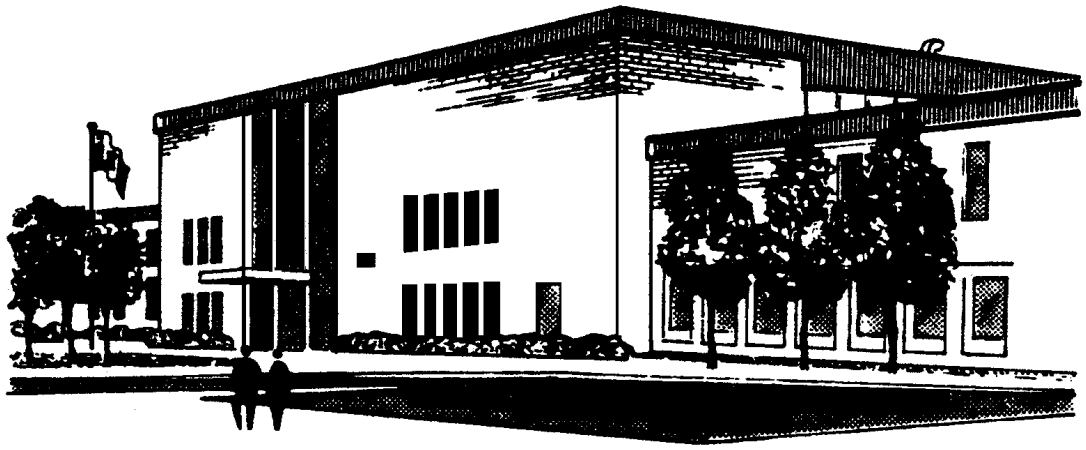
Characterizing the Cold Start Exhaust and Hot Soak Evaporative Emissions of the Test Vehicle for the Attached Garage Study



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Summary

The cold temperature cold start and hot start tailpipe emissions and the cold temperature hot soak evaporative emissions from a 1993 Buick Regal were measured. This vehicle was to be used as the test vehicle in a field study to determine the impact of vehicle emissions generated in the attached garage of a residence on the indoor air quality of the residence. A specially designed driving cycle was used to characterise the emissions. This driving cycle, called the "garage" cycle was designed to simulate the normal operation of a vehicle as it is started in the garage, allowed to idle and then backed out of the garage. As such, the 300 second test consisted mostly of idling with a small acceleration in the forward direction used to simulate the vehicle backing out of the garage.

The tailpipe emissions were characterised for carbon monoxide, carbon dioxide, total hydorcarbons, oxides of nitrogen, volatile organic compounds and carbonyl compounds. The evaporative emissions were characterised for total hydrocarbons and volatile organic compounds. The tailpipe and evaporative emissions were also characterised modally – second by second during the driving test and over 5 second intervals for the evaporative emissions test. This information was used to describe how the emission rate changes over the different operating modes. The effect of different test temperatures was also investigated as the house testing occurred over a range of cold ambient temperatures.

The emissions determined in this work will be used as source emissions profiles for the Chemical Mass Balance modelling that forms a later phase of the study.

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1. Introduction

As part of the larger project entitled "Contribution of Vehicle Emissions from an Attached Garage to Residential Indoor Air Pollution Levels", the Emissions Research and Measurement Division (ERMD) of Environment Canada has conducted laboratory studies to characterise the evaporative and start-idle-manoeuvre emissions of a late model light duty vehicle operating on a commercially available winter grade gasoline at a temperature (-10 °C) expected to be typical of the winter time conditions in Ottawa.

The larger project has the following objectives:

- To qualify and quantify cold start and hot start tailpipe and hot soak evaporative emissions from a vehicle in a residential garage due to daily use of the vehicle
- To qualify and quantify those vehicle emissions products which reach an adjacent room in the residence via an attached garage, i.e. through the common door, walls, or attic of the house
- To determine the concentrations of vehicle emission products in the attached garage relative to an adjacent room inside the house
- To model movement/path of entry of vehicle emissions in an attached garage into the house
- To determine the removal efficiency of vehicle emissions in the air of the house versus the air of the attached garage
- To assess human exposure to levels of emissions found in the residence that have originated from vehicle start-up and cool-down in the attached garage.

This report addresses the experimental work conducted by Environment Canada – ERMD in support of the first objective cited above. Prior to the first phase of house testing, the cold start and hot start tailpipe emissions and hot soak evaporative emissions of the vehicle were measured at -10°C. At the conclusion of the first phase of house testing, the vehicle was tested at 0°C and 24°C for cold start tailpipe emissions only. At the conclusion of the second phase of house testing, the vehicle was tested again at 0°C for cold start tailpipe emissions only using the second test fuel. The hydrocarbon composition of the evaporative emissions from the second test fuel was estimated from a sample of evaporated test fuel.

2. Test Vehicle and Fuels

The vehicle used for all house testing, and whose emissions were characterised as described below, was a 1993 Buick Regal Custom. This vehicle is part of the Transport Canada fleet available to ERMD for vehicle emissions studies. This vehicle was selected as it has a large engine, similar in size to typical family-sized passenger cars and minivans. It was designed to meet Canadian Tier 0 emissions standards. Details of the vehicle are presented in Table 1.

Table 1. Description of test vehicle.

Engine Size Transmission Mileage (km)	3.8L V6 Automatic 4 speed 10890 (at end of program)
Emissions Controls	Electronic fuel injection Exhaust gas recirculation Exhaust gas sensor Closed loop Three way catalyst Evaporative emissions canister
Fuel Consumption	11.5 L/100 km city 6.9 L/100 km hwy
Air Conditioner	R-12 refrigerant

The vehicle was operated on a commercially available winter mid-grade gasoline obtained in barrels from a local distributor. Two lots of fuel were required to complete the house testing. Laboratory measurements of the cold start

tailpipe emissions were made using both fuels. The hot start tailpipe and low temperature hot soak evaporative emissions were characterised on the first fuel only. As the actual house testing did not include hot start operation of the vehicle, these emissions were not characterised at the other test temperatures or for the second fuel. The hot soak evaporative emission rate (g/min) was not expected to change substantially with the second fuel due to the similarity of the fuel properties, but the detailed chemical composition of the emissions was expected to differ between the two fuels. Rather than completing a full evaporative emissions test on the second fuel, a simulated evaporative emissions profile was derived from a sample of the evaporated fuel as described later in this report. The properties of the two fuels are summarised in Table 2.

Table 2. Test fuel properties.

	Test Fuel #1	**Test Fuel #2**
Sulphur (ppm)	300	374
Manganese (mg/L)	Not determined	11.3
Lead (mg/L)	<1.0	<1.0
Density (g/L)	722.8	721.2
Octane Number (motor)	83.5	82.4
Vapour Pressure (psi)	13.7	14.1
Hydrocarbon Composition (wt%)		
Paraffins	61.2 (total saturates)	53.03
Olefins	17.2 (total olefins)	12.31
Naphthenes	Not determined	6.74
Aromatics	21.6	26.88
Oxygenates	Not determined	0.0
Benzene	Not determined	1.28

3. Testing Protocol

Initially, the tailpipe emissions that were of interest in this study were the cold start and hot start emissions occurring at low ambient temperatures. Both of these tailpipe emissions were characterised for the test vehicle on the first test fuel as this work was completed prior to the first phase of house testing. As was mentioned above, the hot start emissions were not included in the house testing protocol and so were not included in the vehicle testing that occurred after the first phase of house testing. The test temperature for the first part of the vehicle emission study was -10°C as this was the expected average wintertime temperature for the house testing phase of the project. Additional cold start emissions measurements were made at test temperatures of 0°C and 24°C to characterise the temperature dependence of the cold start tailpipe emissions.

Cold start emissions are produced when a vehicle is started and driven over a defined cycle after having been turned off and allowed to cool to the ambient temperature over several hours (at least 12 hours). Hot start emissions occur when a vehicle is started and driven over a defined cycle after it has been turned off and allowed to cool for only a short period of time (usually less than 30 minutes). In the present study, a soak time of 10 minutes was used. Cold start tailpipe emissions are invariably greater than hot start emissions for several reasons. First, more fuel enrichment is required for ignition at colder temperatures than warmer temperatures; second, mechanical losses due to friction (a result of cold lubricants and bearings) require more energy to overcome and third, the catalytic converter of the vehicle is ineffective when cold. The catalytic converter relies on the heat of the exhaust passing through it to heat it to operating temperature – approximately 300 °C. As the catalyst heats up, its conversion efficiency increases until it reaches maximum efficiency at normal operating temperatures. On cold start at cold ambient temperatures, the length of time that it takes for the catalyst to reach operating temperature is much greater than at warm ambient temperatures. On hot start, there is still residual heat both in the engine and in the exhaust system and the catalyst efficiency quickly returns to optimum.

The evaporative emissions that were of interest in this study were the hot soak evaporative emissions. These emissions occur after a hot vehicle is turned off and cools down. These emissions occur entirely due to the loss of fuel vapour from the vehicle's fuel system (engine, hoses, connections, leakage from the fuel tank or evaporative emissions control system). These emissions occur over several hours after the vehicle has been turned off. They reach a minimum when

the vehicle has reached ambient temperature. This mode of emissions is more important during warm weather, but the combination of a highly volatile winter grade fuel and the usual situation of an attached garage to be warmer than the outdoors may make them significant in the current study.

3.1 Tailpipe Emissions

Before the vehicle testing was initiated, a tune check was performed on the vehicle to ensure it was operating properly. Next, a fuel exchange was done so that the proper test fuel was in the fuel tank. A heat build to canister breakthrough was performed at 25 °C to ensure that the evaporative emissions control system on the vehicle was loaded with the test fuel. The vehicle was then preconditioned with fuel exchange twice according to the Federal Test Procedure[†] (FTP) protocol. At the end of the preconditioning, the vehicle was placed in the cold cell and allowed to soak at the cold start test temperature overnight in preparation for testing the following day. The day before each test, the vehicle was preconditioned and placed in the cold cell for the overnight soak. Figure 1 and Figure 2 show the test vehicle in position in the test cell.

Tailpipe emissions from a vehicle are determined by driving the vehicle on a chassis dynamometer over a pre-defined driving cycle. The dynamometer is computer controlled and has speed and load feedback. The driver of the vehicle attempts to keep a "cross-hair" cursor displayed on the computer monitor on the speed-versus-time trace as the test progresses. The tailpipe of the vehicle is connected to a dilution system in which the vehicle exhaust is mixed with ambient air to cool and dilute it so that samples can be collected for analysis. Samples of the dilution air and the dilute exhaust are collected and analysed for carbon monoxide, carbon dioxide, total hydrocarbons and oxides of nitrogen emissions (CO, CO_2, THC and NO_X respectively). The dilute exhaust samples are corrected for the concentrations of these gases due to the dilution air and the respective mass emission rates are calculated. A similar process is applied to the samples collected for detailed chemical characterisation.

