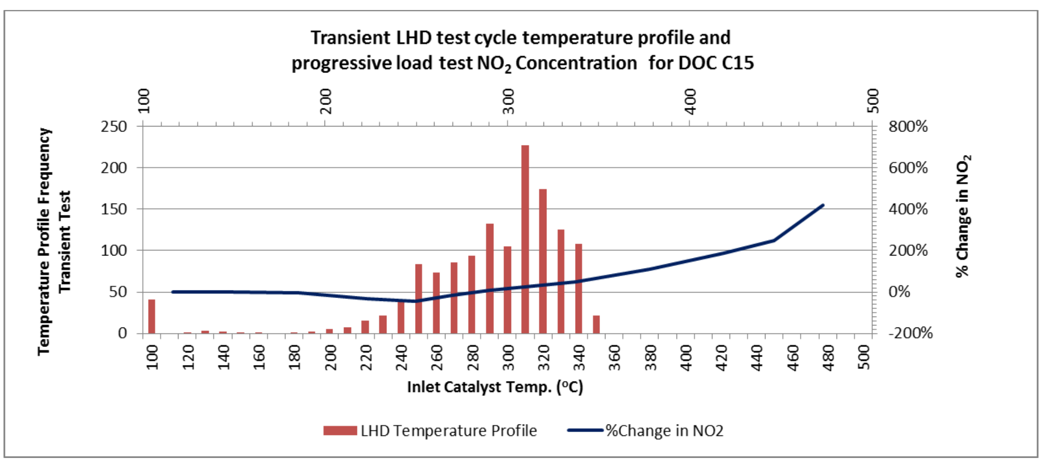




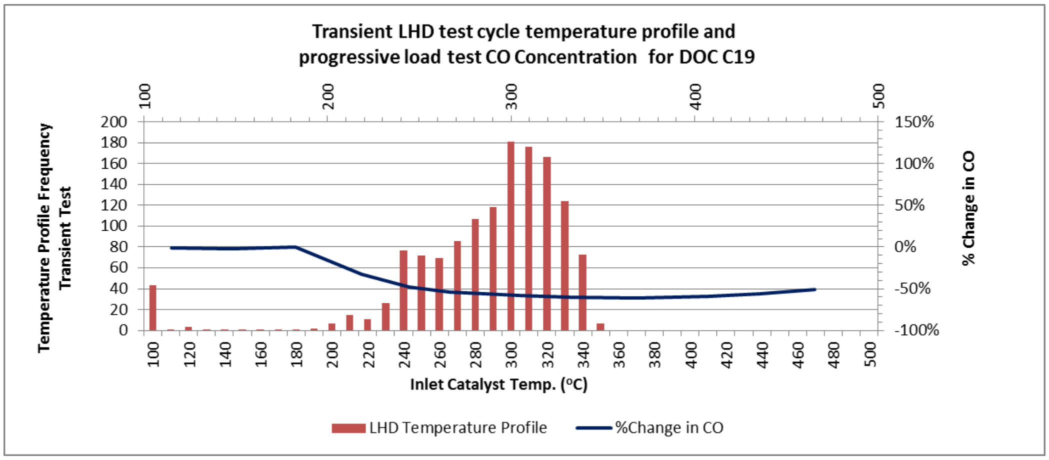
Transient Mine Vehicle Temperature Profile and Change in CO, THC and NO_2 under Progressive Load Testing for DOC C15

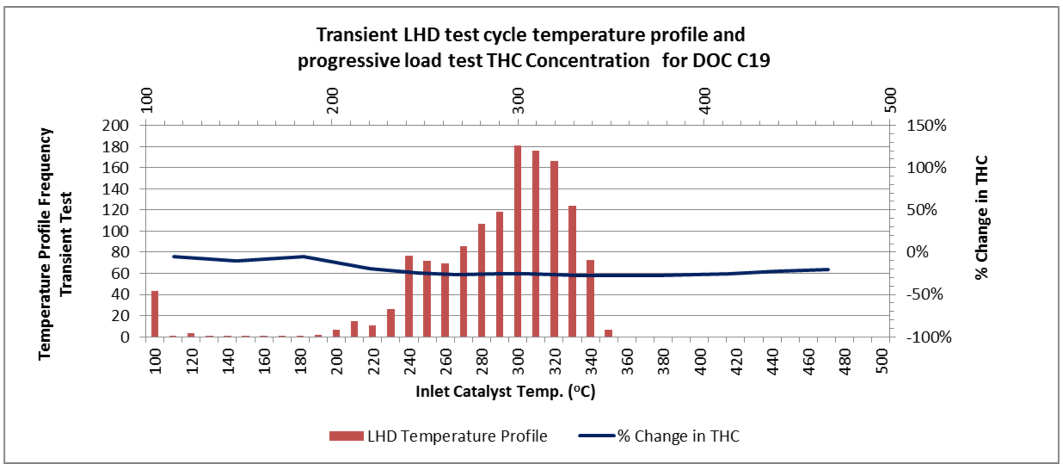


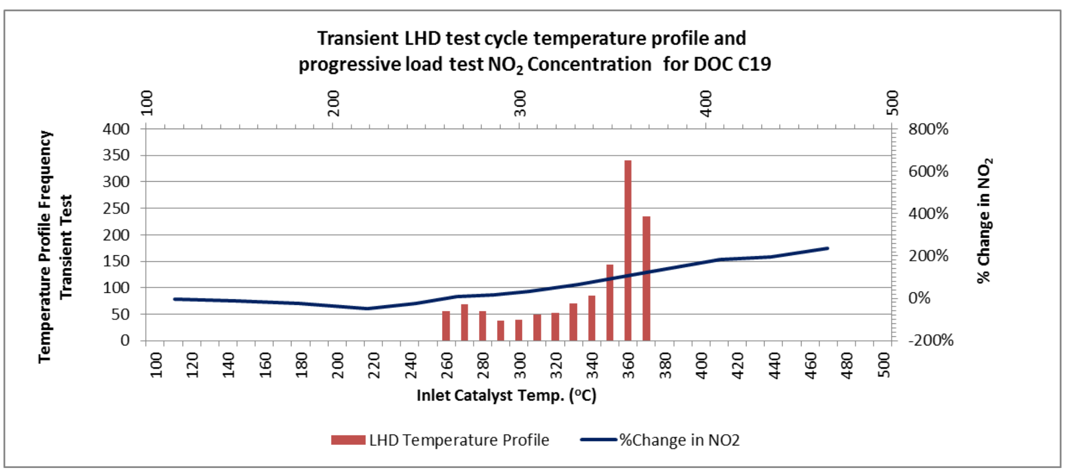




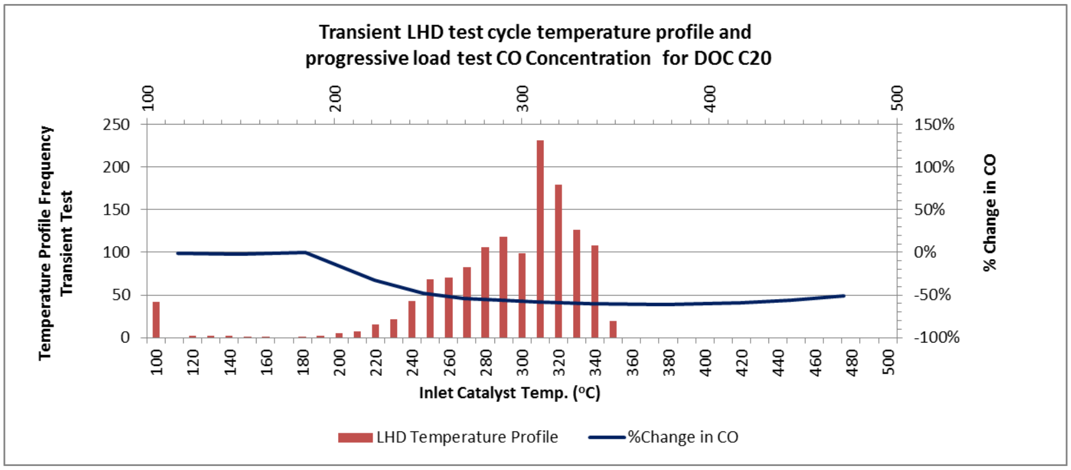
Transient Mine Vehicle Temperature Profile and Change in CO, THC and NO_2 under Progressive Load Testing for DOC C19

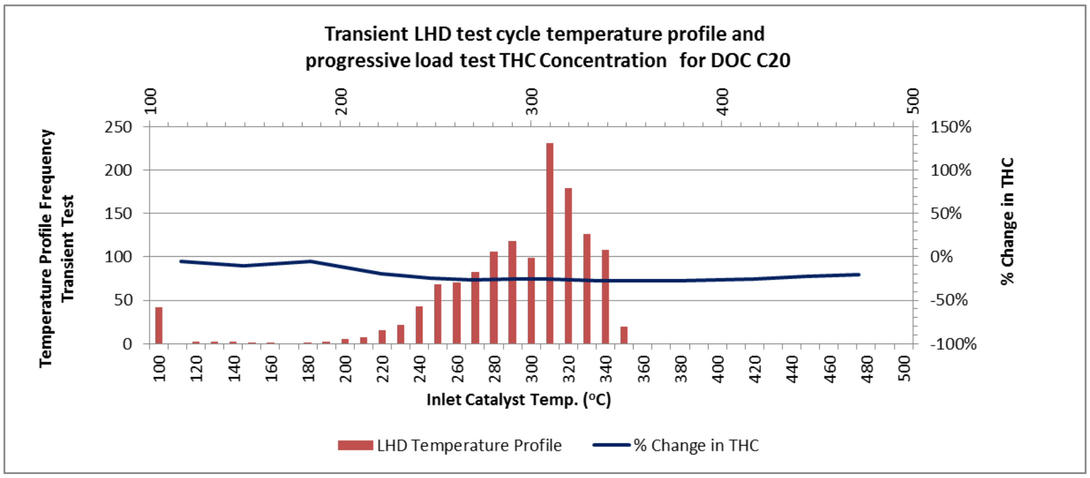


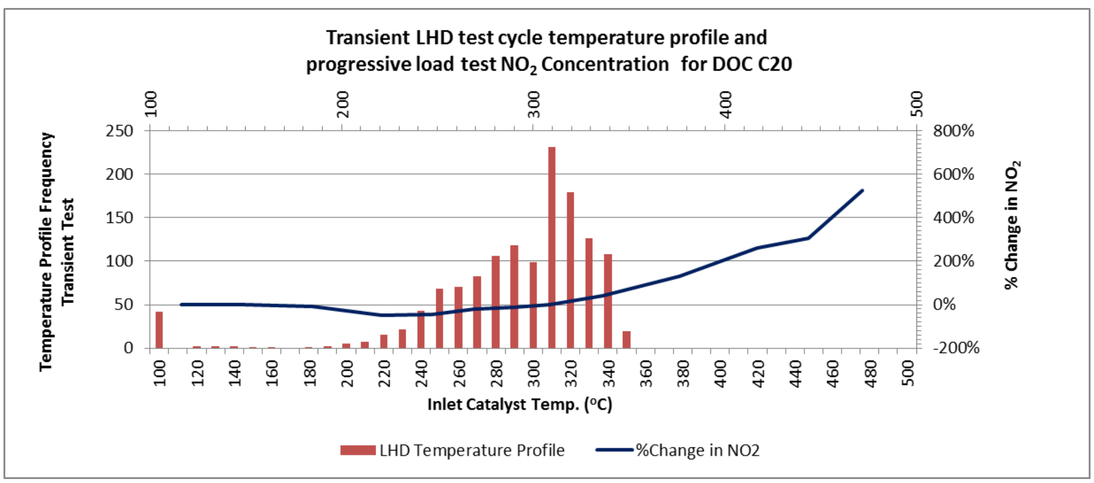




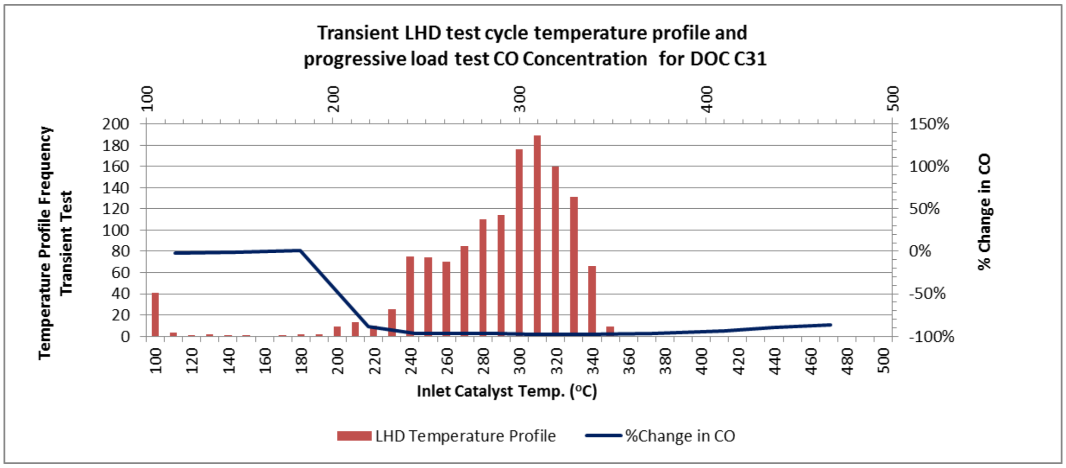
Transient Mine Vehicle Temperature Profile and Change in CO, THC and NO_2 under Progressive Load Testing for DOC C20

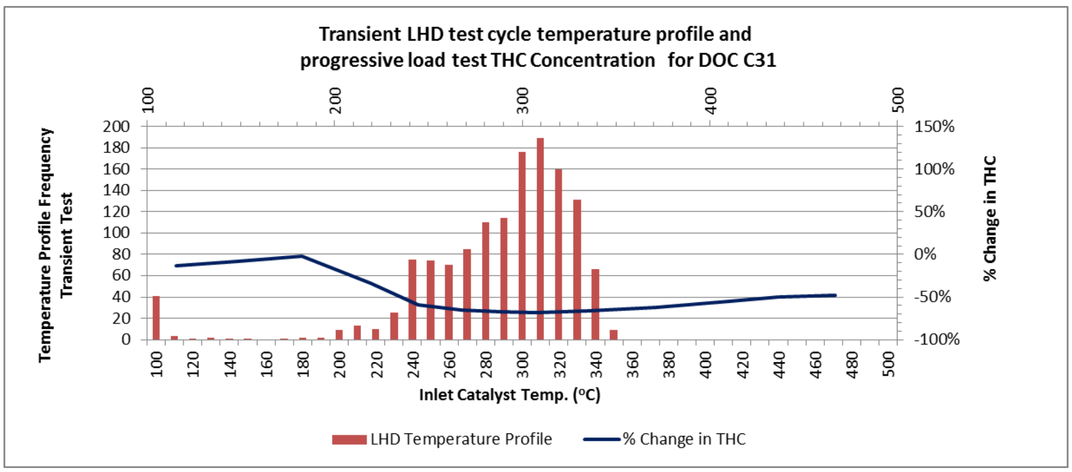


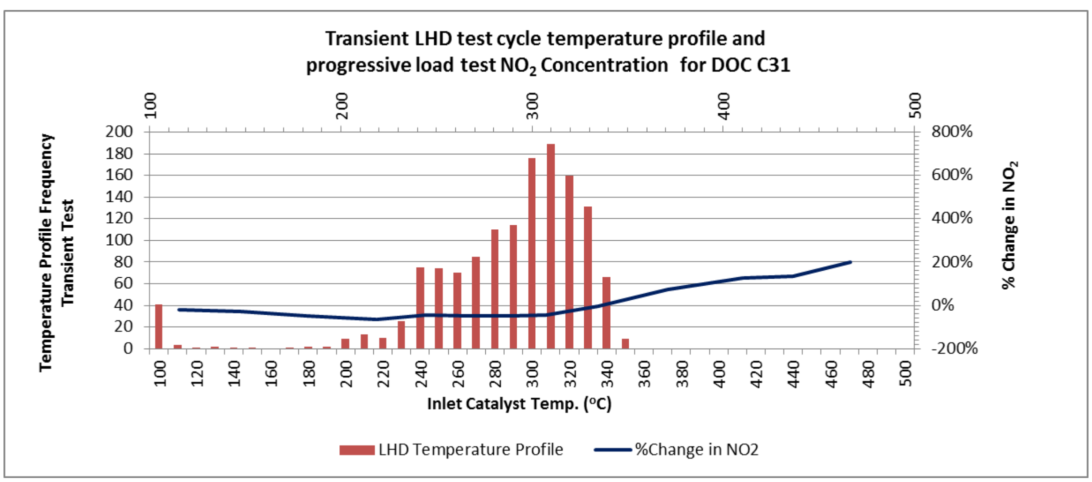




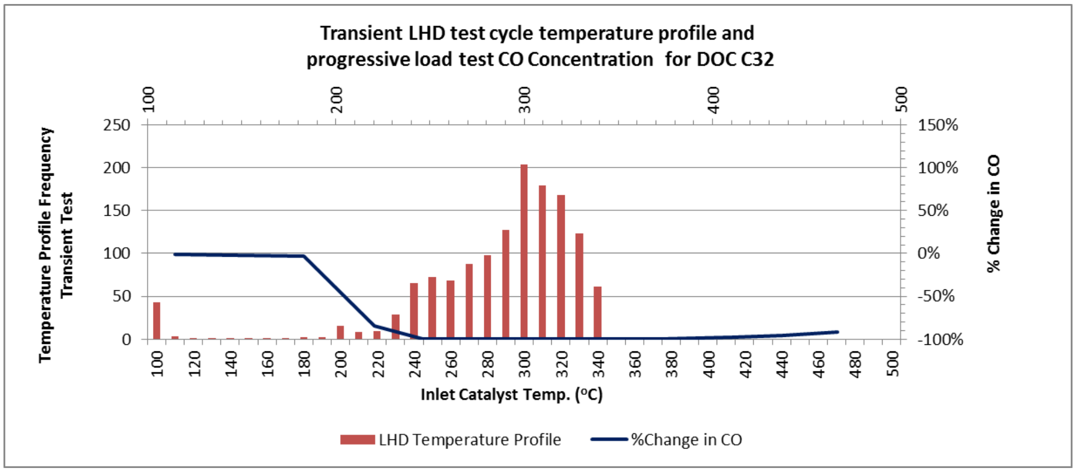
Transient Mine Vehicle Temperature Profile and Change in CO, THC and NO_2 under Progressive Load Testing for DOC C31

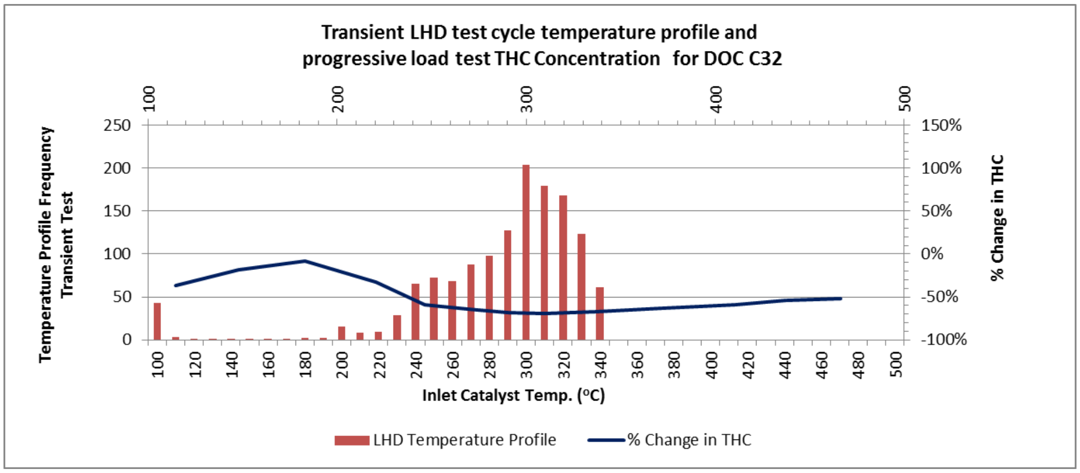


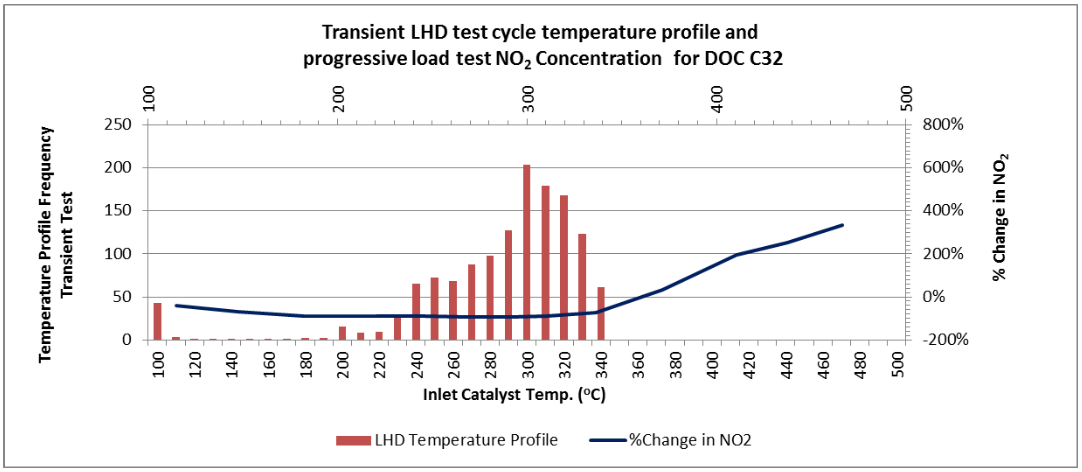




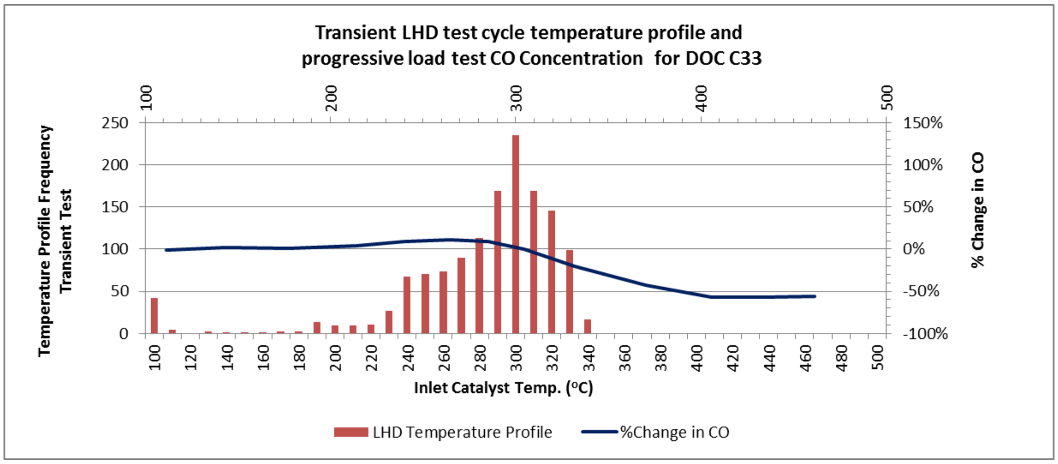
Transient Mine Vehicle Temperature Profile and Change in CO, THC and NO_2 under Progressive Load Testing for DOC C32

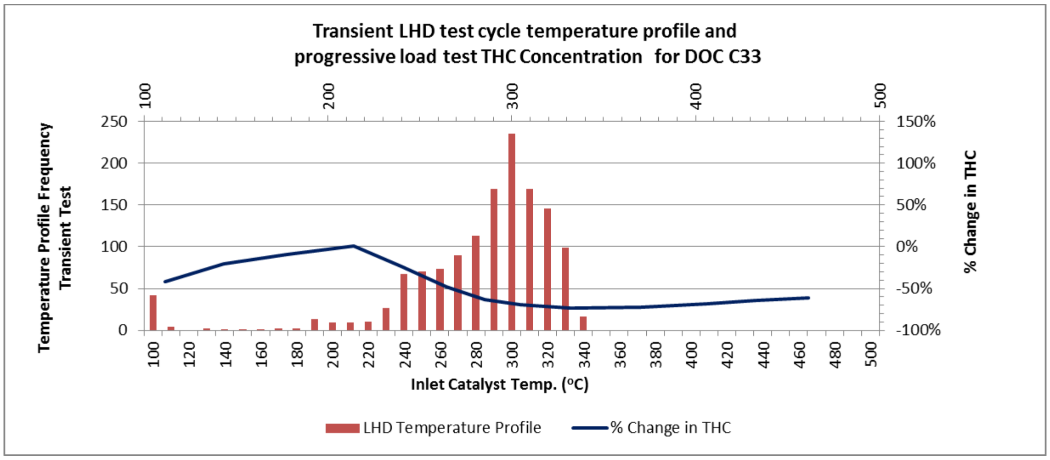


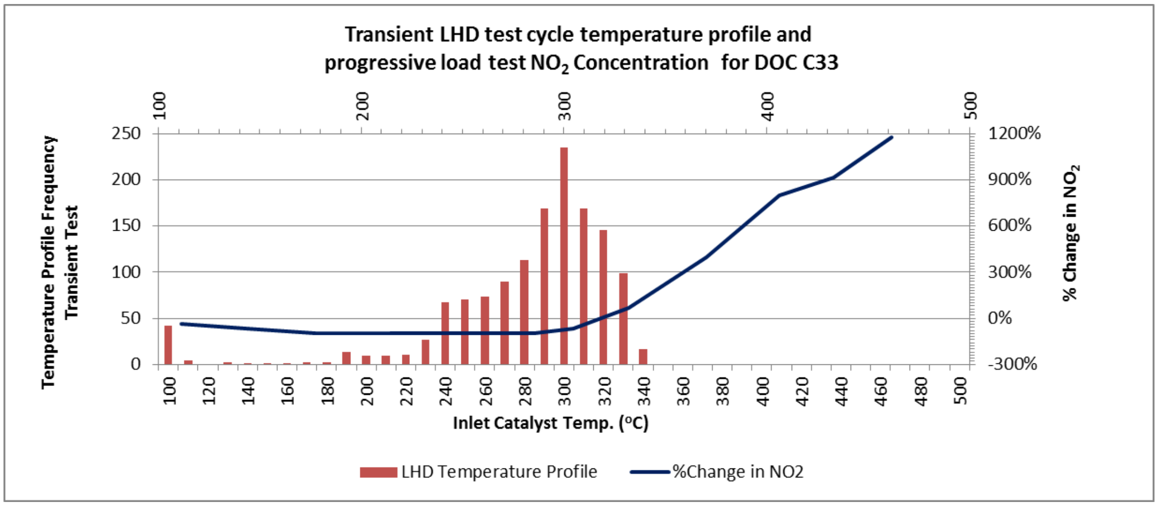




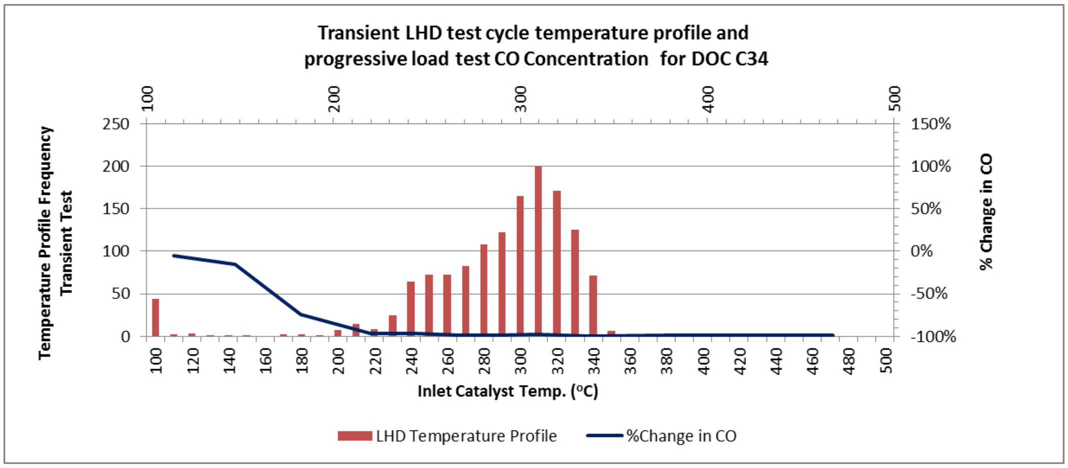
Transient Mine Vehicle Temperature Profile and Change in CO, THC and NO_2 under Progressive Load Testing for DOC C33

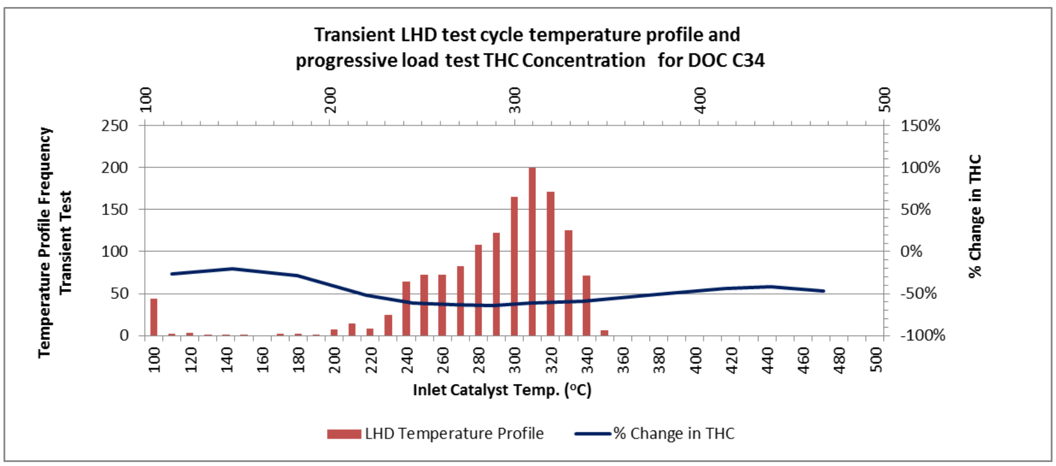


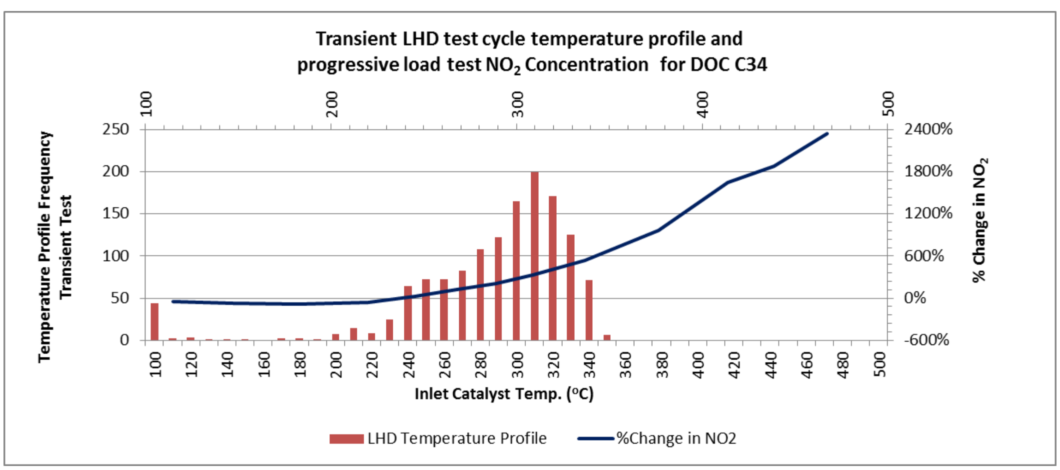




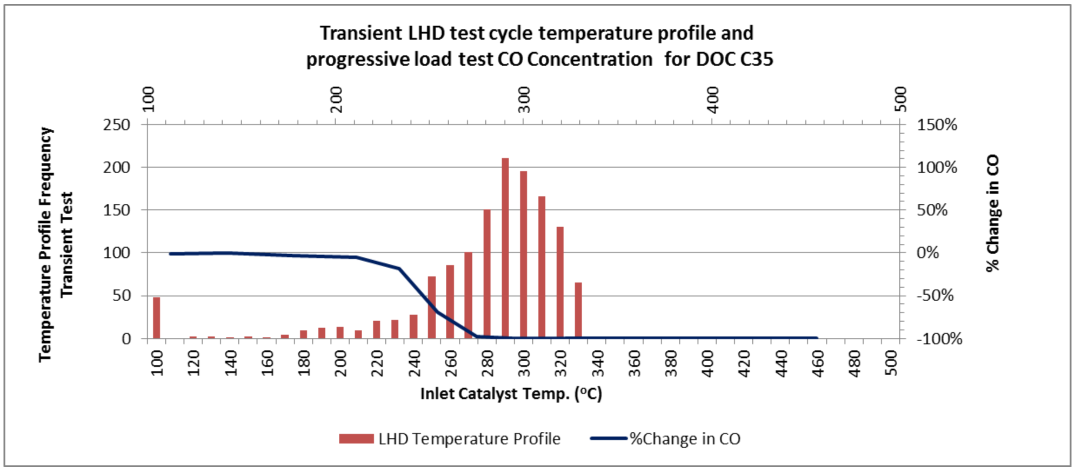
Transient Mine Vehicle Temperature Profile and Change in CO, THC and NO_2 under Progressive Load Testing for DOC C34