Tailpipe emissions were determined over a special test cycle designed for this project, named the "Garage" cycle. The test cycle was 300 seconds long and consisted mostly of vehicle idling, except for a manoeuvre intended to simulate the backing of a vehicle out of a residential garage. The difference between the test cycle and the actual backing up manoeuvre was that it was simulated by driving in the forward direction and was required to occur over a minimum of 20 seconds so that modal emissions could be determined. The speed versus time trace for the cycle is given in Figure 3.

The vehicle tailpipe emissions were collected as one sample over this 300 s test and included the crank (starting of the engine) emissions for both the cold start and the hot start repeats of the cycle. In addition to the bag samples, the dilute exhaust was analysed for CO, CO_2, THC and NO_X on a second by second basis using a second set of analysers. These modal emissions measurements provide information on how the emission rate changes during the test cycle. Between the two Garage cycles, a test cycle named "LA-4" (1370 seconds duration) was driven in order to bring the vehicle to normal operating temperature. This test cycle is identical to the first two phases of the FTP driving cycle. A 10 minute soak was allowed at the end of the LA-4 cycle for the vehicle to cool down somewhat before the hot start Garage cycle was driven. The complete driving test was performed in the ERMD cold weather test cell at -10 °C.

After the completion of the first phase of house testing, the cold start garage test was repeated at 0°C and 24 °C in order to evaluate the temperature dependence of the emissions over this cycle. The LA-4 cycle was driven immediately after the first cold start garage cycle in order to prepare the vehicle for the repeat test the following day. The vehicle underwent a complete fuel exchange and preconditioning cycle between the two test temperatures.

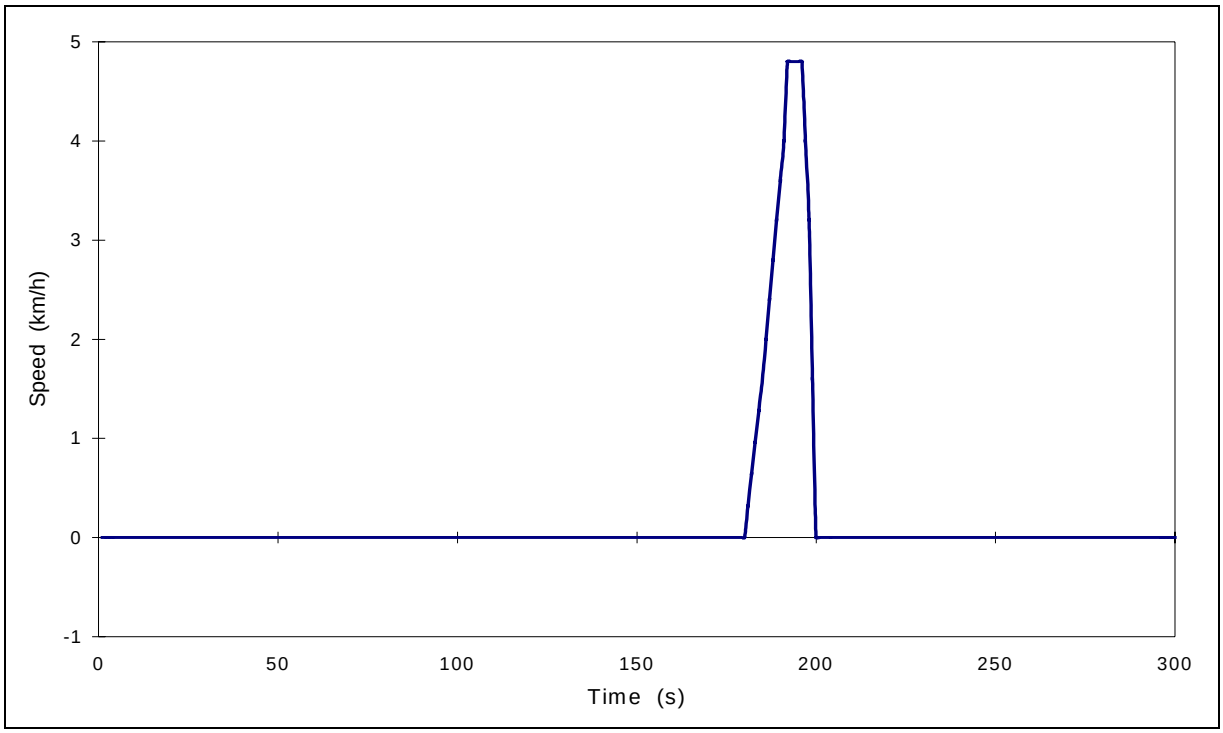
The last three houses tested during phase 2 of the house testing were conducted with the vehicle operating on the second test fuel. At the completion of the second phase of house testing, the vehicle was brought back to the laboratory for measurement of the cold start garage cycle tailpipe emissions on the second test fuel. This set of testing was conducted as described above, except at a test temperature of 0°C. The modal emissions were not measured during this last part of the vehicle testing as they were not expected to change from what was previously measured.

[†] The U.S. EPA Federal Test Procedure is a standard operating procedure for determining motor vehicle emissions.

Figure 1. Vehicle in testing position on chassis dynamometer (front view).

Figure 2. Vehicle in testing position on chassis dynamometer (back view).

Figure 3. Dynamometer trace of Garage test cycle.



Tailpipe emissions samples were collected over each of the cold start and hot start Garage cycles. Samples were collected for gaseous emissions (CO, CO_2, NO_X, THC), volatile organic compound analysis and carbonyl compound analysis. In addition, modal emissions data was collected for (CO, CO_2, NO_X, THC). The dilute exhaust concentration was measured every 2 seconds over each of the cold start and hot start Garage cycles. In order to monitor vehicle operation, the temperatures of the exhaust stream before and after catalyst, oil pan and fuel tank were recorded every 5 seconds over the entire test sequence.

Two analyser benches were used for gaseous emissions measurements. The first bench was used to determine test cycle average emissions (test emissions) while the second bench was configured for modal analysis. Two dataloggers (Omega M50) were used to acquire modal concentration data and temperature data. For the modal emissions data, the voltage output of each analyser was connected to the datalogger. The CO and CO_2 analysers required voltage dividers to bring the output into the 0-2V range of the datalogger. The thermocouple readings were taken directly by programming the datalogger channels to accept thermocouple input. Each analyser was zeroed and spanned while the datalogger was acquiring data so that any input bias on the datalogger could be accounted for. The data was downloaded to PC data files using the M50 software.

3.2 Evaporative Emissions

The evaporative emissions were also determined at a test cell temperature of -10 °C. A temporary SHED (Sealed Housing for Evaporative Determinations) was constructed in the back section of the cold test cell using a temporary garage frame of steel pipe. The enclosure was made of Tedlar sheet with tape sealed seams. A second tarp was placed on the floor of the enclosure on top of the Tedlar to protect the Tedlar from tire wear and other traffic.

The SHED was tested for propane retention according to the FTP protocol. A known mass of propane was injected into the sealed SHED and after 3 minutes of mixing, the initial concentration was determined. This concentration was compared to an expected concentration based on the SHED volume calculated from its dimensions. The change in concentration was monitored using the hydrocarbon analyser over 4 hours and the leakage rate determined. This was repeated at the test temperature of -10 °C once the SHED achieved less than 5% leakage over 4 hours at 20°C.

To measure hot soak emissions from a vehicle, it must first be brought to its normal operating temperature. In order to conserve time and effort, the hot soak test was performed immediately following the hot start garage test. Upon

completion of the hot start garage cycle, the vehicle was removed from the dynamometer under its own power and turned off. The tailpipe connection to the exhaust dilution tunnel was removed and the vehicle was then rolled into the SHED for the hot soak emissions measurement.

Figure 4 shows the temporary SHED structure with the test vehicle inside.

Figure 4. Test vehicle in position inside the SHED.

As it was difficult to ensure that the door seal was reliably made for each test, a tracer gas was used to determine the SHED leakage for each test. A known quantity of sulphur hexafluoride (SF_6) was injected into the SHED just after the door was sealed and the SHED atmosphere was mixed for 3 minutes using a small household oscillating fan. A sample of the SHED atmosphere was taken and analysed by gas chromatography for determining the SF_6 concentration in the SHED after the 3 minute mixing and at the end of the test. Leakage was determined as the percentage loss of mass of SF_6 over the test. Ambient pressure and temperature were also recorded to correct concentration measurements to standard conditions. The SF_6 standard was 2581ppm in N_2. Each litre of this standard mixture at 0 °C and 1 atm contained 0.0168 g SF_6. A 1-standard litre volume was injected into the SHED using a small bellows pump. The line delivering the sample to the SHED was then flushed with approximately 5 L of ambient air to ensure that the full amount was delivered to the SHED. The dead volume of the sample line was approximately 0.15 L, so the line was completely flushed.

The HC concentration was continuously monitored using the hydrocarbon analyser from the modal bench. A datalogger was set to read the analyser output, the vehicle oil pan, fuel tank, SHED and test cell temperatures every 5 seconds over the 2 hour test. From some initial experiments, it was determined that 2 hours was required for the HC concentration in the SHED to reach a steady level.

A sample of the SHED atmosphere before the vehicle was moved was taken to determine background VOC and SF_6 levels. Samples were then taken after the first 3-5 minutes and at the end of the test to determine SF_6 leakage and emission rates for the VOCs.

4. Analytical Methodology

4.1 Gaseous Emissions

Gaseous emissions consisting of CO_2, CO, NO_X and total hydrocarbons (THC) were determined using dedicated analysers specifically used for emissions testing. Two sets of data were acquired for the tailpipe emissions tests - test average data and modal data. Similar analysers were used in both cases. CO_2 and CO were determined using non-dispersive infra-red (NDIR) instruments, NO_X was determined using a chemiluminescence analyser and THC was determined using a flame ionisation detector (FID). The details of the analysers for the different emissions are summarised in Table 3.

Table 3. Gaseous emissions analysers

Test Emissions		**Analyser Concentration Ranges Used**
CO	Horiba NDIR Model AIA-23	0-50, 0-1000 ppm
CO_2	Horiba NDIR Model AIA-23	0-2%
NO_X	Horiba Chemiluminescence Model CLA-22A	0-30 ppm
HC	Horiba Flame Ionisation Model FIA-23A	0-30, 0-300 ppm
Modal Emissions		
CO	California Analytical Instruments NDIR Model 100	0-5000 ppm
CO_2	California Analytical Instruments NDIR Model 200	0-10%
NO_X	Horiba Chemiluminescence Model CLA-220	0-100, 0-300 ppm
HC	Horiba Flame Ionisation Model FIA-220	0-30, 0-300, 0-1000 ppm

4.2 Volatile Organic Compound Analysis

The Tedlar bag samples collected of the dilution air, dilute exhaust and SHED atmosphere were analysed by high resolution gas chromatography with flame ionisation detection (GC-FID) following cryogenic preconcentration. An Entech M7000 cryogenic concentrator, operating in the microscale purge and trap mode, was used as an inlet to the GC, allowing a sample volume of 50 mL to be used.