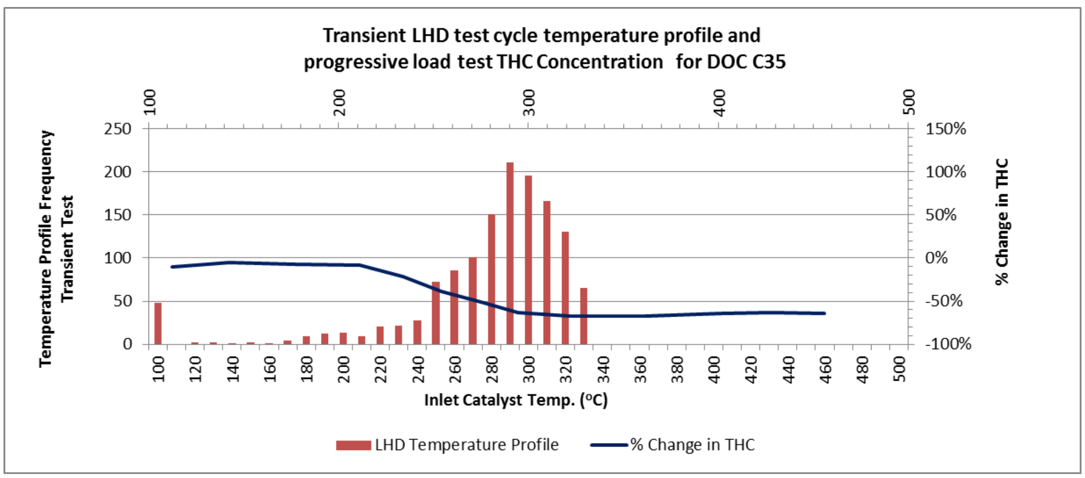


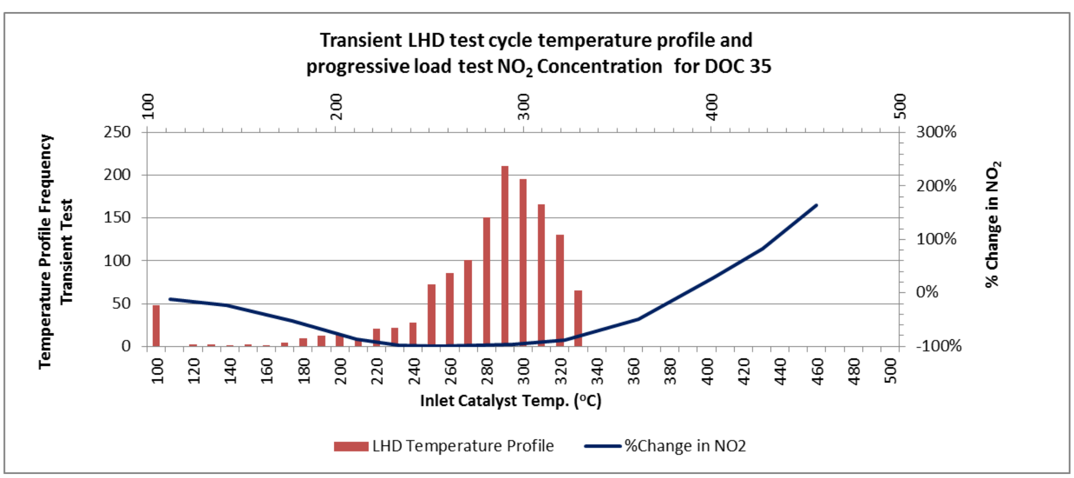




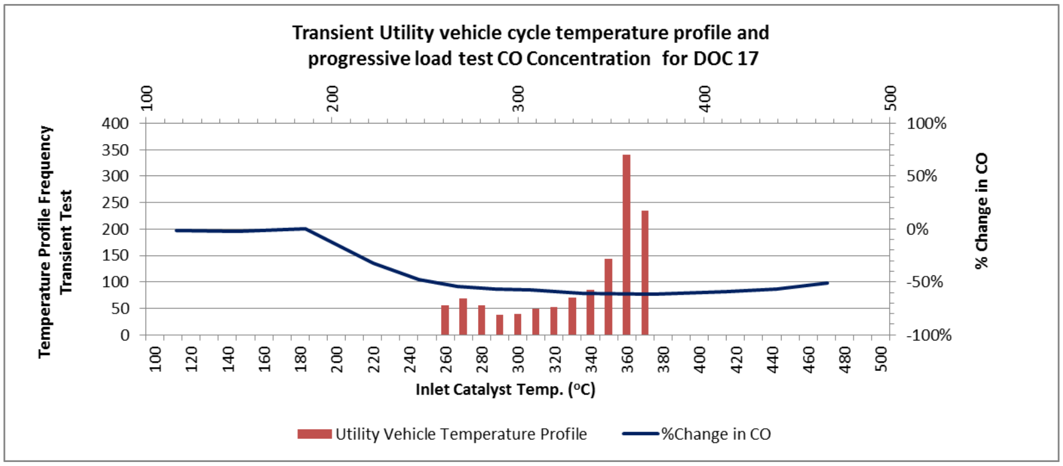
Transient Mine Vehicle Temperature Profile and Change in CO, THC and NO_2 under Progressive Load Testing for DOC C35

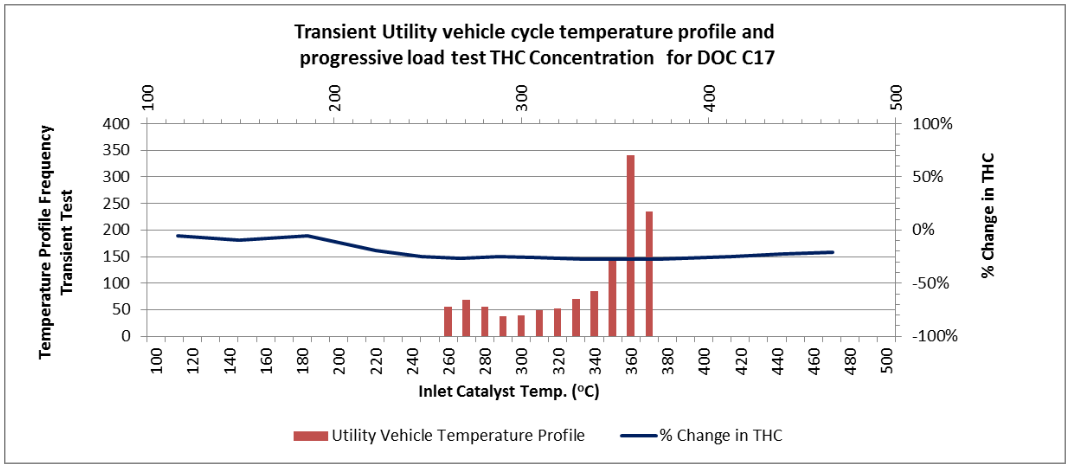


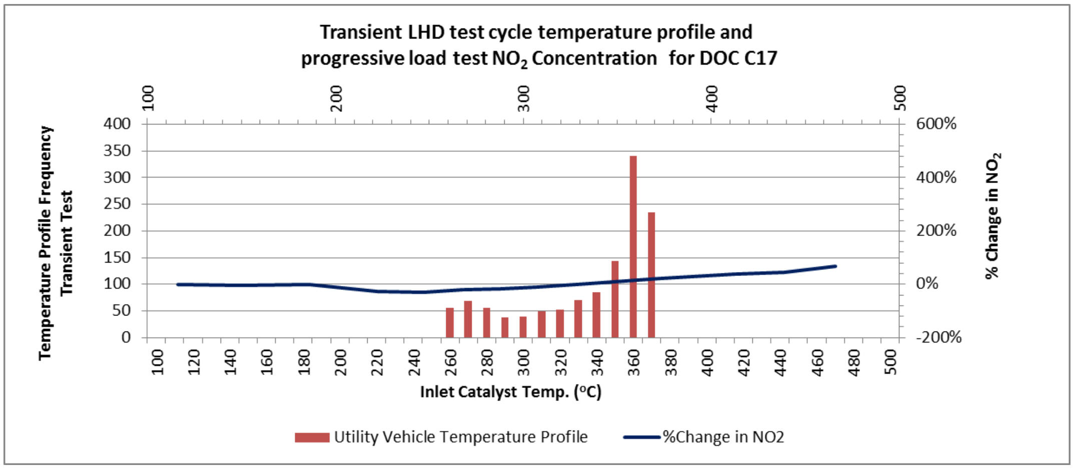




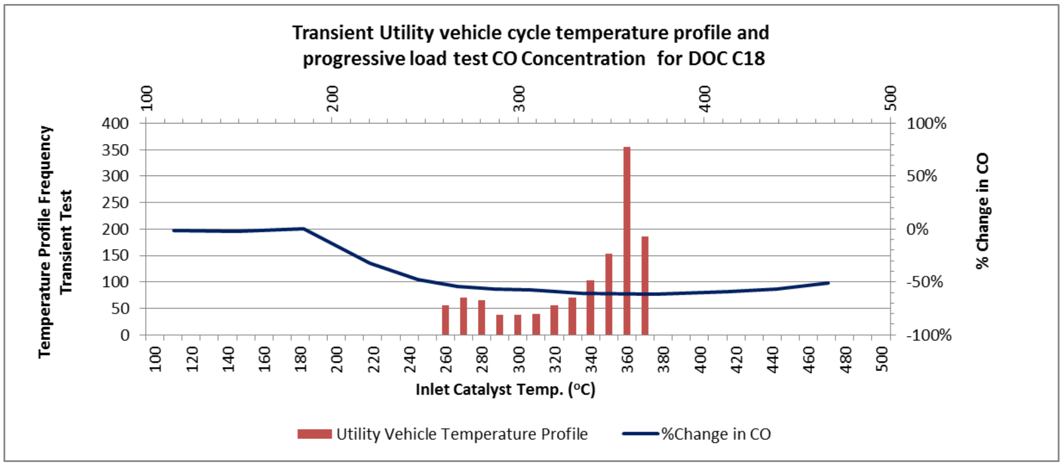
Transient Mine Vehicle Temperature Profile and Change in CO, THC and NO_2 under Progressive Load Testing for DOC C17

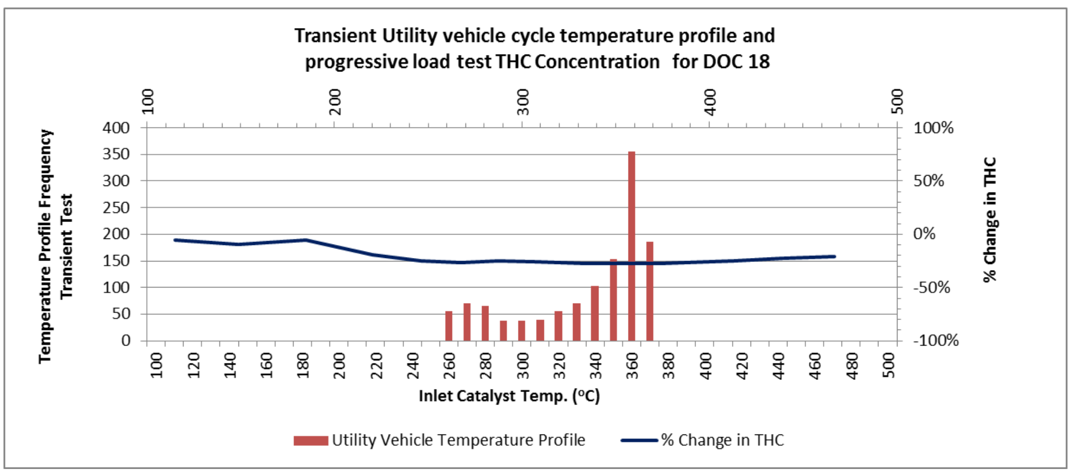


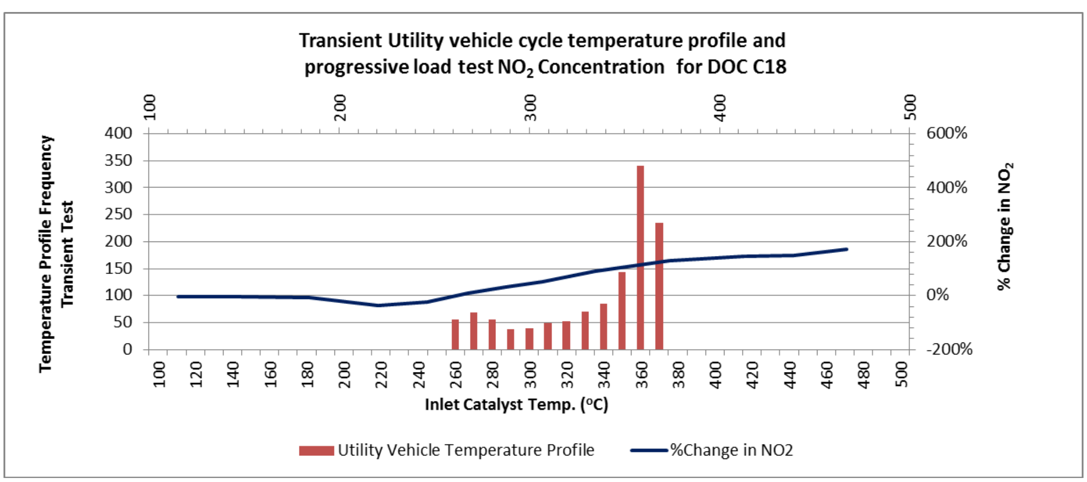




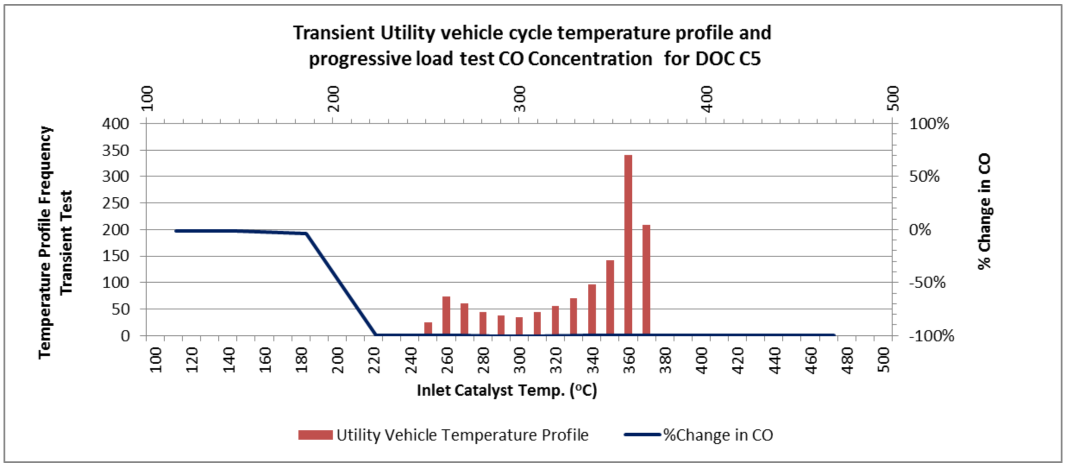
Transient Mine Vehicle Temperature Profile and Change in CO, THC and NO_2 under Progressive Load Testing for DOC C18

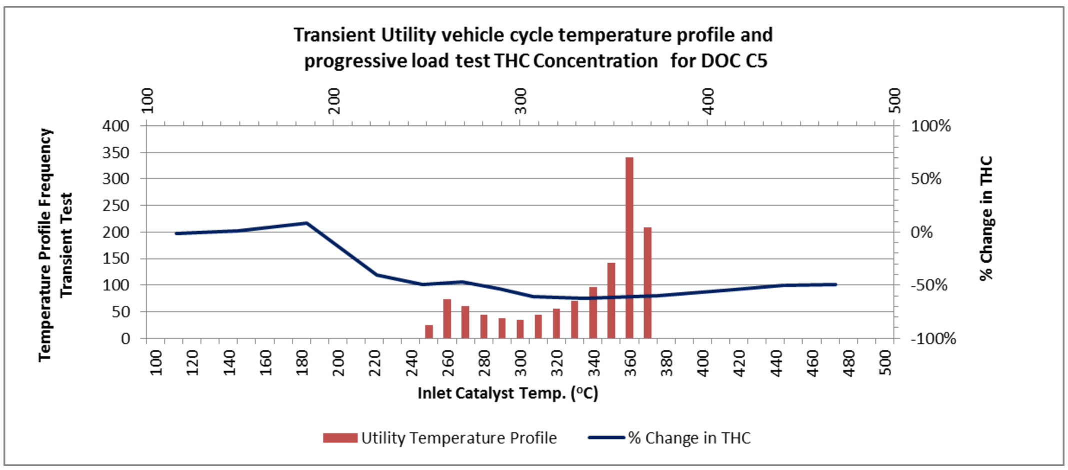


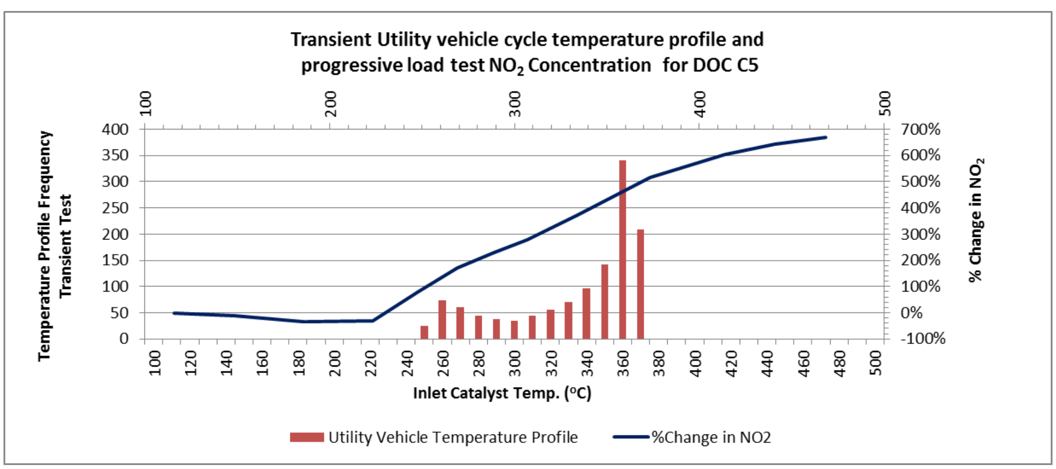




Transient Mine Vehicle Temperature Profile and Change in CO, THC and NO_2 under Progressive Load Testing for DOC C5







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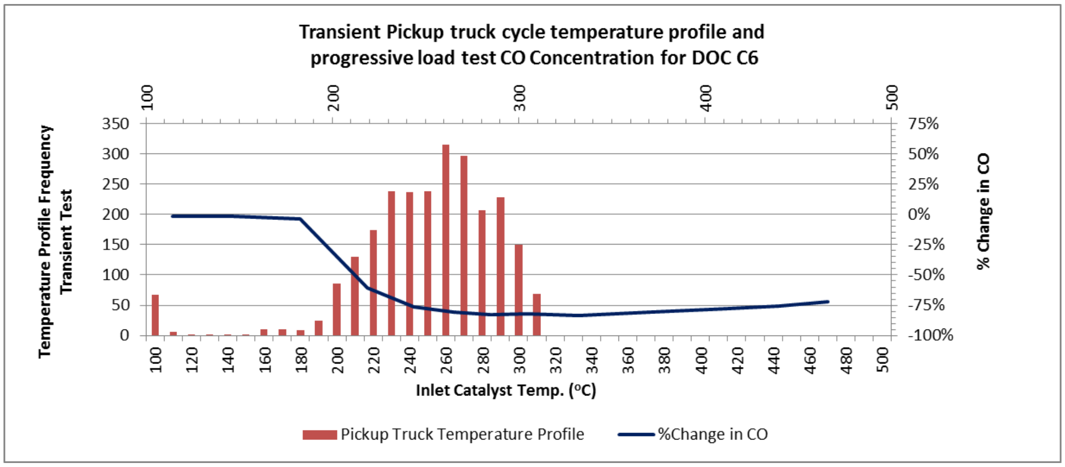
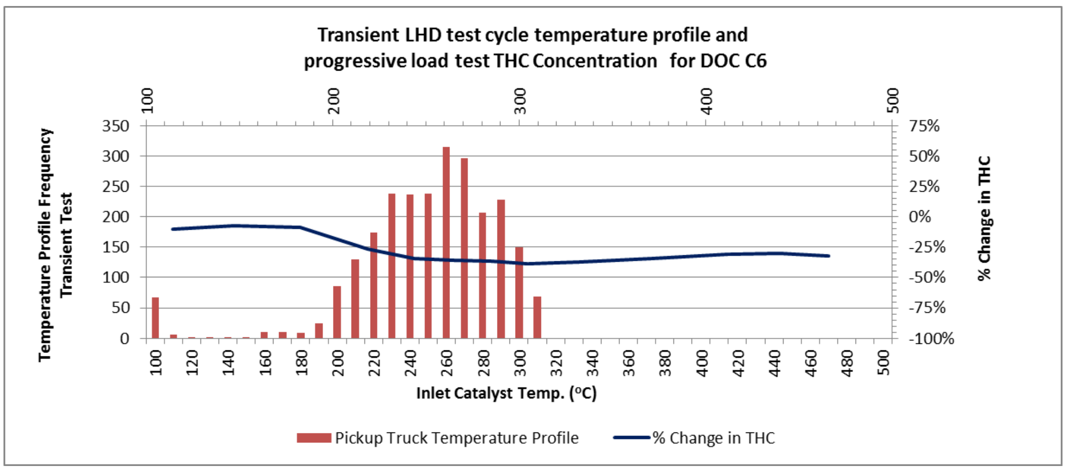
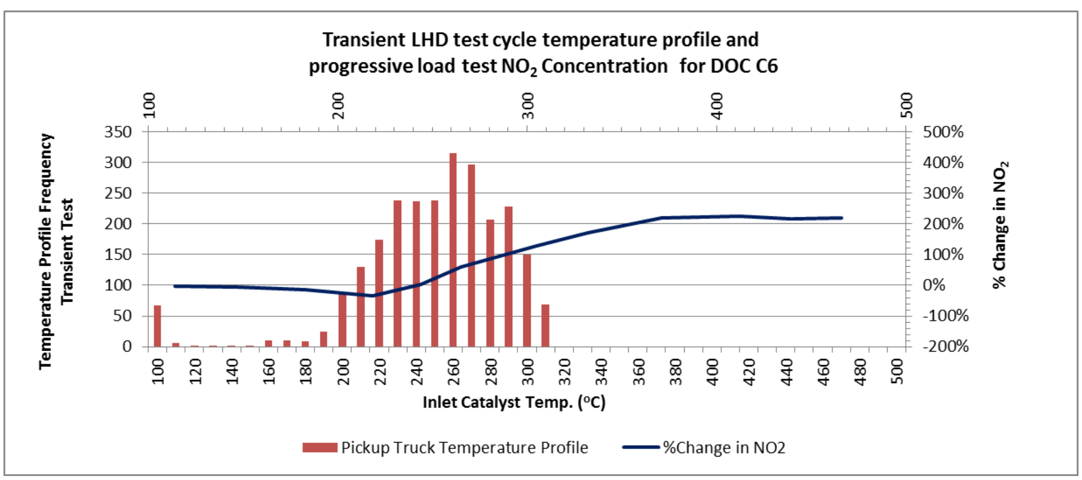
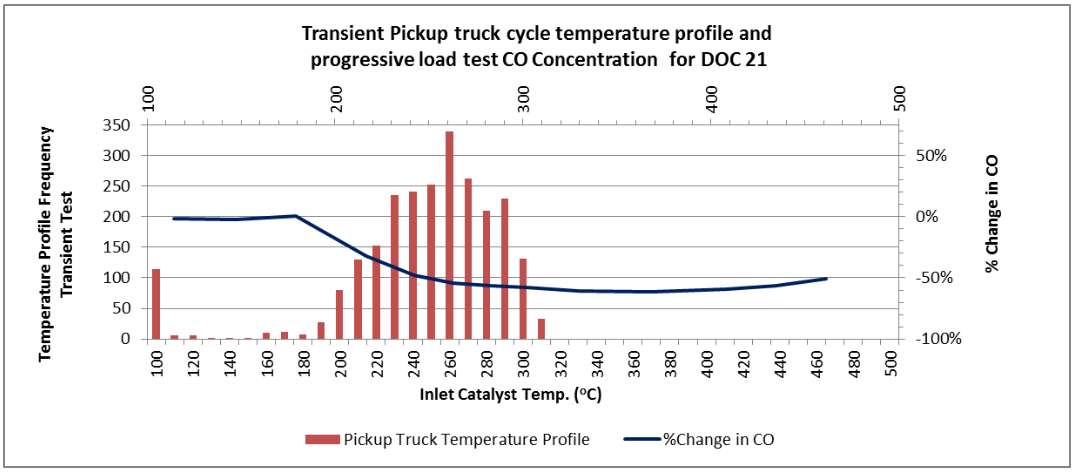
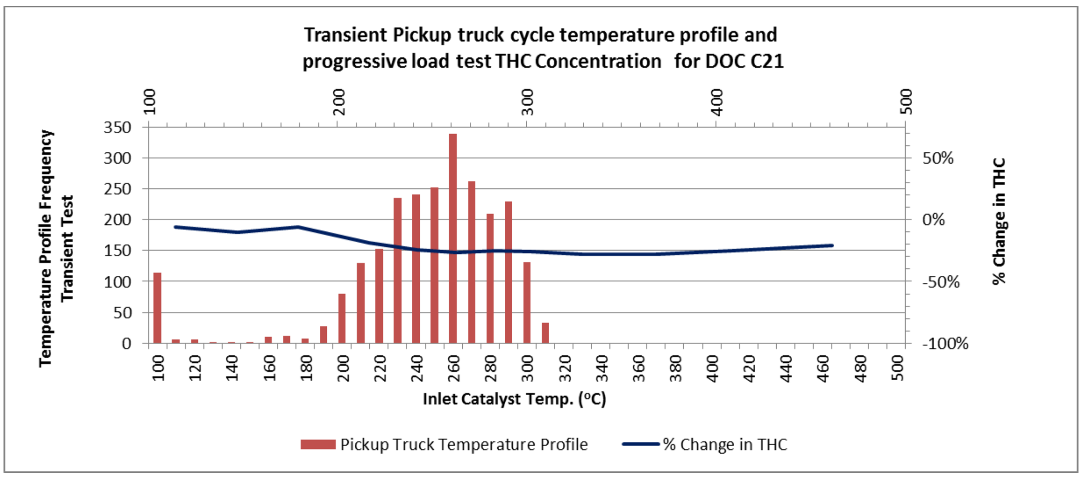


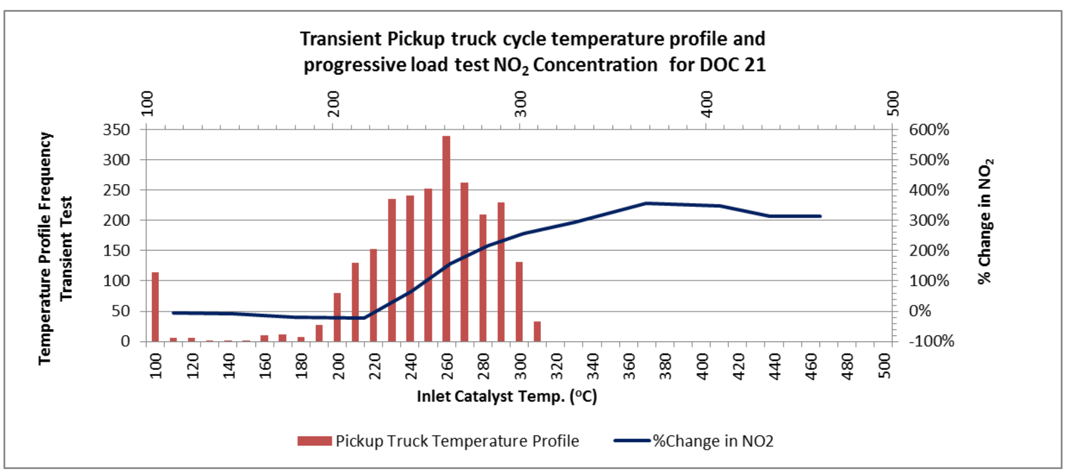




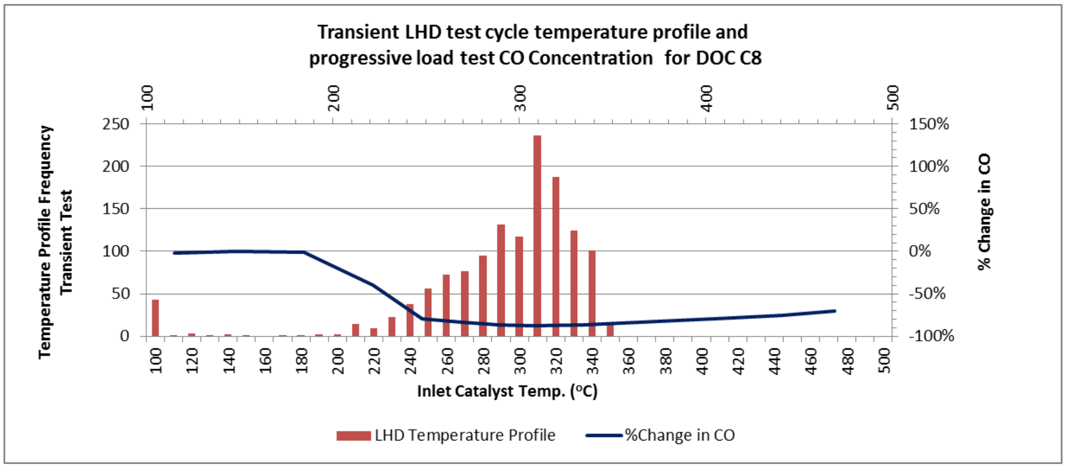
Transient Mine Vehicle Temperature Profile and Change in CO, THC and NO_2 under Progressive Load Testing for DOC C21