A Hewlett Packard 5890 Series II gas chromatograph with a flame ionisation detector was used for the analysis. Data was acquired using the Hewlett Packard 3365 Series II DOS ChemStation multi-instrument software. The system was calibrated using external standards on a per component basis. Compound identification was confirmed on selected samples by GC-Fourier Transform Infra-red analysis. The gas phase standards used were prepared in-house using a permeation tube gas standard generator (Kin-Tek Laboratories, LaMarque, Texas).

The preconcentrator system does not allow for the determination of methane and sometimes the C_2 hydrocarbons are not well retained on the trap. Methane was determined and confirmation of the C_2 and C_3 hydrocarbons was accomplished by simple gas loop injection onto a capillary column. The sample loop was flushed with sample using a small vacuum pump to draw sample from the Tedlar bag through the sample loop. The sample was injected directly onto the capillary column. A Hewlett Packard 5890 Series II gas chromatograph with a flame ionisation detector was used for the analysis. Data was acquired using the Hewlett Packard 3365 Series II DOS ChemStation multi-instrument software. This system was also calibrated using external standards generated from the Kin-Tek bench. The detection limits for the two methods for the samples of this project are given in Table 4.

Table 4. Detection limits for VOCs for tailpipe emissions and evaporative emissions tests.

	Garage Test Cycle (mg/test)	**2-Hour Hot Soak Evaporative Emissions (mg/test)**
methane	5.3	2.3
all other VOCs	0.1	0.05

4.3 Carbonyl Compound Analysis

Sep-Pak silica cartridges were coated with approximately 2 mg 2,4-Dinitrophenylhydrazine (DNPH). The carbonyl compounds in the gas sample (either dilute exhaust or dilution air) selectively react with the DNPH to form hydrazones which are retained on the cartridge. Acetonitrile is used to dissolve the hydrazones from the cartridge and the liquid sample is analysed by high performance liquid chromatography (HPLC).

The carbonyl compound analysis is performed using a Hewlett Packard Series II 1090 Liquid Chromatograph with a diode array detector. The hydrazones show a light absorption maximum at approximately 375 nm. It is this absorption maximum that is used as the detection signal. Two Hypersil ODS (3-µm packing, 2.1 mm by 100 mm long) microbore columns were used. The HPLC is controlled by a Hewlett Packard HPLC DOS 3D ChemStation.

The calibration for carbonyl analysis by HPLC is based on standards purchased from Radian International (Austin, TX.) and on standards prepared from derivatives synthesised in-house.

The detection limits for this method for the samples of this project are given in Table 5.

Table 5. Detection limits for carbonyl compounds for Garage test cycle

	mg/test
Formaldehyde	8
Acetaldehyde	15
2-3 butandione	23
Acrolein	15
Acetone	15
Propionaldehyde	14
Methoxyacetone	23
Crotonaldehyde	19
Methyl Vinyl Ketone	19
Methacrolein	19
Methyl Ethyl Ketone	19
Isobutyraldehyde & Butyraldehyde	19
Benzaldehyde	28
Isovaleraldehyde	23
Trimethylacetaldehyde & 3m2-Butanone	23
Valeraldehyde	23
Acetophenone	32
o-Tolualdehyde	32
m&p-Tolualdehyde	32
Methyl isobutyl Ketone	27
Pinacolone	27
Hexanaldehyde	27

5. Results and Discussion

5.1 Tailpipe Emissions

5.1.1 Test Emissions

The data presented as Test Emissions represents the total tailpipe emissions over the test cycle - cold start or hot start garage cycle. The data is reported as total mass emitted over the entire test (g/test or mg/test as appropriate). An average emission rate over the test can be obtained by dividing the mass emitted per test by the length of the test (300 s). The Modal Emissions data presented later will show how the emission rate varies over the test.

5.1.1.1 Gaseous Emissions

Table 6 reports the average and standard deviation for each of the gaseous emissions for the cold start and hot start Garage Cycle tests conducted at -10°C on the first test fuel. Table 7 compares the cold start Garage Cycle emissions at –10, 0 and 24 °C for the first test fuel. Data are reported in units of g/test. The complete data set is reported in Appendix 1.

Table 6. Gaseous mass emissions for the cold start and hot start Garage Test Cycle at -10°C (g/test) for the first test fuel.

	CO	CO_2	NO_X	HC
Cold Start (average of 3 tests)				
Average	49.5	615	2.23	6.92
Std. Dev.	21	48	2	2
Hot Start (average of 2 tests)				
Average	1.57	305	0.22	0.38
Std. Dev.	1	16	0.1	0.1

Table 7. Comparison of Cold Start Garage Test Cycle emissions at the three test temperatures (g/test) for the first test fuel.

	CO	CO_2	NO_X	HC
-10 °C				
Average	49.5	615	2.23	6.92
Std. Dev.	21	48	2	2
0 °C				
Average	28.6	488	0.57	3.56
Std. Dev.	5	1	0.02	0.3
24 °C				
Average	15.2	399	0.61	2.37
Std. Dev.	0.9	41	0.7	0.3

Table 8 reports the average and standard deviation for each of the gaseous emissions for the cold start Garage Cycle tests conducted at 0°C on the second test fuel. The complete data set is presented in Appendix 1.

Table 8. Gaseous mass emissions for the cold start Garage Test Cycle at 0°C (g/test) for the second test fuel.

	CO	CO_2	NO_X	HC
Cold Start (average of 2 tests)				
average	30.8	466	0.37	3.62
Std. Dev.	0.3	0.003	0.01	0.1

As expected, the cold start emissions are significantly higher than the corresponding hot start emissions. CO is 32 times greater, CO_2 is twice, NO_X is 10 times greater and HC is 18 times greater for cold start over hot start. Approximately twice as much fuel is used in the cold start as the hot start test. Also, as expected, the cold start emissions at -10°C are the greatest of the three test temperatures for all gaseous emissions. The emission rates decrease with increasing temperature for all gaseous emissions. NO_X emissions appear to reach a level at 0°C and do not decrease as the temperature increases to 24°C. The emission rates obtained using the second test fuel at 0°C compare very well with the emission rates obtained using the first test fuel at the same temperature (within 8% for CO and within 2% for CO_2 and THC). NO_X emissions at cold temperatures, during cold start are known to be widely variable. During cold start, the vehicle is operating in a very fuel rich mode. NO_X emissions are very dependent on the temperature of combustion and the amount of fuel present. This fuel rich mode produces variable combustion temperatures that are difficult to reproduce from test to test, thus causing the large variability in NO_X emissions. Also, NOX emissions are not expected to be very significant at idle as they are formed primarily when the vehicle is under load as will be seen in modal emissions data discussed in Section 5.1.2, Figure 10. The other emissions are less sensitive to the combustion temperature changes expected during this operation.

5.1.1.2 Volatile Organic Compounds

Table 9 reports the average and standard deviation for each of the volatile organic compound emissions for the cold start and hot start Garage tests conducted using the first test fuel. Data are reported in units of mg/test. A missing value indicates compound was below detection limits in the sample. The Cold Start -10°C data is an average of 3 test repeats, the Hot Start is an average of 2 test repeats and the Cold Start 0°C and 24°C data are each averages of 2 test repeats. Instances of non-detects were not included in the calculation of the average. Where no standard deviation is reported, the value reported as average is the amount from only one sample that was found above the detection limit. The complete data set is reported in Appendix 1. A list of compound name abbreviations is given in Appendix 1.

Table 9. Volatile organic compound mass emissions for the cold start and hot start Garage Tests (mg/test) conducted using the first test fuel.

Index		Cold Start -10°C		Hot Start -10°C		Cold Start 0°C		Cold Start 24°C	
		Average	Std.Dev.	Average	Std.Dev.	Average	Std.Dev.	Average	Std.Dev.
1	methane	393.7	106.0	62.8	2.6	191.9	18.4	109.0	11.6
2	ethylene	499.9	121.8	31.9	12.2	324.4	40.9	269.9	17.8
3	acetylene	270.1	65.9	3.5	0.4	127.7	12.6	57.9	14.3
4	ethane	59.5	9.6	16.9	1.9	45.1	2.1	35.9	6.5
5	propylene	234.6	55.1	14.2	9.0	157.6	14.1	137.7	5.0
6	propane	5.5	1.4	0.9	0.3			3.0	
7	propyne	24.9	7.4	0.4	0.1	10.8	1.8	7.8	
8	isobutane	74.6	16.5	6.1	1.4	44.2	4.1	37.1	10.0
9	isobutene/1-butene	104.0	22.7	7.7	3.2	70.1	8.3	61.4	6.5
10	13-butadiene	50.3	5.0	3.1		37.5	5.2	30.5	3.5
11	n-butane	156.3	36.5	12.1	3.7	92.1	6.0	74.3	18.9
12	t2-butene	27.4	6.7	1.9	0.9	17.5	2.3	14.6	3.0
13	22-dm-propane	0.8	0.1	0.2	0.1	0.6	0.2	0.4	0.1
14	1-butyne	0.9	0.2			0.7	0.1	0.3	0.0
15	c2-butene	25.3	7.5	1.9	1.0	15.2	3.4	12.0	1.2
16	12-butadiene								
17	3m1-butene	6.8	1.5	0.4	0.2	4.5	0.4	4.1	0.8
18	2m-butane	212.4	55.9	11.8	3.4	120.5	12.3	91.1	23.8
19	14-pentadiene	1.8	0.6	0.4	0.3	2.6	1.6	3.7	0.3
20	2-butyne	1.7	0.3			1.1	0.1	1.0	0.3
21	1-pentene	12.7	3.0	0.6	0.3	7.8	0.6	6.6	1.5
22	2m1-butene	17.7	3.4	1.0	0.5	9.4	1.3	9.6	3.2
23	n-pentane	113.0	31.0	6.0	2.4	62.1	6.1	45.6	10.9
24	2m-13-butadiene	12.3	2.7	1.0	0.3	10.7	2.0	8.3	0.6
25	t2-pentene	20.2	4.6	1.0	0.4	11.9	1.0	9.1	1.8
26	c2-pentene	11.5	2.7	0.6	0.2	7.1	0.7	5.3	0.9
27	2m2-butene	26.4	2.9	1.7	0.8	20.6	1.9	13.2	0.4
28	22-dm-butane	33.2	8.2	2.1	0.7	19.1	1.8	14.3	2.8
29	cyclopentene	3.3	4.5	0.4	0.2	5.1	0.6	4.2	0.7
30	4m1 & 3m1-pentene	4.1	0.9	0.1	0.1	1.9	1.3	1.6	1.0
31	cyclopentane	23.4	6.9	1.1	0.4	12.6	1.3	8.8	2.1
32	23-dm-butane	34.7	10.0	1.7	0.7	18.5	1.7	13.2	3.2
33	c/t-4m2-pentene								
34	2m-pentane	154.0	44.3	7.3	3.3	81.6	8.9	56.5	13.3
35	3m-pentane	100.6	29.5	4.8	2.1	52.5	5.6	36.1	8.5
36	2m1-pentene	5.4	1.8			2.5	0.4	2.1	0.8
37	1-hexene	5.3	1.3	0.2	0.1	3.2	0.4	2.8	0.6
38	n-hexane	95.4	28.2	4.3	1.8	48.3	5.5	31.7	7.5
39	c/t-3-hexene	5.7	1.4	0.2	0.1	3.0	0.5	2.0	0.4
40	t2-hexene	8.1	2.2	0.3	0.1	4.7	0.7	3.3	0.7
41	2m2-pentene	12.0	2.4	0.5	0.2	7.7	1.0	5.0	0.8