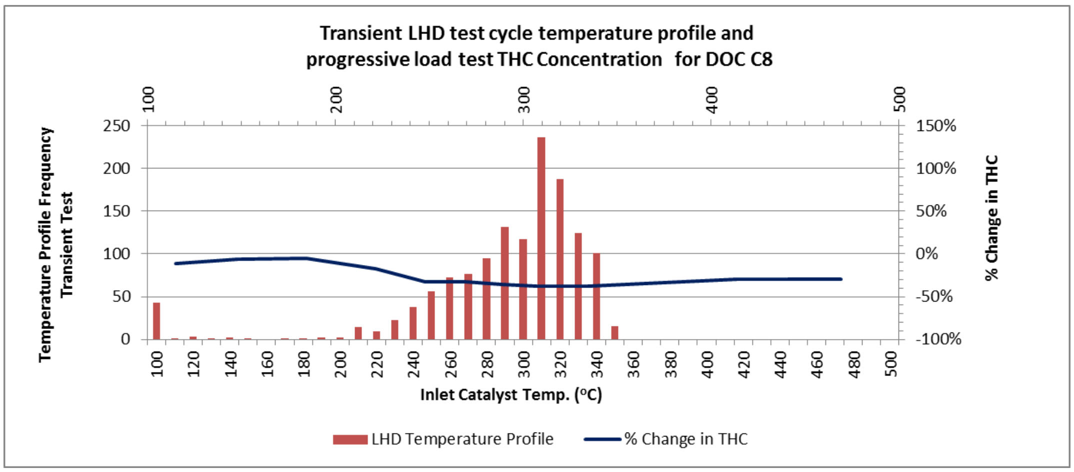


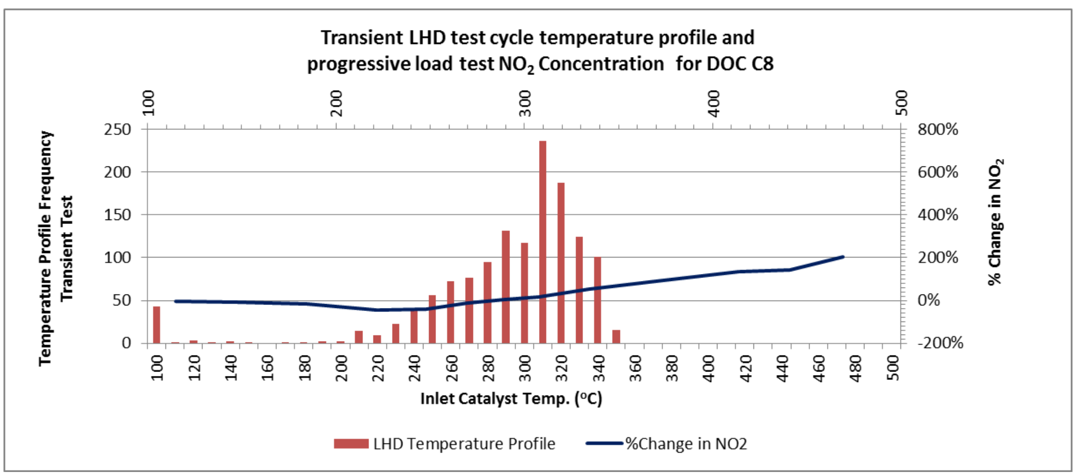




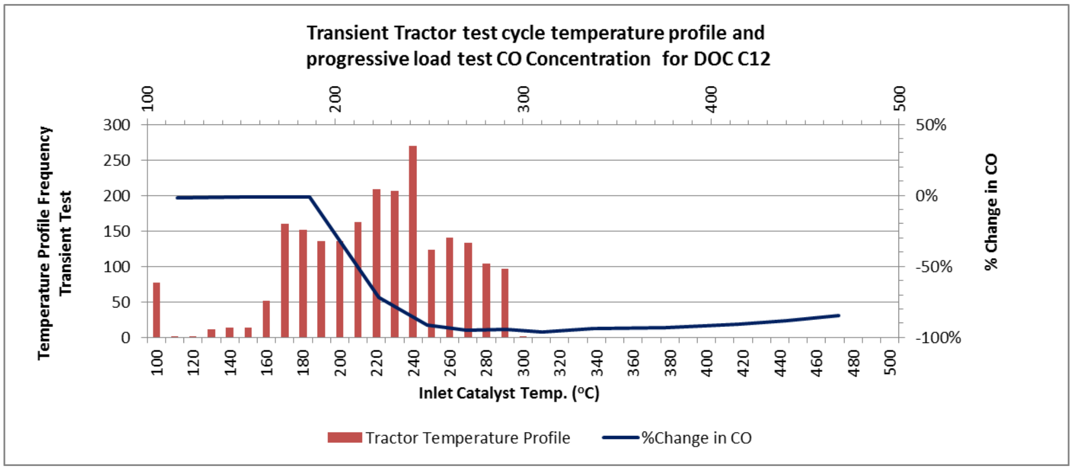
Transient Mine Vehicle Temperature Profile and Change in CO, THC and NO_2 under Progressive Load Testing for DOC C8

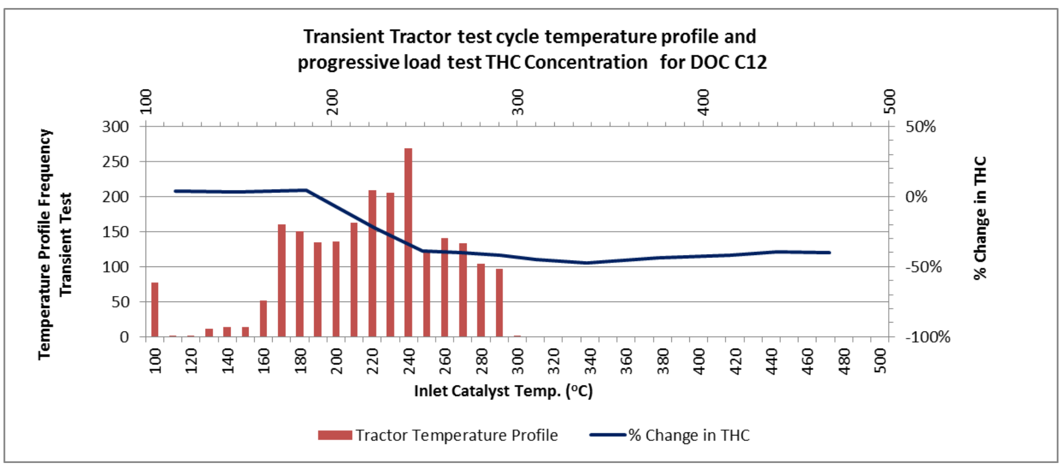


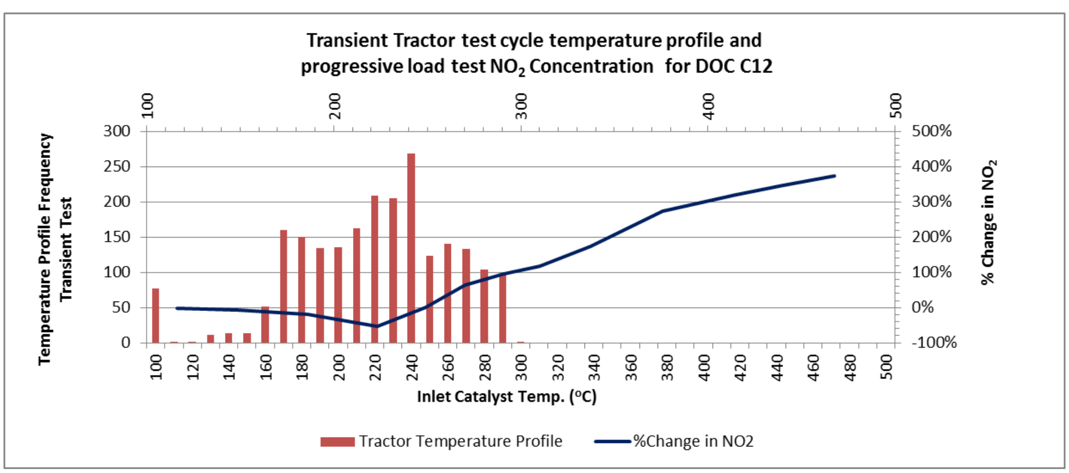




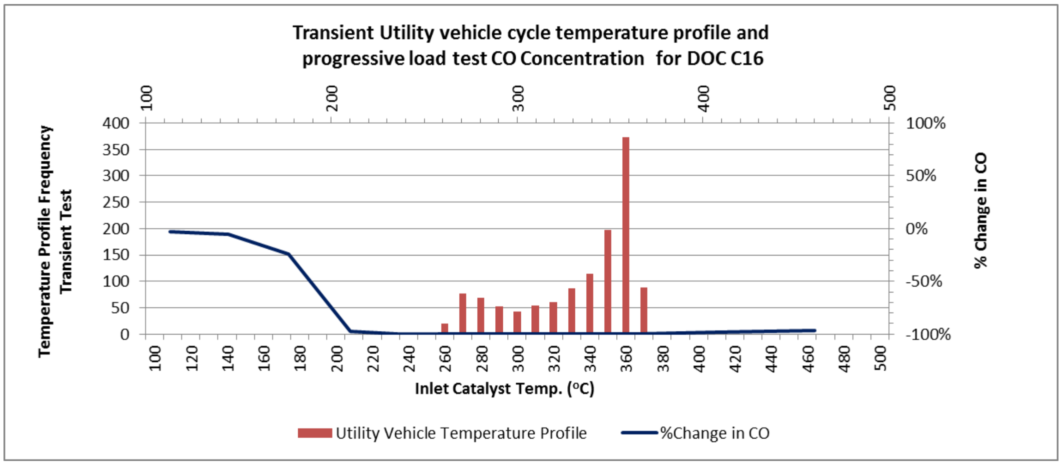
Transient Mine Vehicle Temperature Profile and Change in CO, THC and NO_2 under Progressive Load Testing for DOC C12

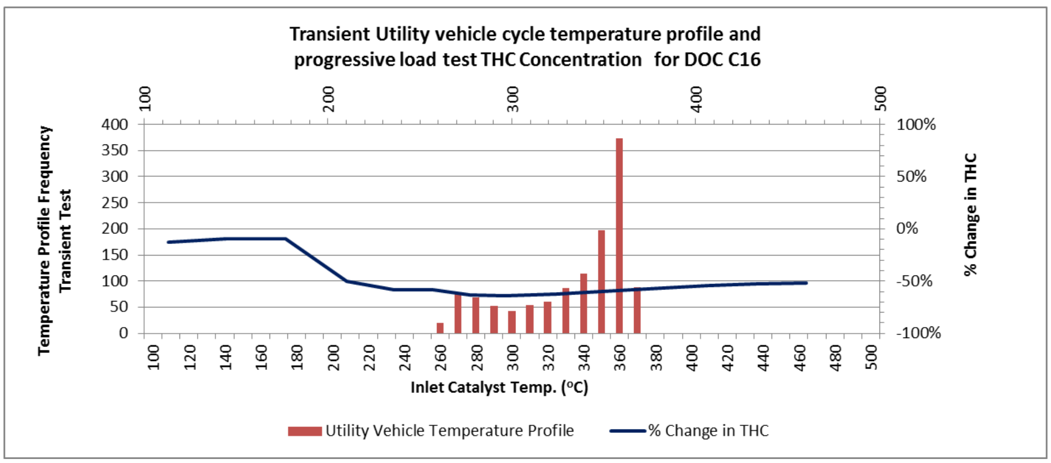


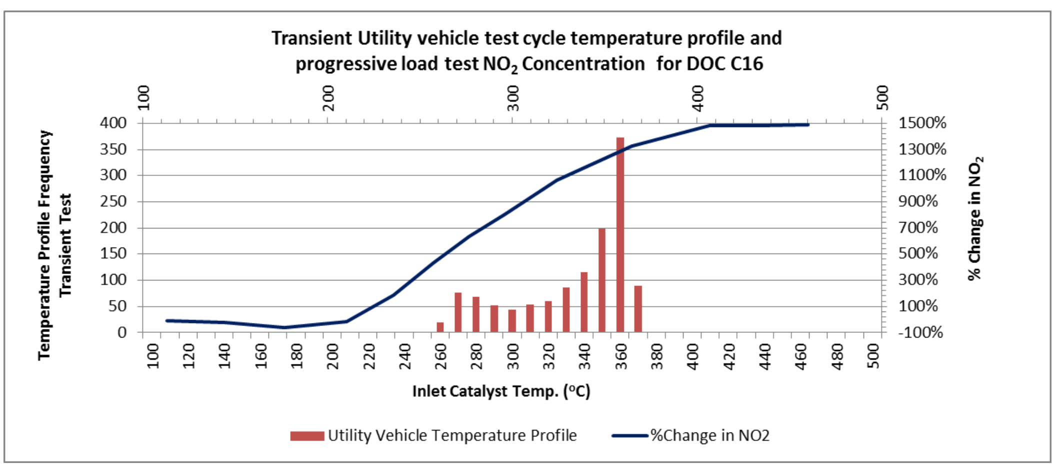




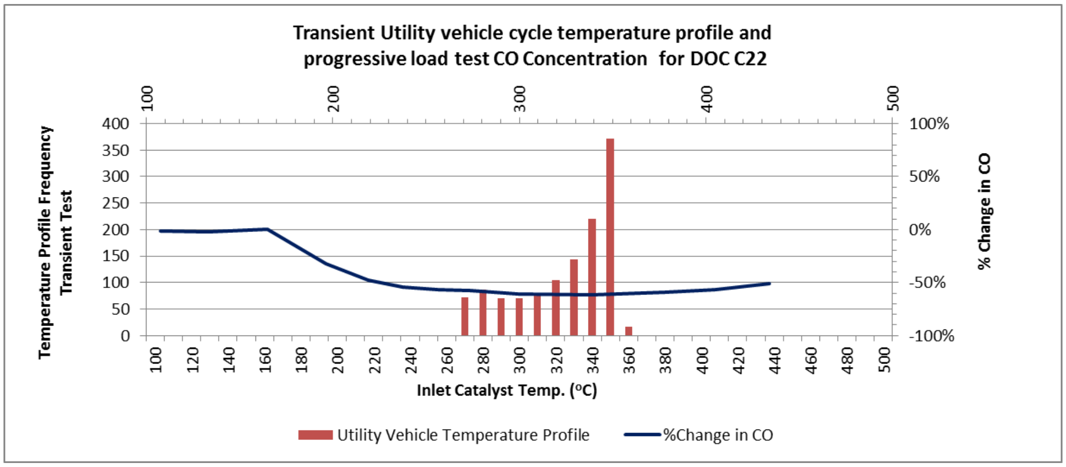
Transient Mine Vehicle Temperature Profile and Change in CO, THC and NO_2 under Progressive Load Testing for DOC C16

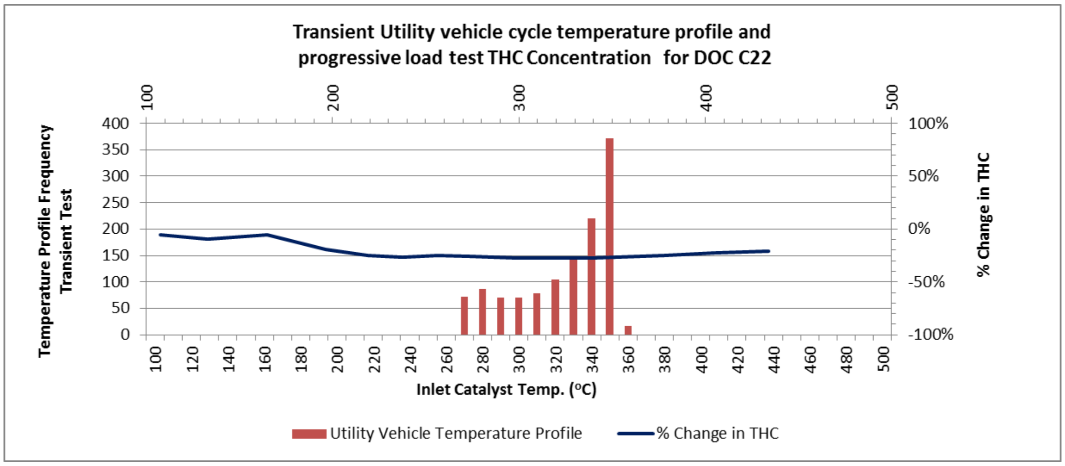


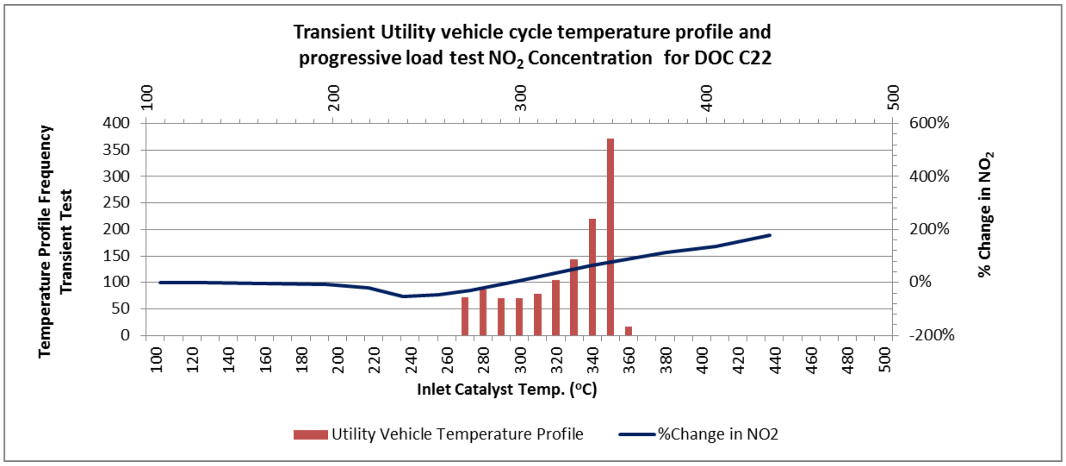




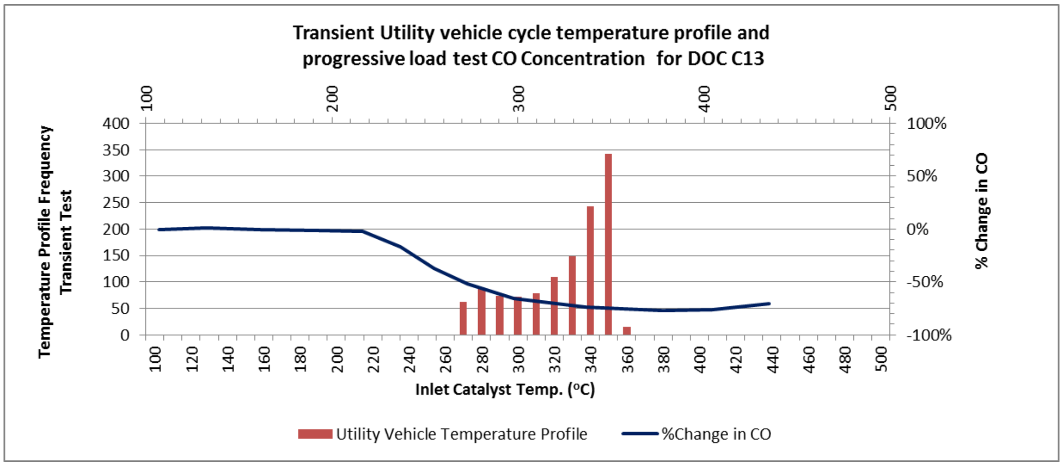
Transient Mine Vehicle Temperature Profile and Change in CO, THC and NO_2 under Progressive Load Testing for DOC C22