Index		Cold Start -10°C		Hot Start -10°C		Cold Start 0°C		Cold Start 24°C	
		Average	Std.Dev.	Average	Std.Dev.	Average	Std.Dev.	Average	Std.Dev.
42	t-3m2-pentene	6.0	1.3	0.3	0.2	4.8	0.8	2.7	0.5
43	c2-hexene	4.5	1.3	0.2	0.1	2.5	0.4	1.7	0.4
44	c-3m2-pentene	8.3	1.0	0.3	0.1	5.4	0.9	3.3	0.4
45	22-dm-pentane			0.2					
46	m-cyclopentane	128.0	38.8	5.4	2.7	65.4	7.7	42.2	9.9
47	24-dm-pentane	13.5	3.3	0.7	0.2	8.1	1.4	5.0	0.7
48	223-tm-butane	1.3	0.2	0.1	0.0	1.2	0.5	0.7	0.1
49	1m-cyclopentene	1.2	0.0	0.1					
50	benzene	266.1	68.8	17.3	1.8	149.7	33.3	97.6	0.0
51	33-dm-pentane	6.1	1.6	0.3	0.1	3.4	0.6	2.3	0.4
52	cyclohexane	25.8	7.9	1.1	0.6	13.4	1.5	8.0	2.0
53	2m-hexane	61.6	18.2	3.0	1.1	33.2	5.3	20.4	4.9
54	23-dm-pentane	19.2	5.3	1.0	0.4	10.4	1.5	6.6	1.6
55	11-dm-cyP	3.9	0.9	0.3	0.2	2.1	0.3	1.4	0.3
56	cyclohexene	2.0	0.5	0.2	0.1	1.4	0.2	1.1	0.3
57	3m-hexane	64.3	19.0	3.3	1.2	34.7	5.5	21.2	5.1
58	c-13-dm-cyP	13.0	3.6	0.7	0.4	7.0	0.9	4.2	1.0
59	3e-pentane/t-13-dm-cyP	21.5	6.1	1.1	0.5	11.5	1.7	7.1	1.8
60	t-12-dm-cyP	10.3							
61	224-tm-pentane/1-heptene	43.8	18.0	2.3	0.3	24.9	4.0	15.4	3.9
62	t3-heptene	3.6	1.2	0.2	0.1	1.8	0.4	1.0	0.4
63	n-heptane	70.0	21.5	3.2	1.0	37.4	7.1	21.8	5.0
64	c3-heptane	8.9	2.7	0.3	0.1	5.0	1.0	2.6	0.6
65	t2-heptene	3.5	1.2	0.2	0.0	1.8	0.4	1.1	0.3
66	c2-heptene	3.3	1.0	0.2	0.0	1.9	0.5	1.0	0.2
67	22-dm-hexane	1.0	0.3			0.6	0.1	0.4	0.1
68	m-cyH/c12-dm-cyP/113-tm-cyP	29.4	8.4	1.2	0.2	15.6	2.3	9.1	2.2
69	12-dm-cyH	2.5	0.8	0.2	0.1	1.4	0.2	1.0	0.1
70	25-dm-hexane/e-cyP	21.0	6.6	1.0	0.2	11.0	2.0	6.4	1.6
71	24-dm-hexane/223-tm-pentane	22.3	7.2	1.1	0.2	11.9	2.3	6.6	1.7
72	33-dm-hexane/ctc-124-tm-cyP	8.8	2.5	0.3	0.1	4.6	0.9	2.8	0.6
73	ctc-123-tm-cyP	3.8	1.0	0.3	0.1	2.1	0.5	1.2	0.3
74	234-tm-pentane	20.2	4.9	0.8	0.1	9.8	2.3	5.3	1.2
75	toluene/233-tm-pentane	783.0	242.9	64.0	52.9	303.7	89.4	186.6	26.7
76	23-dm-hexane/2m3e-pentane	0.8	0.2			0.5		0.3	
77	112-tm-cyP	2.1	0.8			1.0	0.3	0.6	0.1
78	2m-heptane	38.6	12.2	2.3	1.1	19.8	4.1	11.3	2.6
79	4m-C7/3m3e-C5/1m-cyHexene	14.5	4.7	0.9	0.5	7.5	1.5	4.4	1.1
80	34-dm-hexane	6.1	1.8	0.6	0.4	3.3	0.6	2.0	0.5
81	3m-heptane	48.4	15.5	2.7	1.2	24.8	5.1	14.0	3.4
82	3e-hexane								
83	cct-124-tm-cyP/c-13-dm-cyH	9.4	2.9	0.7	0.4	4.9	0.9	2.8	0.7
84	t-14-dm-cyH	2.8	0.8	0.3	0.2	1.5	0.3	0.9	0.2
85	225-tm-hexane	6.3	2.1	0.6	0.5	3.0	0.7	1.8	0.6
86	11-dm-cyH								
87	1-octene	7.1	2.2	0.7	0.3	3.8	0.8	2.2	0.5
88	1e1m-cyP	3.4	1.4	0.5	0.5	1.6	0.4	0.7	0.2
89	n-octane/t-12-dm-cyH	47.7	15.5	2.2	0.6	22.7	5.1	12.4	3.1
90	224-tm-hexane								
91	t2-octene	3.8	1.3	0.2	0.1	1.8	0.4	1.0	0.3
92	ccc-123-tm-cyP	9.8	3.4	0.8		5.1	1.0	3.6	0.9
93	244-tm-hexane	3.3	0.9			1.5	0.4		
94	c2-octene	1.6	0.7					0.6	

Index		Cold Start -10°C		Hot Start -10°C		Cold Start 0°C		Cold Start 24°C	
		Average	Std.Dev.	Average	Std.Dev.	Average	Std.Dev.	Average	Std.Dev.
95	ip-cyP	2.5	0.9	0.2		1.3	0.3	0.8	0.2
96	235-tm-hexane	2.5	0.9			1.3	0.3	0.8	0.2
97	44&22-dm-heptane	1.6	0.7	0.1		0.8	0.3	0.7	0.1
98	24-dm-heptane	8.6	3.0	0.6	0.3	4.3	0.9	2.5	0.6
99	26-dm-heptane/c-12-dm-cyH	9.2	3.2	0.5	0.1	4.5	0.9	2.7	0.6
100	np-cyP/ccc-135-tm-cyH/e-cyH	2.9	1.1			1.4	0.3	0.8	0.2
101	25-dm-heptane	15.6	4.7	0.5	0.1	6.8	1.4	3.8	1.0
102	33-dm-heptane	4.2	1.4			1.8	0.4	1.1	0.3
103	114-tm-cyH	4.7	1.4	0.2		2.0	0.4	1.2	0.3
104	e-benzene	165.5	54.1	8.1	0.4	71.0	21.7	42.6	7.1
105	ctt-124-tm-cyH	4.1	1.0	0.6	0.4	2.3	0.3	1.2	0.6
106	35-dm-heptane	4.6	1.9	0.6		2.2	0.4	1.2	0.5
107	m&p-xylene/23-dm-heptane	533.9	186.0	21.5	2.3	205.4	67.7	122.6	21.7
108	34-dm-heptane/4m-octane	32.8	11.1	1.9		14.5	3.0	8.4	2.2
109	2m-octane/246-tm-hexane	25.4	8.5	1.2	0.1	12.2	1.8	7.1	1.5
110	ctc-124-tm-cyH	29.7	7.0	1.0	0.6	1.1	0.3	8.9	0.3
111	3m-octane/33-de-C5/3e-C7	2.9							
112	o-xylene	224.2	79.3	9.4	1.9	89.3	27.3	54.3	10.2
113	112-tm-cyH								
114	1-nonene	6.9	2.4	0.2		3.4	0.2	1.9	0.5
115	t3-nonene	4.1	1.6			1.9	0.1	0.8	0.2
116	ib-cyP								
117	c3-nonene	3.0	1.1			1.4	0.0	0.7	0.2
118	n-nonane	19.9	6.5	0.8	0.0	8.3	1.5	4.4	0.9
119	t2-nonene	1.9	0.7			0.8	0.1		
120	c2-nonene	4.4	1.3			2.4	0.2	1.1	0.3
121	ip-benzene	14.5	4.4	0.6	0.1	6.4	1.3	3.7	0.9
122	22-dm-octane	5.0	1.7			1.4	1.1	0.7	0.5
123	ip-cyH	8.9	3.2	0.2	0.3	4.0	0.3	1.8	0.3
124	nb-cyP	12.3	3.6	0.7	0.6	4.4	0.9	2.8	1.1
125	33-dm-octane	1.3	0.4	0.1	0.2	0.9	0.1	0.5	0.3
126	np-benzene	45.6	15.7	2.6	1.3	16.1	4.6	10.0	2.1
127	3e-toluene	147.3	49.4	5.3	0.1	51.1	19.1	31.7	6.9
128	23-dm-octane								
129	4e-toluene	63.1	21.7	1.8	0.4	21.0	7.2	12.4	2.8
130	135-tm-benzene	79.4	26.6	2.5	0.1	28.5	8.9	17.0	3.3
131	2m-nonane	11.4	3.6	0.3	0.4	3.9	0.8	1.3	0.5
132	3e-octane	2.8	0.8			1.0	0.0	0.4	0.0
133	3m-nonane								
134	2e-toluene	65.8	20.1	1.8	2.6	24.4	7.0	15.1	2.9
135	124-tm&tb-benzene/1-decene	211.8	72.4	6.0	0.5	68.6	24.3	42.7	7.5
136	ib-cyH	0.5							
137	n-decane	6.0	1.3	0.4	0.0	3.0	0.5	1.5	0.1
138	ib-benzene	4.5	2.4			1.7	0.3	0.6	0.2
139	sb-benzene	3.9	1.8	0.5	0.7	1.6	0.2	0.8	0.2
140	3-ip-toluene	1.5		0.5	0.7	1.0	0.1	1.3	0.0
141	123-tm-benzene	8.3	5.9			2.3	0.5	1.5	0.4
142	4-ip-toluene	43.7	19.2	2.0	0.7	15.5	5.3	9.8	2.1
143	indan	0.8	0.5	1.8	2.6	0.8	0.0	0.5	0.2
144	2-ip-toluene	25.1	14.1	0.7	0.9	7.9	2.6	4.9	1.1
145	13-de-benzene								
146	14-de-benzene	21.4	10.7	2.5	2.2	3.7	4.1	1.5	1.4
147	3-np-toluene	8.4	2.2	0.8	0.1	3.7	0.7	2.6	0.5

Index		Cold Start -10°C		Hot Start -10°C		Cold Start 0°C		Cold Start 24°C	
		Average	Std.Dev.	Average	Std.Dev.	Average	Std.Dev.	Average	Std.Dev.
148	4-np-toluene/nb-&13dm-5e-benz	36.3	15.3	0.8	1.2	13.2	4.1	8.4	1.2
149	12-de-benzene	3.9	1.5	0.8	1.2	1.6	0.4	1.0	0.2
150	2-np-toluene	1.2		1.3	1.9	0.7	0.2	0.4	0.1
151	14-dm-2e-benzene	18.4	10.3	0.4	0.6	6.7	1.9	4.6	0.8
152	13-dm-4e-benzene	13.1	6.4	1.2	1.2	4.7	1.6	3.2	0.5
153	12-dm-4e-benzene	21.6	10.3	1.4	1.0	7.6	2.6	4.9	0.9
154	13-dm-2e-benzene	7.2	3.2	1.0	0.9	2.7	0.6	1.8	0.4
155	n-undecane/12-dm-3e-benzene	3.5		1.1	1.1	1.9	0.5	1.4	0.1
156	1245-ttm-benzene	4.8	2.0	0.7	1.0	1.6	0.8	0.9	0.3
157	2mb-benzene	9.4	4.9	0.5	0.1	2.9	0.9	2.0	0.4
158	tb-2m-benzene	1.2	0.0			0.6	0.1	0.4	0.1
159	1234-ttm-benzene	6.7	3.1	0.5	0.7	2.1	0.6	1.5	0.4
160	n-pentylbenzene	7.1	3.6	0.6	0.4	1.9	0.9	1.5	0.4
161	tb-35-dm-benzene	1.1	0.5	0.1	0.1	0.4	0.1	0.5	0.1
162	tb-4e-benzene			0.6	0.8				
163	n-dodecane	1.5		3.0	3.3	1.1	0.1	1.1	0.3

Table 10 reports the average and standard deviation for each of the volatile organic compound emissions for the cold start Garage tests conducted using the second test fuel. Data are reported in units of mg/test. . The complete data set is reported in Appendix 1.

Table 10. Volatile organic compound mass emissions for the cold start Garage Test conducted using the second test fuel (mg/test).

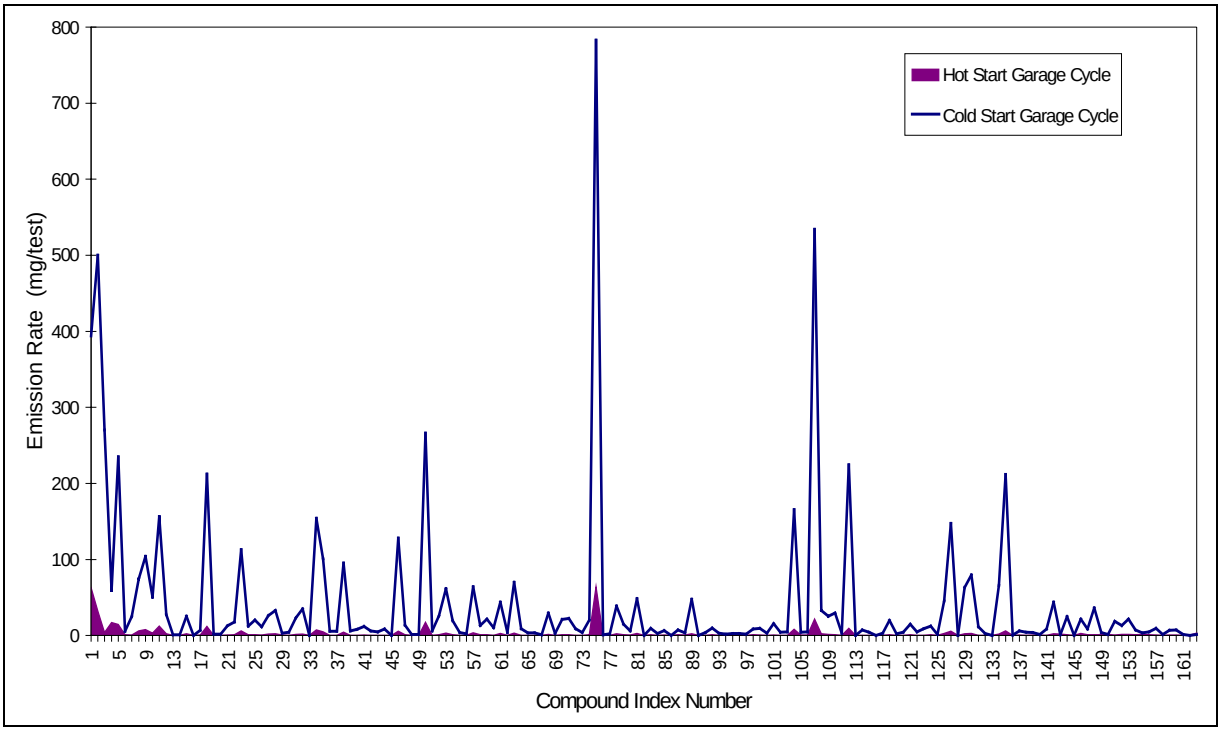
Index		Cold Start 0°C	
		Average	Std.Dev.
1	methane	197.4	2.8
2	ethylene	397.8	17.0
3	acetylene	120.2	7.1
4	ethane	53.3	5.6
5	propylene	191.2	3.3
6	propane	144.9	
7	propyne	12.8	2.6
8	isobutane	29.2	5.4
9	isobutene/1-butene	60.5	12.9
10	13-butadiene	33.7	5.5
11	n-butane	149.4	21.4
12	t2-butene	14.4	2.1
13	22-dm-propane	0.6	0.1
14	1-butyne	0.5	0.2
15	c2-butene	13.0	0.7
16	12-butadiene		
17	3m1-butene	4.5	0.7
18	2m-butane	125.5	24.2
19	14-pentadiene	1.7	0.9
20	2-butyne	1.2	0.1
21	1-pentene	7.8	1.0
22	2m1-butene	10.9	2.4
23	n-pentane	78.5	13.8
24	2m-13-butadiene	10.1	0.8
25	t2-pentene	13.6	1.5
26	c2-pentene	7.5	0.8

Index		Cold Start 0°C	
		Average	Std.Dev.
27	2m2-butene	22.1	1.9
28	22-dm-butane	13.2	2.4
29	cyclopentene	6.3	0.9
30	4m1 & 3m1-pentene	0.7	0.2
31	cyclopentane	13.0	2.6
32	23-dm-butane	16.8	3.2
33	c/t-4m2-pentene		
34	2m-pentane	81.3	14.8
35	3m-pentane	48.2	8.7
36	2m1-pentene	2.5	0.6
37	1-hexene	2.7	0.4
38	n-hexane	42.1	7.7
39	c/t-3-hexene	2.6	0.4
40	t2-hexene	3.9	0.5
41	2m2-pentene	6.7	0.7
42	t-3m2-pentene	4.3	0.5
43	c2-hexene	2.1	0.3
44	c-3m2-pentene	4.6	0.6
45	22-dm-pentane	1.9	0.2
46	m-cyclopentane	31.5	5.9
47	24-dm-pentane	6.7	0.9
48	223-tm-butane	0.8	0.1
49	1m-cyclopentene	0.7	0.0
50	benzene	74.3	14.5
51	33-dm-pentane	2.6	0.3
52	cyclohexane	6.7	1.2
53	2m-hexane	24.0	3.3
54	23-dm-pentane	8.6	1.3
55	11-dm-cyP	0.9	0.1
56	cyclohexene	1.0	0.1
57	3m-hexane	25.5	3.6
58	c-13-dm-cyP	4.6	0.6
59	3e-pentane/t-13-dm-cyP	7.8	1.0
60	t-12-dm-cyP		
61	224-tm-pentane/1-heptene	15.1	2.2
62	t3-heptene	1.2	0.1
63	n-heptane	22.8	3.4
64	c3-heptane	3.5	0.3
65	t2-heptene	1.1	0.1
66	c2-heptene	1.5	0.1
67	22-dm-hexane	0.5	0.0
68	m-cyH/c12-dm-cyP/113-tm-cyP	9.0	1.2
69	12-dm-cyH	0.8	0.1
70	25-dm-hexane/e-cyP	6.7	1.0
71	24-dm-hexane/223-tm-pentane	7.1	0.9
72	33-dm-hexane/ctc-124-tm-cyP	2.7	0.4
73	ctc-123-tm-cyP	1.3	0.1
74	234-tm-pentane	8.8	1.0
75	toluene/233-tm-pentane	81.3	10.7
76	23-dm-hexane/2m3e-pentane	0.1	
77	112-tm-cyP	0.8	0.0
78	2m-heptane	10.9	1.2
79	4m-C7/3m3e-C5/1m-cyHexene	3.9	0.5

Index		Cold Start 0°C	
		Average	Std.Dev.
80	34-dm-hexane	1.8	0.2
81	3m-heptane	13.3	1.5
82	3e-hexane		
83	cct-124-tm-cyP/c-13-dm-cyH	3.3	0.5
84	t-14-dm-cyH	1.0	0.2
85	225-tm-hexane	2.1	0.3
86	11-dm-cyH		
87	1-octene	2.5	0.3
88	1e1m-cyP	1.1	0.1
89	n-octane/t-12-dm-cyH	10.8	1.2
90	224-tm-hexane		
91	t2-octene	1.3	0.1
92	ccc-123-tm-cyP	3.5	0.4
93	244-tm-hexane	1.2	0.0
94	c2-octene	0.6	0.1
95	ip-cyP	1.0	0.1
96	235-tm-hexane	0.8	0.1
97	44&22-dm-heptane	0.5	0.1
98	24-dm-heptane	2.5	0.2
99	26-dm-heptane/c-12-dm-cyH	2.7	0.3
100	np-cyP/ccc-135-tm-cyH/e-cyH	1.1	0.1
101	25-dm-heptane	7.4	6.3
102	33-dm-heptane	2.1	1.5
103	114-tm-cyH	2.5	1.3
104	e-benzene	33.6	4.6
105	ctt-124-tm-cyH	1.4	0.4
106	35-dm-heptane		
107	m&p-xylene/23-dm-heptane	107.5	12.3
108	34-dm-heptane/4m-octane	7.0	1.0
109	2m-octane/246-tm-hexane	5.8	0.8
110	ctc-124-tm-cyH	1.0	0.2
111	3m-octane/33-de-C5/3e-C7		
112	o-xylene	49.1	4.7
113	112-tm-cyH		
114	1-nonene	2.6	0.2
115	t3-nonene	1.2	0.2
116	ib-cyP		
117	c3-nonene	1.1	0.1
118	n-nonane	4.1	0.4
119	t2-nonene	0.7	0.0
120	c2-nonene	2.0	0.1
121	ip-benzene	3.2	0.1
122	22-dm-octane	0.9	
123	ip-cyH	2.4	0.0
124	nb-cyP	3.7	0.3
125	33-dm-octane	0.5	0.0
126	np-benzene	7.1	0.1
127	3e-toluene	24.9	3.9
128	23-dm-octane		
129	4e-toluene	11.0	1.2
130	135-tm-benzene	15.2	0.5
131	2m-nonane	1.6	0.2
132	3e-octane	1.2	0.2