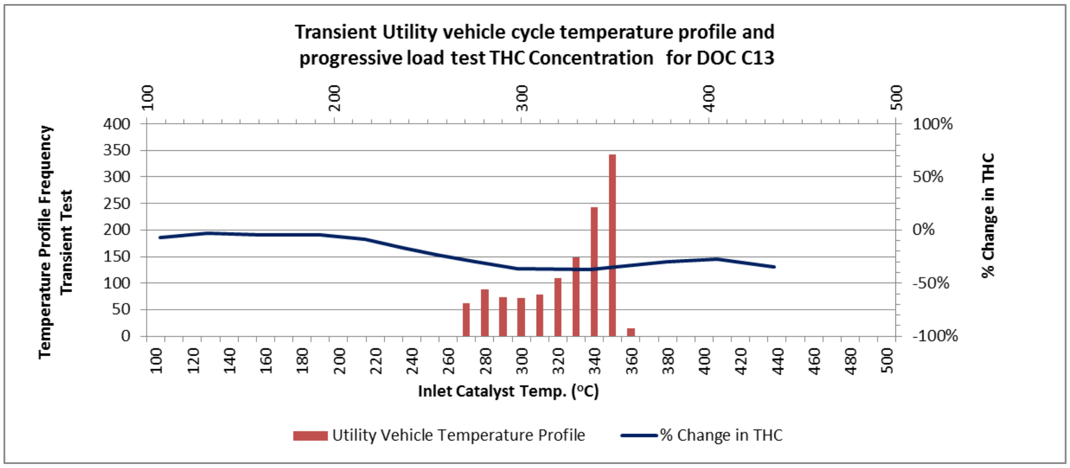


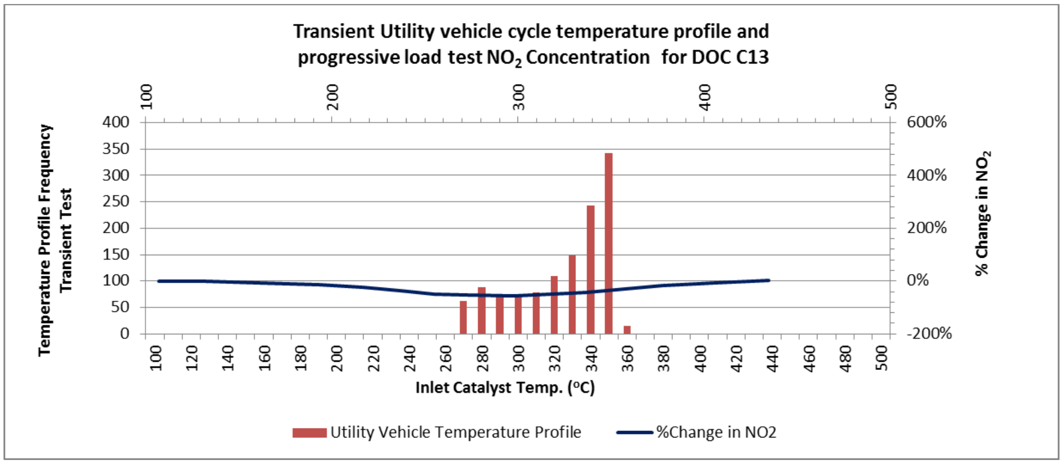




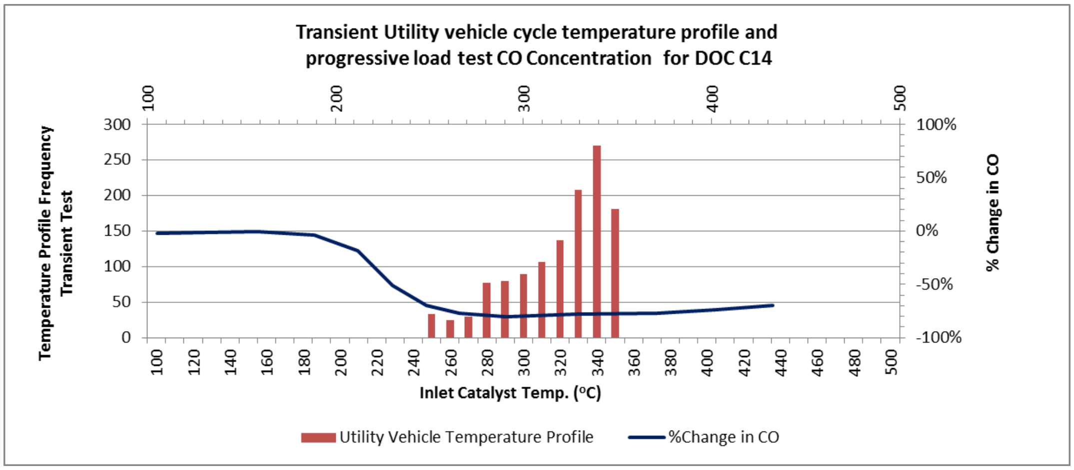
Transient Mine Vehicle Temperature Profile and Change in CO, THC and NO_2 under Progressive Load Testing for DOC C13

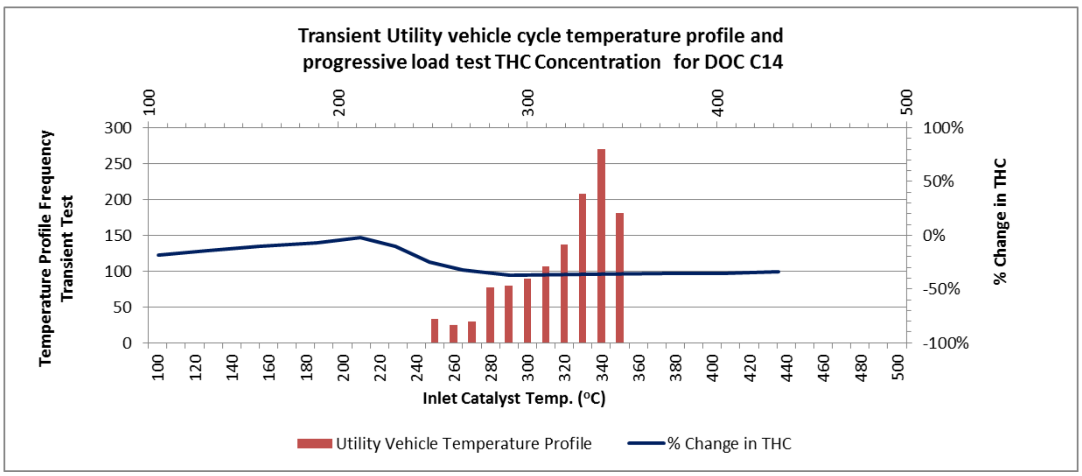


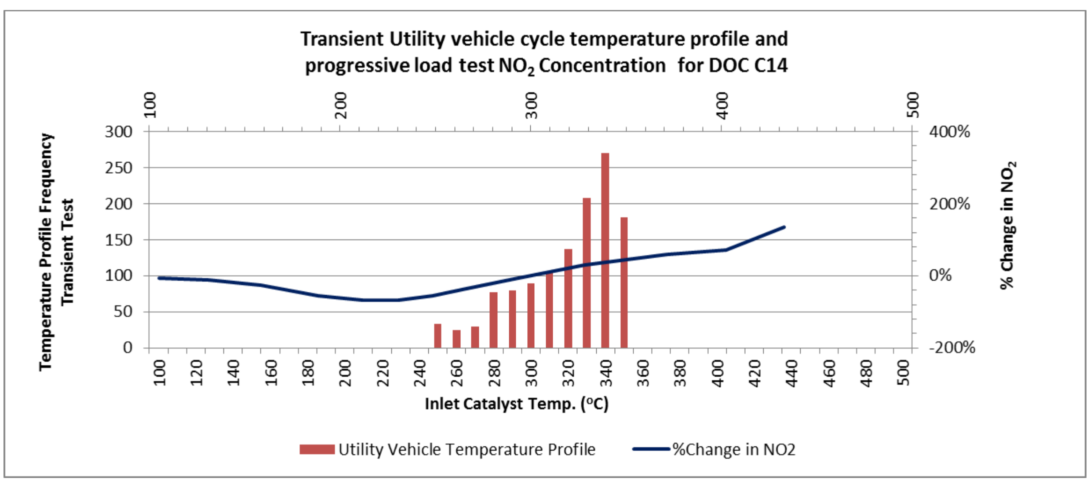




Transient Mine Vehicle Temperature Profile and Change in CO, THC and NO_2 under Progressive Load Testing for DOC C14







APPENDIX G

Estimation of Change in Specific Emissions Calculated from Transient Vehicle Temperature Profile and Progressive Load Test Emission

Estimating DOC Emissions from Transient Vehicle Cycle Temperature Profile

Providing a means to help assess engine and DOC application would be of benefit to users. In the field, diesel mining equipment produce a characteristic exhaust temperature profile related to its engine duty cycle. Knowing the exhaust temperature profile and progressive load test data, one can estimate change in emissions due to a DOC for a particular transient vehicle duty cycle.

The effect of a DOC on engine exhaust emissions has been described previously. Figures 10-12 were developed from the transient vehicle temperature profile and the 13 progressive load test points, with each point having the associated specific gas emissions for both the engine (baseline) and DOC steady state conditions. Each of these 13 DOC inlet temperatures were aligned with the 40 temperature bins (e.g. 100-110, 110-120, …..490-500) used to build test cycle temperature profile. Missing data of specific emission values were interpolated between the known 13 points following a linear model to construct the specific emission tables. These examples were prepared for four typical DOCs (C3, C32, C16 and C6) and are shown in this Appendix G. It also incorporates the bin temperature range and temperature tally counts per bin, derived from the analysis of the progressive load and transient duty cycle temperatures measurement. The shaded areas represent interpolated values.

An estimate of the specific emissions for a complete duty cycle would depend on the time spent at each bin temperature throughout the cycle. The time spent at any particular temperature, was derived from a vehicle cycle temperature histogram which provides a means to assess the time that the DOC was exposed to any particular temperature. Given the cycle time and specific emissions at any one temperature, one can estimate the portion of that specific emission to the overall cycle. An estimate of cycle specific emission was derived by summing up each individual portion for the entire cycle.

Appendix G presents a matrix of the specific emissions apportioned per temperature bin per duty cycle for DOCs C3 and C32 (LHD), C16 (Utility), and C6 (Pick-up). The estimated specific emission per individual gas emissions per cycle was the sum of all portions within each gases respective column. By comparing engine baseline and DOC estimates, one can then compare the relative engine baseline to DOC emissions. In addition, comparing the estimated specific emissions per cycle with actual transient duty cycle test values, helped validate this method.

As an example, a summary of the estimates of specific emissions for CO_2 and NO_2 per duty cycle versus laboratory measured transient test values, for DOCs (C3, C32, C16, and C6) are shown in Table 6. In this table, measured values of specific emissions for the transient duty cycle are taken from Appendix E, while estimated values are taken from the tables of Appendix G. The space velocity for DOCs C3, C32, C16 and C6 are calculated at 235,000h^{-1}; 125, 000h^{-1}; 380, 000h^{-1} and 300, 000h^{-1}.

Table 6 – Average specific CO_2 and NO_2 emission estimates versus laboratory measured values

	CO_2						NO_2					
DOC	Engine Baseline	Transient DOC	Diff	Engine Baseline	Transient DOC	Diff	Engine Baseline	Transient DOC	Diff	Engine Baseline	Transient DOC	Diff
	Measured			Estimated			Measured			Estimated		
	g/kWh	g/kWh	%	g/kWh	g/kWh	%	g/kWh	g/kWh	%	g/kWh	g/kWh	%
C3 (LHD)	706.1	685.8	-3%	660.3	659.9	0%	0.40	0.53	32%	0.44	0.71	60%
C32 (LHD)	706.6	720.2	2%	666.4	666.9	0%	0.40	0.08	-81%	0.43	0.18	-58%
C6 (Pick-up)	890.8	910.5	2%	711.5	720.1	1%	0.62	1.26	102%	0.64	0.76	18%
C16 (Utility)	752.1	755.2	0%	635.9	636.9	0%	0.33	1.82	446%	0.24	2.33	875%

It is interesting to note that the estimated percent difference for CO_2 is within 3% of the measured values for these DOCs. The reason is that DOCs do not change CO_2 emissions; nevertheless it shows that the above method for estimation is reasonable. Figure 12 shows the relative amounts of NO_2 increase versus DOC C3 catalyst inlet temperature. Transient engine testing confirmed that DOC C3 caused a net increase in NO_2 (32%); this method estimate a net increase in NO_2 of 60%. DOCs C32, C16, and C6 showed similar trends, although values were much different, showing that the different types of catalyst formulations produce significant differences in emissions. In addition, the engineering of each DOC for the required vehicle application may affect emissions depending on the design performance and cost targets.

Since the DOC substrate is required to have sufficient volume to enable a catalytic process, it has thermal inertia. Heat can be stored and released by the substrate depending on the difference between the average substrate core temperature and the instantaneous engine exhaust temperature. This inertia can affect the transient test results. In addition, the internal volume of the DOC affects emissions performance. This is known as "space velocity (SV)" which is the inverse of residence time described earlier. A smaller volume (higher space velocity) means less time available for the catalytic reaction to take place. This can limit the ability of the DOC to work under cycles where the exhaust flow is high.

In Table 6, the best agreement with the model was found at low DOC space velocities. As the space velocity (SV) increased, the agreement with the model becomes poorer. This is possibly due to the effects of thermal inertia and space velocity. Future work on predicting DOC performance will require including SV and thermal inertia effects.

Using this method, steady state and progressive load torques are used to derive specific emission and exhaust temperatures (Appendix G). In reality, temperatures and specific emissions vary in real-time throughout a transient cycle by any combinations of engine speed and load over the engines operating range. Moreover, the temperature histogram does not provide details on the duration of any consecutive temperature measurements nor the amplitude. The ultimate temperature at the surface of the catalyst could very well be different even if the transient and steady state temperature were the same. Moreover, exhaust mass flow rate through the DOC would also impact on the rate of conversion of some gases, adding another level of complexity when comparing steady state and transient conditions. The purpose of this simplified method was to place a numeric value on the data as presented in Figure 12 and others like it, and to demonstrate trends in emissions that are relatively close to those measured in the field. It was not to be used to predict real time transient emissions. This method can ultimately be used to provide an aid to end users when selecting a DOC device for any engine and DOC application.