Index		Cold Start 0°C	
		Average	Std.Dev.
133	3m-nonane		
134	2e-toluene	12.9	0.1
135	124-tm&tb-benzene/1-decene	33.9	1.6
136	ib-cyH	0.1	0.2
137	n-decane	1.7	0.4
138	ib-benzene		
139	sb-benzene	0.9	0.3
140	3-ip-toluene	0.4	0.4
141	123-tm-benzene	8.3	0.2
142	4-ip-toluene		
143	indan	0.5	0.2
144	2-ip-toluene	3.8	0.0
145	13-de-benzene	1.9	1.9
146	14-de-benzene	2.2	0.0
147	3-np-toluene	3.7	0.0
148	4-np-toluene/nb-&13dm-5e-benz	0.9	0.2
149	12-de-benzene	0.5	0.1
150	2-np-toluene	3.6	0.1
151	14-dm-2e-benzene	2.8	0.1
152	13-dm-4e-benzene	5.2	0.1
153	12-dm-4e-benzene	1.8	0.0
154	13-dm-2e-benzene	1.6	0.1
155	n-undecane/12-dm-3e-benzene	1.5	0.1
156	1245-ttm-benzene	1.6	0.0
157	2mb-benzene	2.4	0.1
158	tb-2m-benzene	1.3	0.1
159	1234-ttm-benzene	0.6	0.3
160	n-pentylbenzene	1.3	0.1
161	tb-35-dm-benzene	0.4	0.0
162	tb-4e-benzene	2.1	1.1
163	n-dodecane	1.0	0.0

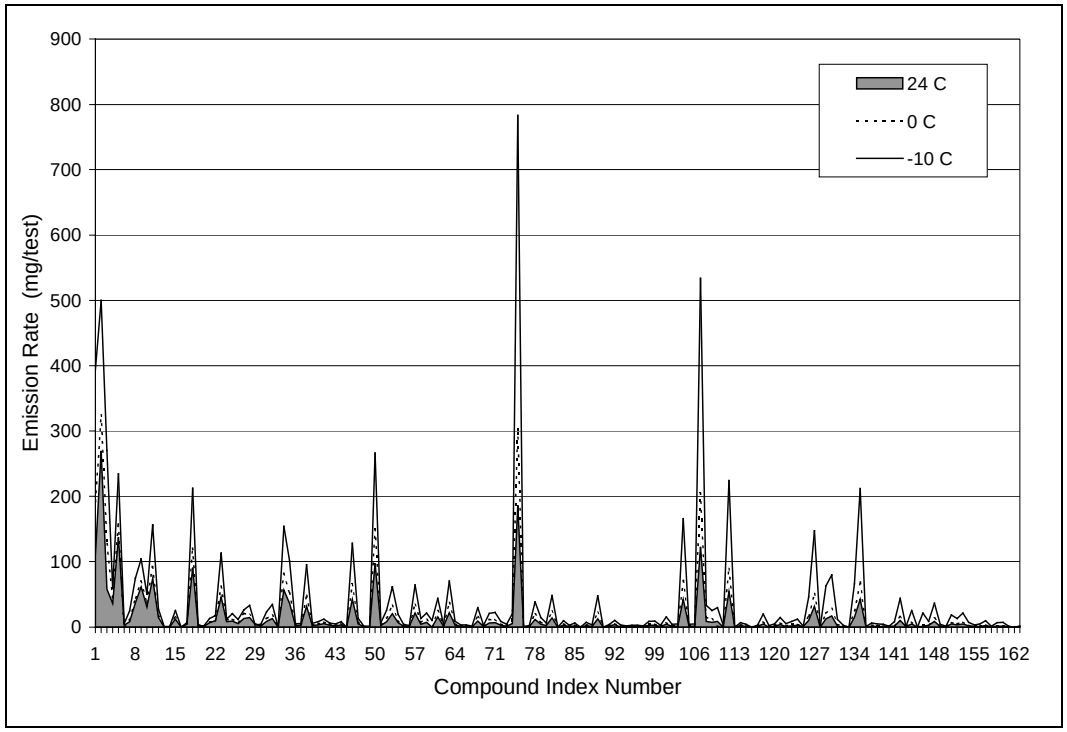
Figure 5. Comparison of cold start and hot start VOC emissions profiles using the first test fuel.



In Figure 5, the Compound Index Number corresponds to the order in which the compounds are listed in Table 9. The VOC emissions profile for the cold start is very similar to the emissions seen with pre-control vehicles, specifically the amount of acetylene in the emissions. Acetylene has been used as an indicator of motor vehicle emissions in atmospheric studies. As the only other significant sources of acetylene are welding operations, it may serve as a tracer species to track motor vehicle emissions infiltration for the cold start at least. This cannot be done in outdoor environments as it is quite photochemically reactive, but it may be useful in indoor studies such as this.

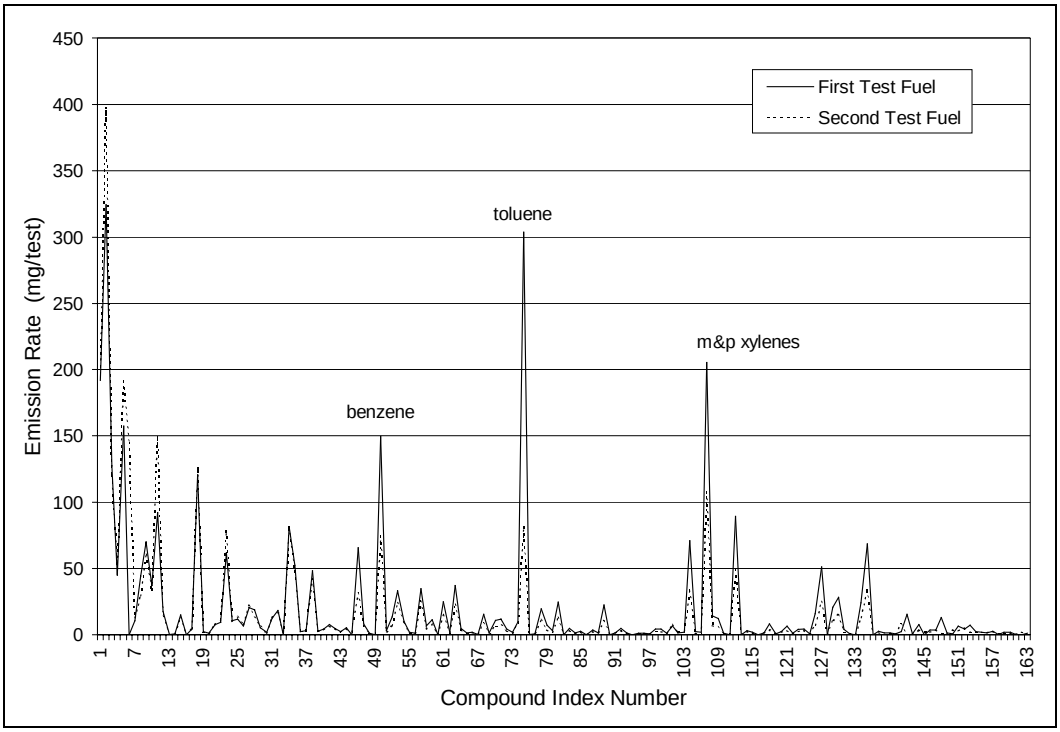
Figure 6 compares the cold start Garage Cycle VOC emissions for the first test fuel at three test temperatures. The trend observed in the THC emissions – that of decreasing emissions with increasing temperature is reflected in these profiles. The decrease in emission rate is greater with the heavier compounds (higher ID number) as these compounds are present as a result of unburned fuel from the fuel rich air/fuel mixture during the initial part of the vehicle start. As the temperature increases, the vehicle requires a less rich mixture to start.

Figure 6. Comparison of Cold Start Garage Cycle VOC emissions for the three test temperatures using the first test fuel.



A comparison of the cold start emission profiles at 0°C for the two test fuels is shown in Figure 7. The second test fuel shows lower emissions of aromatic compounds (benzene, toluene and the xylenes) as compared to the first fuel, and also shows higher emissions of unsaturated compounds (ethylene, propylene) and lighter saturated hydrocarbons (n-butane and 2m-butane).

Figure 7. Comparison of Cold Start Garage Cycle VOC emissions for the two test fuels at 0°C.



5.1.1.3 Carbonyl Compounds

Table 11 reports the average and standard deviation for each of the carbonyl compound mass emissions obtained from tests using the first test fuel. Data are reported in units of mg/test. A missing value indicates compound was below detection limits in the sample. The Cold Start -10°C data is an average of 3 test repeats, the Hot Start is an average of 2 test repeats and the Cold Start 0°C and 24°C are each an average of 2 test repeats. Instances of non-detects were not included in the calculation of the average. Where no standard deviation is reported, the value reported as average is the amount from only one sample that was found above the detection limit. The complete data set is reported in Appendix 1.

Table 11. Carbonyl compound mass emissions for the Cold Start and Hot Start Garage Test Cycle (mg/test).

	Cold Start -10°C		Hot Start -10°C		Cold Start 0°C		Cold Start 24°C	
	Average	Std. Dev.	Average	Std. Dev.	Average	Std. Dev.	Average	Std. Dev.
Formaldehyde	148	16	8.1					
Acetaldehyde	298	53.9	27					
2-3 butandione								
Acrolein	22							
Acetone	101	32			146			
Propionaldehyde	25	2						
Methoxyacetone								
Crotonaldehyde								
Methyl Vinyl Ketone								
Methacrolein	34							
Methyl Ethyl Ketone	33				90			
Isobutyraldehyde & Butyraldehyde								
Benzaldehyde	97							
Isovaleraldehyde								
Trimethylacetaldehyde & 3m2-Butanone					42			
Valeraldehyde								
Acetophenone								
o-Tolualdehyde								
m&p-Tolualdehyde								
Methyl isobutyl Ketone								
Pinacolone								
Hexanaldehyde								

Again, cold start emissions are substantially greater than the hot start emissions at -10°C. Carbonyl compounds are products of incomplete combustion, so it is not surprising that they are found at higher levels in the cold start emissions. Only one of two hot start tests showed any measurable carbonyl levels. These values were very near the detection limits for the method as given in Table 5. For the cold start at -10°C, only formaldehyde, acetaldehyde and propionaldehyde were reliably detected. Acetone showed a large variability and the other compounds with values reported were found in only one of the samples. The cold start tests at 0°C and 24°C showed no measurable carbonyl emissions. The carbonyl samples collected on the cold start Garage cycle tests conducted on the second fuel were lost (due to a power failure affecting the storage refrigerator) before they could be analysed. They were not expected to show results any different from the 0°C tests on the first fuel.

5.1.2 Modal Emissions

The modal emissions data presented in this section illustrate where in the test cycle the emissions occur. For the tailpipe emissions, data was acquired at 2 second intervals over the 300 second test, thus excellent time resolution is achieved. The emissions profiles are shown with the Garage test cycle overlaid, so the impact of the back-up manoeuvre can be seen. Modal emissions data were collected only on the tests conducted using the first test fuel. Again, the trends shown in this data are not expected to show any differences due to the use of the second test fuel.