Estimation of Change in Specific Emissions Calculated from Transient Vehicle Temperature Profile and Progressive Load Test Emission for DOC C3

Exhaust Temperature Profile			Progressive Load Specific Emission - Before DOC C3						Progressive Load Specific Emission - After DOC C3					
Bin Temperature Range	Progressive Load Bin Tally	Transient cycle Bin Tally	DOC Inlet Temperature	CO_2	CO	NO_2	NO	THC	DOC Inlet Temperature	CO_2	CO	NO_2	NO	THC
(^oC)	*Frequency*		(^oC)	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh	(^oC)	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh
100	0	0	96	4136	65.70	13.05	33.68	20.16	95	4107	64.20	12.35	33.68	17.26
110	0	1	106	3504	54.03	10.86	28.60	16.47	106	3482	52.82	10.24	28.65	14.14
120	2	3	117	2873	42.35	8.66	23.53	12.78	117	2858	41.44	8.12	23.63	11.01
130	0	2	127	2241	30.68	6.46	18.45	9.09	128	2234	30.06	6.00	18.60	7.88
140	0	0	137	1610	19.00	4.26	13.38	5.41	139	1609	18.68	3.88	13.57	4.76
150	2	1	148	978	7.33	2.06	8.30	1.72	150	985	7.30	1.76	8.55	1.63
160	0	1	156	931	6.28	1.85	7.89	1.46	158	938	6.25	1.52	8.15	1.40
170	0	1	165	885	5.22	1.63	7.48	1.21	167	891	5.20	1.27	7.76	1.17
180	0	1	174	838	4.17	1.41	7.08	0.96	176	844	4.16	1.03	7.37	0.93
190	2	2	182	791	3.12	1.19	6.67	0.70	185	797	3.11	0.79	6.98	0.70
200	0	3	194	761	2.50	1.04	6.27	0.59	194	774	2.39	0.68	6.66	0.59
210	0	13	206	731	1.88	0.90	5.86	0.48	203	751	1.66	0.57	6.35	0.47
220	1	10	218	701	1.26	0.75	5.46	0.37	212	728	0.94	0.46	6.04	0.35
230	1	24	227	695	1.13	0.69	5.36	0.34	221	705	0.22	0.35	5.73	0.23
240	0	66	236	689	0.99	0.63	5.26	0.31	234	693	0.13	0.47	5.41	0.18
250	2	71	245	683	0.85	0.57	5.16	0.28	246	681	0.05	0.60	5.09	0.12
260	0	71	256	675	0.75	0.52	5.06	0.26	257	670	0.04	0.66	4.88	0.11
270	2	89	267	666	0.65	0.47	4.97	0.24	268	658	0.02	0.72	4.67	0.09
280	0	105	277	652	0.59	0.42	4.83	0.22	278	652	0.02	0.70	4.58	0.08
290	2	119	287	638	0.52	0.38	4.68	0.20	288	646	0.02	0.69	4.49	0.07
300	0	140	297	640	0.50	0.36	4.66	0.19	298	643	0.25	0.70	4.56	0.13
310	2	209	306	642	0.48	0.34	4.63	0.18	307	639	0.48	0.70	4.63	0.18
320	0	181	315	636	0.45	0.32	4.59	0.17	316	633	0.32	0.71	4.49	0.14
330	0	125	324	631	0.43	0.29	4.55	0.16	325	628	0.16	0.71	4.35	0.10
340	2	82	333	625	0.41	0.27	4.50	0.15	334	622	0.01	0.72	4.21	0.06
350	0	9	342	623	0.42	0.25	4.51	0.14	343	621	0.01	0.72	4.18	0.06
360	0	0	352	621	0.43	0.23	4.51	0.13	353	620	0.01	0.72	4.16	0.06
370	0	0	361	620	0.44	0.21	4.52	0.12	362	619	0.02	0.71	4.13	0.05
380	2	0	370	618	0.44	0.19	4.52	0.11	371	618	0.02	0.71	4.11	0.05
390	0	0	383	616	0.51	0.18	4.60	0.10	381	619	0.03	0.70	4.17	0.05
400	0	0	397	614	0.57	0.17	4.69	0.09	391	619	0.03	0.68	4.22	0.05
410	1	0	410	611	0.63	0.15	4.77	0.08	401	620	0.04	0.67	4.28	0.05
420	1	0	419	609	0.68	0.15	4.79	0.08	411	621	0.04	0.65	4.34	0.04
430	0	0	428	607	0.72	0.14	4.82	0.07	424	613	0.06	0.62	4.42	0.04
440	2	0	437	605	0.76	0.13	4.84	0.07	437	605	0.07	0.58	4.49	0.04
450	0	0	447	604	0.72	0.12	4.86	1.67	447	605	0.07	0.56	4.55	0.04
460	0	0	456	602	0.68	0.11	4.87	3.28	457	604	0.07	0.55	4.61	0.04
470	2	0	465	600	0.64	0.10	4.88	4.88	466	604	0.07	0.53	4.67	0.04
480	0	0												
490	0	0												
500	0	0												
Total	26	1329	Interpolated Values											

Estimation of Change in Specific Emissions Calculated from Transient Vehicle Temperature Profile and Progressive Load Test Emission for DOC C3

Exhaust Temperature Profile			Progressive Load Specific Emission - Before DOC C3 Weighted					Progressive Load Specific Emission - After DOC C3 Weighted				
Bin Temperature Range	Progressive Load Bin Tally	Transient Bin Tally	CO_2	CO	NO_2	NO	THC	CO_2	CO	NO_2	NO	THC
(^oC)	*Frequency*		g/kWh	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh
100	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
110	0	1	2.64	0.04	0.01	0.02	0.01	2.62	0.04	0.01	0.02	0.01
120	2	3	6.49	0.10	0.02	0.05	0.03	6.45	0.09	0.02	0.05	0.02
130	0	2	3.37	0.05	0.01	0.03	0.01	3.36	0.05	0.01	0.03	0.01
140	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
150	2	1	0.74	0.01	0.00	0.01	0.00	0.74	0.01	0.00	0.01	0.00
160	0	1	0.70	0.00	0.00	0.01	0.00	0.71	0.00	0.00	0.01	0.00
170	0	1	0.67	0.00	0.00	0.01	0.00	0.67	0.00	0.00	0.01	0.00
180	0	1	0.63	0.00	0.00	0.01	0.00	0.64	0.00	0.00	0.01	0.00
190	2	2	1.19	0.00	0.00	0.01	0.00	1.20	0.00	0.00	0.01	0.00
200	0	3	1.72	0.01	0.00	0.01	0.00	1.75	0.01	0.00	0.02	0.00
210	0	13	7.15	0.02	0.01	0.06	0.00	7.35	0.02	0.01	0.06	0.00
220	1	10	5.28	0.01	0.01	0.04	0.00	5.48	0.01	0.00	0.05	0.00
230	1	24	12.55	0.02	0.01	0.10	0.01	12.73	0.00	0.01	0.10	0.00
240	0	66	34.21	0.05	0.03	0.26	0.02	34.42	0.01	0.02	0.27	0.01
250	2	71	36.47	0.05	0.03	0.28	0.02	36.39	0.00	0.03	0.27	0.01
260	0	71	36.04	0.04	0.03	0.27	0.01	35.78	0.00	0.04	0.26	0.01
270	2	89	44.63	0.04	0.03	0.33	0.02	44.08	0.00	0.05	0.31	0.01
280	0	105	51.55	0.05	0.03	0.38	0.02	51.53	0.00	0.06	0.36	0.01
290	2	119	57.17	0.05	0.03	0.42	0.02	57.86	0.00	0.06	0.40	0.01
300	0	140	67.43	0.05	0.04	0.49	0.02	67.71	0.03	0.07	0.48	0.01
310	2	209	100.92	0.07	0.05	0.73	0.03	100.52	0.07	0.11	0.73	0.03
320	0	181	86.64	0.06	0.04	0.63	0.02	86.28	0.04	0.10	0.61	0.02
330	0	125	59.31	0.04	0.03	0.43	0.01	59.05	0.02	0.07	0.41	0.01
340	2	82	38.57	0.03	0.02	0.28	0.01	38.38	0.00	0.04	0.26	0.00
350	0	9	4.22	0.00	0.00	0.03	0.00	4.21	0.00	0.00	0.03	0.00
360	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
370	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
380	2	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
390	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
400	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
410	1	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
420	1	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
430	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
440	2	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
450	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
460	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
470	2	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
480	0	0										
490	0	0										
500	0	0										
Total	26	1329	660.28	0.79	0.44	4.87	0.27	659.87	0.41	0.71	4.76	0.18
Estimated Change >			0%	-48%	60%	-2%	-33%					

Estimation of Change in Specific Emissions Calculated from Transient Vehicle Temperature Profile and Progressive Load Test Emission for DOC C32

Exhaust Temperature Profile			Progressive Load Specific Emissions - Before DOC C32						Progressive Load Specific Emissions - After DOC C32					
Bin Temperature Range	Progressive Load Bin Tally	Transient cycle Bin Tally	DOC Inlet Temperature	CO_2	CO	NO_2	NO	THC	DOC Inlet Temperature	CO_2	CO	NO_2	NO	THC
(^oC)	*Frequency*		(^oC)	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh	(^oC)	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh
100	0	0	94	4158	69.20	13.08	34.46	21.13	93	4086	67.53	7.94	36.52	12.93
110	0	3	104	3522	56.91	10.88	29.24	17.28	104	3466	55.55	6.48	31.12	10.65
120	2	1	115	2885	44.62	8.69	24.02	13.43	115	2846	43.57	5.03	25.72	8.37
130	0	1	125	2249	32.34	6.49	18.79	9.58	126	2226	31.60	3.57	20.32	6.09
140	0	1	136	1612	20.05	4.30	13.57	5.72	137	1607	19.62	2.12	14.91	3.81
150	2	1	146	975	7.76	2.10	8.35	1.87	148	987	7.64	0.66	9.51	1.53
160	0	1	155	930	6.63	1.87	7.98	1.59	157	939	6.52	0.53	9.04	1.33
170	0	1	163	884	5.51	1.65	7.61	1.30	165	892	5.40	0.39	8.58	1.13
180	0	2	172	839	4.39	1.42	7.24	1.02	174	844	4.28	0.25	8.11	0.93
190	2	2	181	793	3.27	1.19	6.87	0.73	183	797	3.16	0.12	7.65	0.73
200	0	15	193	766	2.62	1.04	6.46	0.62	195	772	2.18	0.11	7.14	0.58
210	0	8	206	739	1.97	0.89	6.05	0.50	208	748	1.19	0.09	6.63	0.42
220	1	9	218	711	1.33	0.74	5.64	0.38	217	730	0.45	0.08	6.25	0.30
230	1	29	227	703	1.18	0.68	5.51	0.35	220	724	0.21	0.08	6.13	0.26
240	0	65	236	694	1.03	0.63	5.37	0.32	233	703	0.10	0.07	5.82	0.19
250	2	72	244	685	0.88	0.57	5.23	0.28	246	682	0.00	0.06	5.51	0.11
260	0	68	257	673	0.76	0.50	5.15	0.26	258	674	0.00	0.05	5.39	0.10
270	2	88	270	662	0.64	0.44	5.06	0.23	270	665	0.00	0.03	5.27	0.08
280	0	98	280	657	0.59	0.40	4.96	0.22	277	662	0.00	0.03	5.21	0.08
290	1	127	290	651	0.55	0.37	4.86	0.20	284	659	0.00	0.03	5.15	0.07
300	1	204	299	646	0.51	0.34	4.79	0.19	291	656	0.00	0.03	5.09	0.07
310	2	179	309	641	0.48	0.32	4.72	0.18	310	641	0.48	0.32	4.72	0.18
320	0	168	318	640	0.46	0.29	4.72	0.17	319	642	0.32	0.23	4.76	0.13
330	0	123	327	640	0.44	0.27	4.72	0.16	327	643	0.16	0.15	4.81	0.09
340	2	61	335	639	0.42	0.25	4.72	0.15	336	643	0.00	0.06	4.86	0.05
350	0	0	344	635	0.43	0.23	4.73	0.14	345	640	0.00	0.11	4.81	0.05
360	0	0	353	632	0.44	0.21	4.73	0.13	354	638	0.00	0.15	4.76	0.04
370	0	0	362	628	0.45	0.19	4.73	0.12	363	635	0.00	0.19	4.72	0.04
380	2	0	370	625	0.46	0.18	4.73	0.11	371	633	0.00	0.24	4.67	0.04
390	0	0	383	622	0.53	0.16	4.76	0.10	381	629	0.00	0.28	4.66	0.04
400	0	0	396	619	0.59	0.15	4.79	0.10	391	626	0.01	0.31	4.65	0.04
410	1	0	409	616	0.66	0.13	4.82	0.09	401	622	0.01	0.35	4.64	0.04
420	1	0	418	613	0.70	0.13	4.86	0.09	411	619	0.01	0.39	4.63	0.04
430	0	0	428	610	0.74	0.12	4.90	0.08	424	617	0.02	0.39	4.76	0.04
440	2	0	437	607	0.78	0.11	4.94	0.08	437	615	0.04	0.39	4.89	0.04
450	0	0	446	606	0.73	0.10	4.99	1.75	447	611	0.04	0.38	4.88	0.04
460	0	0	456	605	0.68	0.09	5.04	3.42	457	608	0.05	0.37	4.86	0.04
470	2	0	465	604	0.62	0.08	5.10	5.10	466	605	0.05	0.36	4.85	0.04
480	0	0												
490	0	0												
500	0	0												
More	0	0												
Total	26	1327	Interpolated Values											

Estimation of Change in Specific Emissions Calculated from Transient Vehicle Temperature Profile and Progressive Load Test Emission for DOC C32

Exhaust Temperature Profile			Progressive Load Specific Emissions - Before DOC Weighted					Progressive Load Specific Emissions - After DOC 32 Weighted				
Bin Temperature Range	Progressive Load Bin Tally	Transient Bin Tally	CO_2	CO	NO_2	NO	THC	CO_2	CO	NO_2	NO	THC
(^oC)	*Frequency*		g/kWh	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh
100	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
110	0	3	7.96	0.10	0.02	0.05	0.03	6.43	0.10	0.01	0.06	0.02
120	2	1	1.69	0.02	0.00	0.01	0.01	1.68	0.02	0.00	0.02	0.00
130	0	1	1.69	0.02	0.00	0.01	0.01	1.68	0.02	0.00	0.02	0.00
140	0	1	1.21	0.02	0.00	0.01	0.00	1.21	0.01	0.00	0.01	0.00
150	2	1	0.74	0.01	0.00	0.01	0.00	0.74	0.01	0.00	0.01	0.00
160	0	1	0.70	0.00	0.00	0.01	0.00	0.71	0.00	0.00	0.01	0.00
170	0	1	0.67	0.00	0.00	0.01	0.00	0.67	0.00	0.00	0.01	0.00
180	0	2	1.26	0.01	0.00	0.01	0.00	1.27	0.01	0.00	0.01	0.00
190	2	2	1.20	0.00	0.00	0.01	0.00	1.20	0.00	0.00	0.01	0.00
200	0	15	8.66	0.03	0.01	0.07	0.01	8.73	0.02	0.00	0.08	0.01
210	0	8	4.45	0.01	0.01	0.04	0.00	4.51	0.01	0.00	0.04	0.00
220	1	9	4.83	0.01	0.01	0.04	0.00	4.95	0.00	0.00	0.04	0.00
230	1	29	15.35	0.03	0.01	0.12	0.01	15.81	0.00	0.00	0.13	0.01
240	0	65	33.98	0.05	0.03	0.26	0.02	34.43	0.00	0.00	0.28	0.01
250	2	72	37.16	0.05	0.03	0.28	0.02	37.01	0.00	0.00	0.30	0.01
260	0	68	34.51	0.04	0.03	0.26	0.01	34.52	0.00	0.00	0.28	0.00
270	2	88	43.90	0.04	0.03	0.34	0.02	44.11	0.00	0.00	0.35	0.01
280	0	98	48.49	0.04	0.03	0.37	0.02	48.90	0.00	0.00	0.38	0.01
290	1	127	62.33	0.05	0.04	0.47	0.02	62.81	0.00	0.00	0.49	0.01
300	1	204	99.35	0.08	0.05	0.74	0.03	98.62	0.07	0.05	0.73	0.03
310	2	179	86.50	0.06	0.04	0.64	0.02	86.53	0.06	0.04	0.64	0.02
320	0	168	81.08	0.06	0.04	0.60	0.02	81.28	0.04	0.03	0.60	0.02
330	0	123	59.29	0.04	0.02	0.44	0.01	59.56	0.01	0.01	0.45	0.01
340	2	61	29.37	0.02	0.01	0.22	0.01	29.56	0.00	0.00	0.22	0.00
350	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
360	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
370	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
380	2	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
390	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
400	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
410	1	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
420	1	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
430	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
440	2	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
450	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
460	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
470	2	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
480	0	0										
490	0	0										
500	0	0										
More	0	0										
Total	26	1327	666.38	0.81	0.43	5.00	0.27	666.92	0.42	0.18	5.16	0.17
Emission Change >			0%	-47%	-58%	3%	-36%	-	-	-	-	-

Estimation of Change in Specific Emissions Calculated from Transient Vehicle Temperature Profile and Progressive Load Test Emission for DOC C16

Exhaust Temperature Profile			Progressive Load Specific Emissions - Before DOC C16						Progressive Load Specific Emissions - After DOC C16					
Bin Temperature Range	Progressive Load Bin Tally	Transient cycle Bin Tally	DOC Inlet Temperature	CO_2	CO	NO_2	NO	THC	DOC Inlet Temperature	CO_2	CO	NO_2	NO	THC
(^oC)	*Frequency*		(^oC)	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh	(^oC)	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh
100	0	0	93	4242	68.80	12.31	35.84	20.69	92	4127	65.76	11.12	35.42	17.72
110	0	0	103	3594	56.56	10.24	30.41	16.91	102	3502	54.04	9.19	30.16	14.50
120	2	0	113	2945	44.31	8.16	24.98	13.12	113	2877	42.32	7.25	24.90	11.28
130	0	0	123	2296	32.07	6.09	19.55	9.34	124	2251	30.60	5.32	19.64	8.05
140	0	0	133	1648	19.83	4.01	14.13	5.55	134	1626	18.88	3.39	14.37	4.83
150	2	0	142	999	7.58	1.94	8.70	1.77	145	1001	7.15	1.45	9.11	1.61
160	0	0	153	933	6.13	1.67	8.11	1.41	155	938	5.59	1.11	8.57	1.31
170	0	0	164	868	4.67	1.39	7.53	1.06	166	875	4.02	0.77	8.03	1.01
180	2	0	174	802	3.22	1.12	6.94	0.71	177	812	2.45	0.43	7.49	0.71
190	0	0	185	770	2.57	0.98	6.52	0.60	185	789	1.85	0.47	7.06	0.58
200	0	0	196	739	1.93	0.84	6.11	0.49	194	765	1.24	0.52	6.63	0.45
210	1	0	208	708	1.29	0.69	5.69	0.38	202	741	0.64	0.56	6.20	0.32
220	1	0	214	703	1.18	0.65	5.60	0.36	210	717	0.03	0.60	5.77	0.19
230	0	0	221	698	1.07	0.61	5.51	0.34	210	732	0.63	0.86	5.77	0.30
240	2	0	233	689	0.86	0.53	5.33	0.30	236	692	0.00	1.52	4.49	0.12
250	0	0	245	681	0.75	0.48	5.26	0.26	247	679	0.00	1.86	4.01	0.11
260	2	19	256	672	0.65	0.42	5.19	0.23	257	667	0.00	2.21	3.54	0.10
270	0	77	266	663	0.59	0.38	5.06	0.21	267	661	0.00	2.38	3.26	0.08
280	2	69	276	653	0.53	0.35	4.94	0.20	277	654	0.00	2.55	2.97	0.07
290	0	52	285	648	0.50	0.32	4.87	0.18	287	650	0.23	1.43	3.88	0.12
300	2	43	295	643	0.46	0.30	4.79	0.16	296	647	0.46	0.30	4.79	0.16
310	0	54	298	643	0.46	0.29	4.79	0.16	305	644	0.31	1.11	4.04	0.13
320	0	60	304	641	0.44	0.28	4.78	0.15	315	641	0.15	1.92	3.28	0.09
330	2	86	323	638	0.41	0.23	4.76	0.14	324	638	0.00	2.73	2.53	0.05
340	0	115	333	634	0.41	0.22	4.74	0.13	334	635	0.00	2.66	2.57	0.05
350	0	198	343	631	0.42	0.20	4.72	0.12	344	632	0.00	2.59	2.60	0.05
360	0	373	353	627	0.43	0.19	4.71	0.11	355	628	0.00	2.52	2.64	0.05
370	2	89	363	623	0.43	0.17	4.69	0.10	365	625	0.00	2.45	2.68	0.04
380	0	0	371	621	0.47	0.16	4.73	0.10	375	624	0.00	2.34	2.82	0.04
390	0	0	379	619	0.51	0.15	4.77	0.09	386	623	0.01	2.23	2.95	0.04
400	0	0	388	617	0.54	0.14	4.81	0.09	396	621	0.01	2.11	3.09	0.04
410	2	0	405	612	0.62	0.13	4.89	0.08	407	620	0.01	2.00	3.22	0.04
420	0	0	414	612	0.66	0.12	4.94	0.08	415	616	0.01	1.88	3.37	0.04
430	0	0	423	611	0.71	0.11	4.99	0.07	424	612	0.02	1.76	3.52	0.03
440	2	0	432	610	0.76	0.10	5.03	0.07	433	609	0.02	1.64	3.67	0.03
450	0	0	445	610	0.83	0.09	5.11	0.07	442	607	0.02	1.53	3.81	0.03
460	1	0	459	598	0.61	0.08	5.02	5.02	451	605	0.02	1.41	3.95	0.03
470	1	0	468	591	0.53	0.07	5.02	7.50	460	604	0.02	1.29	4.10	0.03
480	0	0												
490	0	0												
500	0	0												
More	0	0												
Total	26	1235	Interpolated Values											

Estimation of Change in Specific Emissions Calculated from Transient Vehicle Temperature Profile and Progressive Load Test Emission for DOC C16

Exhaust Temperature Profile			Progressive Load Specific Emissions - Before DOC C16 Weighted					Progressive Load Specific Emissions - After DOC 16 Weighted				
Bin Temperature Range	Progressive Load Bin Tally	Transient cycle Bin Tally	CO_2	CO	NO_2	NO	THC	CO_2	CO	NO_2	NO	THC
(^oC)	*Frequency*		g/kWh	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh
100	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
110	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
120	2	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
130	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
140	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
150	2	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
160	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
170	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
180	2	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
190	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
200	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
210	1	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
220	1	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
230	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
240	2	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
250	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
260	2	19	10.35	0.01	0.01	0.08	0.00	10.27	0.00	0.03	0.05	0.00
270	0	77	41.33	0.04	0.02	0.32	0.01	41.20	0.00	0.15	0.20	0.01
280	2	69	36.50	0.03	0.02	0.28	0.01	36.56	0.00	0.14	0.17	0.00
290	0	52	27.29	0.02	0.01	0.20	0.01	27.39	0.01	0.06	0.16	0.00
300	2	43	22.39	0.02	0.01	0.17	0.01	22.51	0.02	0.01	0.17	0.01
310	0	54	28.10	0.02	0.01	0.21	0.01	28.14	0.01	0.05	0.18	0.01
320	0	60	31.16	0.02	0.01	0.23	0.01	31.13	0.01	0.09	0.16	0.00
330	2	86	44.42	0.03	0.02	0.33	0.01	44.41	0.00	0.19	0.18	0.00
340	0	115	59.06	0.04	0.02	0.44	0.01	59.10	0.00	0.25	0.24	0.00
350	0	198	101.10	0.07	0.03	0.76	0.02	101.26	0.00	0.42	0.42	0.01
360	0	373	189.34	0.13	0.06	1.42	0.03	189.82	0.00	0.76	0.80	0.01
370	2	89	44.91	0.03	0.01	0.34	0.01	45.07	0.00	0.18	0.19	0.00
380	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
390	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
400	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
410	2	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
420	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
430	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
440	2	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
450	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
460	1	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
470	1	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
480	0	0										
490	0	0										
500	0	0										
More	0	0										
Total	26	1235	635.94	0.45	0.24	4.77	0.14	636.86	0.05	2.33	2.91	0.06
Estimated Chage >			0%	-90%	875%	-39%	-54%	-	-	-	-	-

Estimation of Change in Specific Emissions Calculated from Transient Vehicle Temperature Profile and Progressive Load Test Emission for DOC C6

Exhaust Temperature Profile			Progressive Load Specific Emissions - Before DOC C6						Progressive Load Specific Emissions - After DOC C6					
Bin Temperature Range	Progressive Load Bin Tally	Transient cycle Bin Tally	DOC Inlet Temperature	CO_2	CO	NO_2	NO	THC	DOC Inlet Temperature	CO_2	CO	NO_2	NO	THC
(^oC)	*Frequency*		(^oC)	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh	(^oC)	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh
100	0	0	83.0	4947.3	78.67	15.83	41.82	23.90	81	4958.73	77.53	15.22	41.76	21.42
110	0	0	98.5	3966.7	60.86	12.42	33.59	18.36	98	3976.63	59.99	11.94	33.58	16.47
120	2	2	114.0	2986.0	43.06	9.01	25.35	12.82	114	2994.52	42.44	8.66	25.40	11.53
130	0	1	124.4	2332.3	31.18	6.73	19.86	9.13	125	2339.78	30.75	6.47	19.95	8.23
140	0	1	134.7	1678.5	19.31	4.46	14.37	5.44	136	1685.04	19.05	4.28	14.50	4.93
150	2	2	145.0	1024.8	7.44	2.19	8.88	1.75	147	1030.30	7.36	2.09	9.05	1.63
160	0	10	152.1	983.9	6.58	2.00	8.52	1.54	154	989.76	6.49	1.90	8.68	1.45
170	0	10	159.2	943.1	5.72	1.82	8.15	1.34	161	949.22	5.63	1.70	8.32	1.26
180	0	9	166.3	902.3	4.86	1.63	7.78	1.13	169	908.67	4.76	1.50	7.95	1.08
190	2	24	180.4	820.6	3.14	1.27	7.04	0.72	183	827.59	3.03	1.10	7.22	0.72
200	0	86	192.3	792.7	2.52	1.11	6.65	0.61	195	799.49	2.19	0.91	6.84	0.57
210	0	130	204.2	764.8	1.91	0.95	6.25	0.50	207	771.40	1.35	0.72	6.46	0.43
220	2	174	216.1	736.8	1.30	0.80	5.86	0.40	219	743.30	0.51	0.54	6.08	0.29
230	0	238	224.8	727.6	1.15	0.74	5.75	0.37	215	761.16	1.25	0.76	6.26	0.40
240	0	237	233.6	718.4	1.01	0.68	5.64	0.34	227	733.06	0.41	0.57	5.88	0.26
250	2	238	242.3	709.2	0.86	0.62	5.54	0.31	244	712.59	0.20	0.64	5.48	0.20
260	0	315	253.1	696.8	0.77	0.56	5.38	0.28	254	700.30	0.16	0.72	5.25	0.18
270	2	297	263.9	684.4	0.67	0.50	5.22	0.24	265	688.01	0.13	0.79	5.01	0.16
280	0	207	273.9	676.2	0.61	0.46	5.15	0.23	275	681.02	0.11	0.81	4.91	0.15
290	2	228	283.9	668.0	0.55	0.43	5.07	0.21	285	674.02	0.10	0.83	4.80	0.14
300	0	150	293.7	664.8	0.52	0.40	5.08	0.20	295	669.87	0.29	0.84	4.95	0.16
310	2	68	303.5	661.6	0.49	0.37	5.09	0.18	305	665.72	0.49	0.85	5.09	0.18
320	0	0	312.6	656.3	0.46	0.35	5.01	0.17	314	661.01	0.35	0.84	4.88	0.15
330	0	0	321.7	651.0	0.44	0.32	4.93	0.16	323	656.30	0.21	0.83	4.67	0.12
340	2	0	330.8	645.6	0.41	0.30	4.84	0.14	332	651.59	0.07	0.82	4.47	0.09
350	0	0	343.6	644.8	0.42	0.28	4.86	0.13	342	650.07	0.07	0.81	4.49	0.09
360	0	0	356.4	643.9	0.43	0.26	4.88	0.12	351	648.54	0.08	0.79	4.52	0.08
370	1	0	369.2	643.0	0.44	0.24	4.90	0.11	361	647.01	0.08	0.78	4.54	0.08
380	1	0	377.6	639.7	0.47	0.23	4.92	0.10	371	645.48	0.08	0.76	4.57	0.07
390	0	0	385.9	636.3	0.51	0.22	4.93	0.10	381	642.43	0.10	0.73	4.60	0.07
400	0	0	394.2	633.0	0.55	0.21	4.94	0.09	391	639.37	0.11	0.69	4.63	0.06
410	0	0	402.6	629.6	0.58	0.20	4.95	0.09	402	636.32	0.12	0.65	4.66	0.06
420	2	0	410.9	626.3	0.62	0.19	4.96	0.08	412	633.26	0.14	0.62	4.69	0.06
430	0	0	424.6	623.6	0.70	0.18	5.06	0.08	426	629.00	0.16	0.57	4.79	0.05
440	2	0	438.3	620.9	0.78	0.16	5.16	0.07	439	624.74	0.19	0.52	4.89	0.05
450	0	0	447.5	617.5	0.72	0.16	5.18	1.79	448	620.75	0.18	0.50	4.92	0.05
460	0	0	456.8	614.2	0.66	0.15	5.20	3.51	457	616.75	0.18	0.48	4.95	0.05
470	2	0	466.1	610.8	0.61	0.14	5.23	5.23	466	612.76	0.17	0.45	4.97	0.05
480	0	0												
490	0	0												
500	0	0												
More	0	0												
Total	26	2427	Interpolated Values											

Estimation of Change in Specific Emissions Calculated from Transient Vehicle Temperature Profile and Progressive Load Test Emission for DOC C6

Exhaust Temperature Profile			Progressive Load Specific Emissions - Before DOC C6 Weighted					Progressive Load Specific Emissions - After DOC 6 Weighted				
Bin Temperature Range	Progressive Load Bin Tally	Transient cycle Bin Tally	CO_2	CO	NO_2	NO	THC	CO_2	CO	NO_2	NO	THC
(^oC)	*Frequency*		g/kWh	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh
100	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
110	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
120	2	2	2.46	0.04	0.01	0.02	0.01	2.47	0.03	0.01	0.02	0.01
130	0	1	0.96	0.01	0.00	0.01	0.00	0.96	0.01	0.00	0.01	0.00
140	0	1	0.69	0.01	0.00	0.01	0.00	0.69	0.01	0.00	0.01	0.00
150	2	2	0.84	0.01	0.00	0.01	0.00	0.85	0.01	0.00	0.01	0.00
160	0	10	4.05	0.03	0.01	0.04	0.01	4.08	0.03	0.01	0.04	0.01
170	0	10	3.89	0.02	0.01	0.03	0.01	3.91	0.02	0.01	0.03	0.01
180	0	9	3.35	0.02	0.01	0.03	0.00	3.37	0.02	0.01	0.03	0.00
190	2	24	8.11	0.03	0.01	0.07	0.01	8.18	0.03	0.01	0.07	0.01
200	0	86	28.09	0.09	0.04	0.24	0.02	28.33	0.08	0.03	0.24	0.02
210	0	130	40.96	0.10	0.05	0.33	0.03	41.32	0.07	0.04	0.35	0.02
220	2	174	52.83	0.09	0.06	0.42	0.03	53.29	0.04	0.04	0.44	0.02
230	0	238	71.35	0.11	0.07	0.56	0.04	74.64	0.12	0.07	0.61	0.04
240	0	237	70.15	0.10	0.07	0.55	0.03	71.58	0.04	0.06	0.57	0.03
250	2	238	69.55	0.08	0.06	0.54	0.03	69.88	0.02	0.06	0.54	0.02
260	0	315	90.44	0.10	0.07	0.70	0.04	90.89	0.02	0.09	0.68	0.02
270	2	297	83.76	0.08	0.06	0.64	0.03	84.19	0.02	0.10	0.61	0.02
280	0	207	57.67	0.05	0.04	0.44	0.02	58.08	0.01	0.07	0.42	0.01
290	2	228	62.75	0.05	0.04	0.48	0.02	63.32	0.01	0.08	0.45	0.01
300	0	150	41.09	0.03	0.02	0.31	0.01	41.40	0.02	0.05	0.31	0.01
310	2	68	18.54	0.01	0.01	0.14	0.01	18.65	0.01	0.02	0.14	0.01
320	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
330	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
340	2	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
350	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
360	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
370	1	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
380	1	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
390	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
400	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
410	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
420	2	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
430	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
440	2	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
450	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
460	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
470	2	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
480	0	0										
490	0	0										
500	0	0										
More	0	0										
Total	26	2427	711.54	1.07	0.64	5.57	0.34	720.10	0.62	0.76	5.58	0.27
Estimated Chnage >			1%	-43%	18%	0%	-20%					