5.1.2.1 Emission Rate Profiles

Figure 8 through Figure 11 show the mass emission rate (g/s) versus time for both cold start and hot start garage tests. Clearly, in both the cold start and hot start tests, for CO, NO_X and HC, the largest emissions can be attributed to the crank (starting the engine). The load placed on the vehicle during the back-up manoeuvre is very small in comparison. Also, the shape of the emissions profiles differs for the cold start and the hot start, mainly due to the residual heat in the engine which allows it to reach stoichiometric combustion more quickly and the residual heat in the catalyst which allows it to

return to optimum operating temperature more quickly. During the cold start, the engine must operate in a fuel rich mode longer to keep the engine from stalling. From these figures, it appears that the duration of peak emissions is approximately 90-110 s for the cold start and 40-50 s for the hot start. This should be an indication of how long the actual tests at the residences should be. The hot start operation may be more difficult to track at the residences as both tracers, CO and acetylene, are emitted in much lower amounts. Based on these profiles, the tailpipe VOC emission profiles will be dominated by crank emissions. The NO_X emissions profile for the cold start test reflects the complex chemistry that is occurring on the catalyst as it warms up and as the hydrocarbon concentration in the exhaust gas decreases. The NO_X emission rate drops quite quickly after 20-30 s, indicating the catalyst has reached a minimum operating temperature for reducing NO_X. Note also the increase in NO_X when the vehicle is "backed up" (i.e. placed under load) in the cold start garage cycle.

Figure 12 and Figure 13 show the comparison of CO and HC emission profiles for the three test temperatures. For CO there is very little difference in the emission profiles for the -10°C and 0°C tests. The profile for CO at 24°C shows a smaller peak rate of emission and a narrower profile. The CO emissions drop after approximately 35 seconds as compared to approximately 80 seconds for the -10°C and 0°C tests. The HC emission rate profiles show a gradual decrease in peak emission rate and a gradual narrowing of the profile with increasing temperature. A shoulder begins to emerge in the peak emission rate in the first 15 seconds. The source of this phenomenon is not known, but could be due to air/fuel ratio control of the engine.

Figure 8. Typical CO_2 emission rate profiles for Garage Test at -10°C.

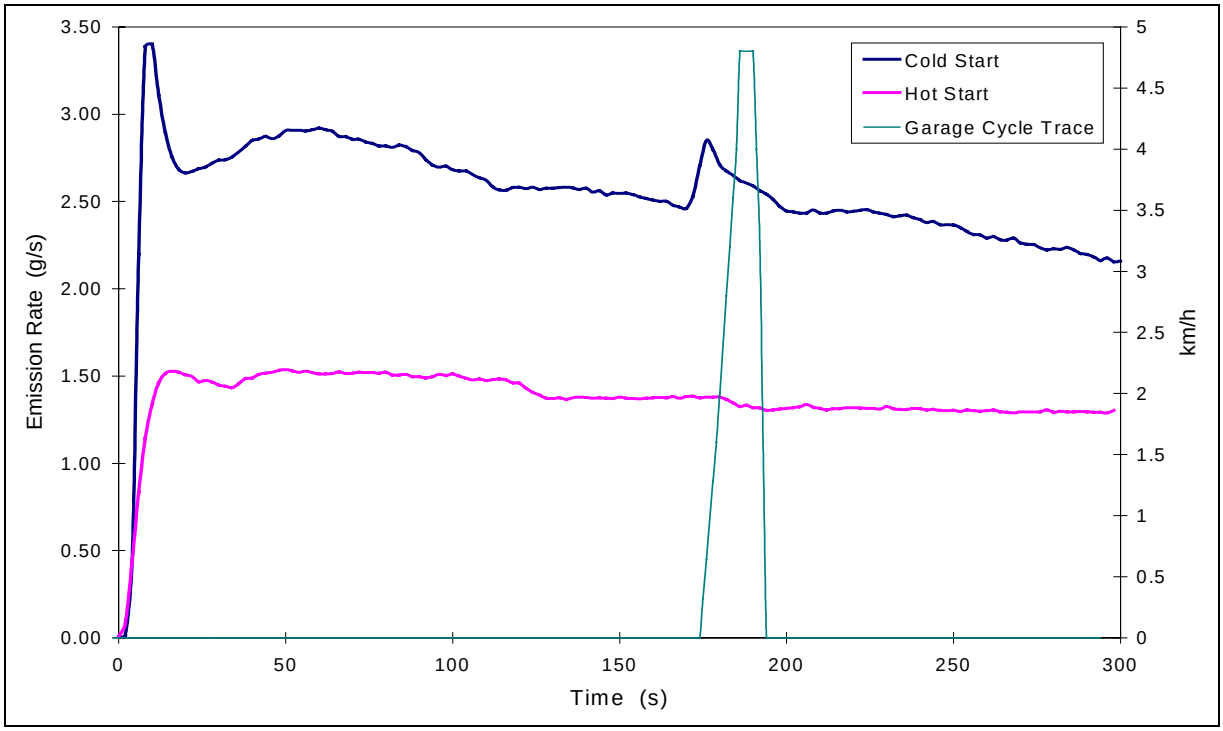


Figure 9. Typical CO emission rate profiles for Garage Test at -10°C.

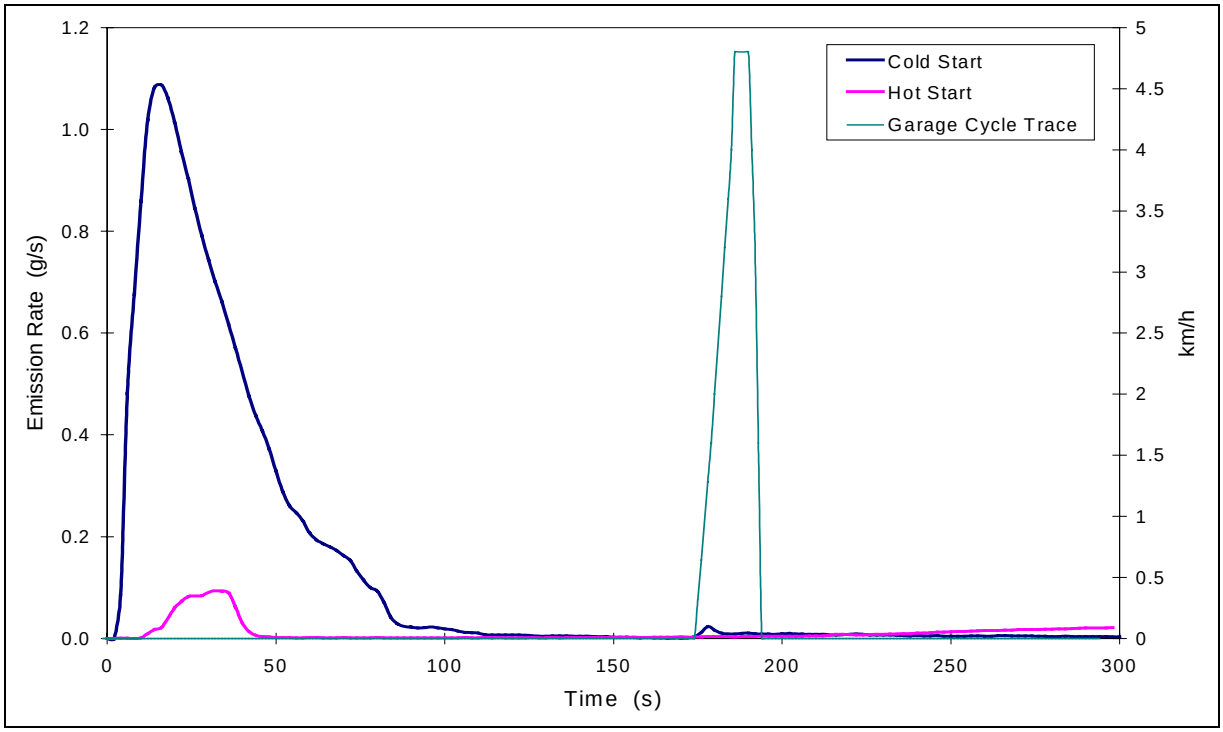


Figure 10. Typical NO_X emission rate profiles for Garage Test at -10°C.

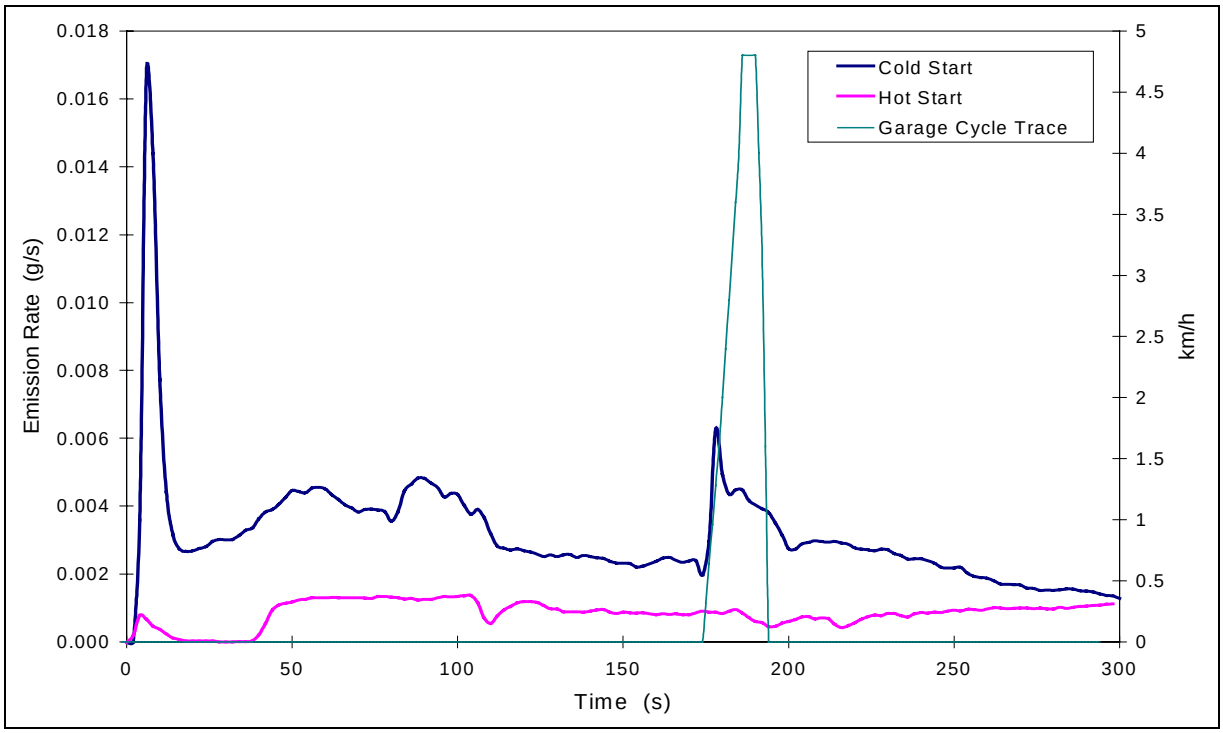


Figure 11. Typical HC emission rate profiles for Garage Test at -10°C.

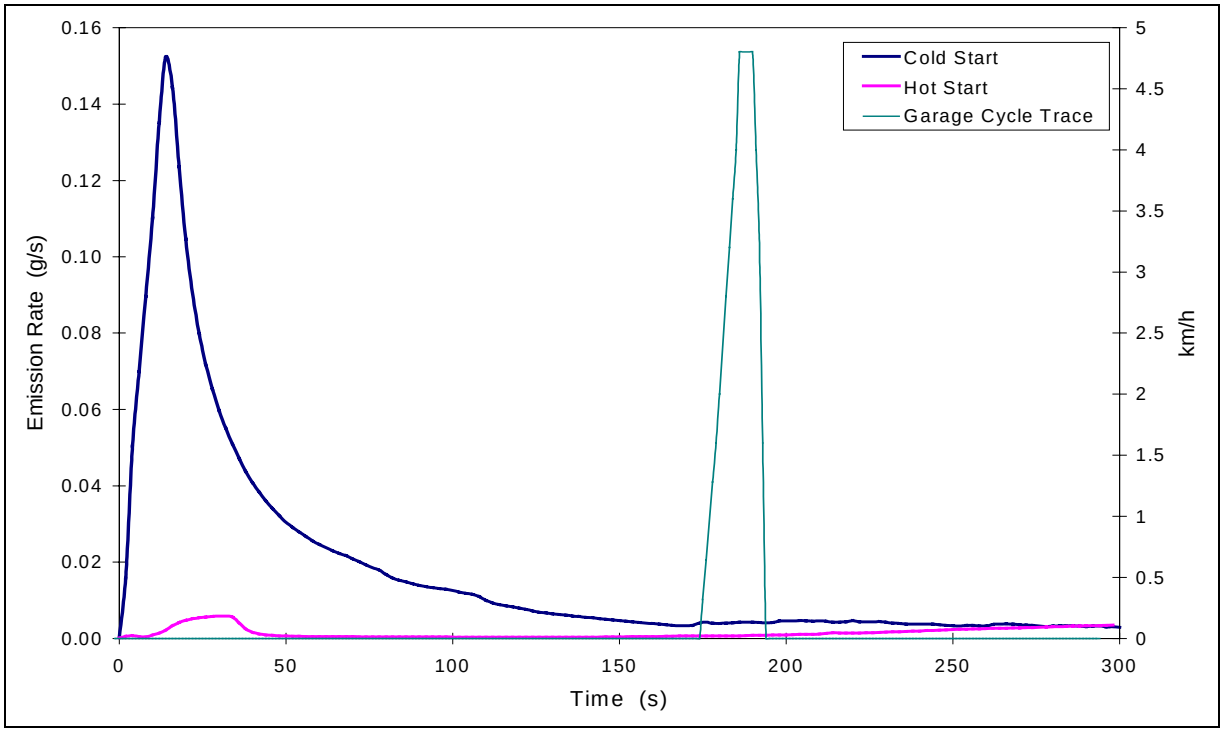


Figure 12. Comparison of cold start CO emission rate profiles for the three test temperatures.

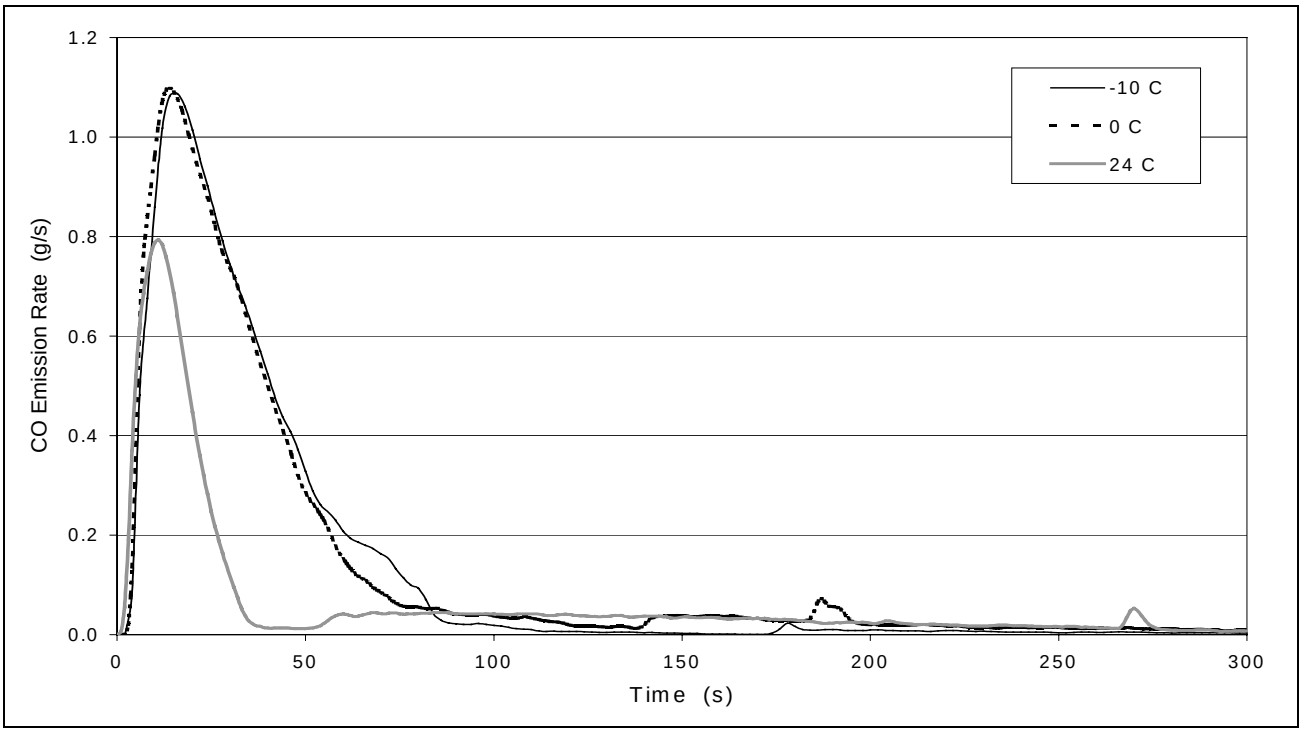
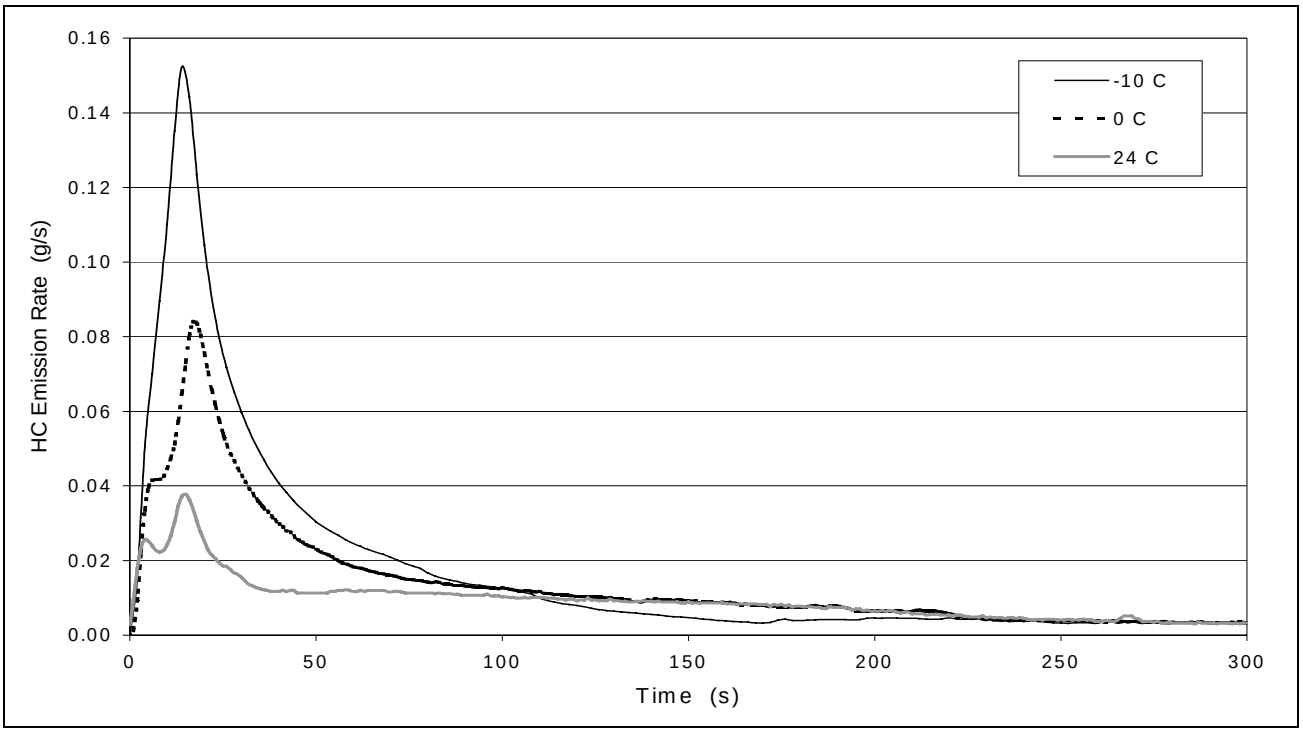


Figure 13. Comparison of cold start HC emission rate profiles for the three test temperatures.



5.1.2.2 Temperature Profiles

The profiles for pre- and post-catalyst exhaust gas temperatures give an indication of how long it takes for the catalyst to reach optimum operating temperature and how much heat is retained by the exhaust system during the 10-minute soak after the LA-4 warm-up. Temperatures of interest are summarised in Table 12.

Table 12. Exhaust gas temperatures at different times during the driving cycle (test temperature -10°C).

	Pre-Catalyst Exhaust Gas Temperature (°C)	**Post-Catalyst Exhaust Gas Temperature (°C)**
Maximum during LA-4 warm-up	570	580
Maximum during cold start Garage Cycle	287	350
Maximum during hot start Garage Cycle	180	330

The cold start garage cycle pre-catalyst temperature reached a maximum of only 287 °C at the end of the 300 s, well below the temperature of highest efficiency reached during the LA-4 warm-up. The hot start test began with a pre-catalyst temp of 32 °C and reached a maximum of 180 °C. The post-catalyst temperature begins at 130 °C, increases to 330 °C and drops slightly toward the end of the test as the engine reaches an efficient idle point quite quickly. This data is shown in Figure 14. As suggested by the NO_X emission rate profile in Figure 10, the minimum operating temperature is reached after 20-30 s. This temperature is approximately 170 °C.

The fuel tank temperature profile was valid for only one of the test sequences. The data showed a continuous rise from the cell temperature of -10 °C to about 3 °C at the end of the LA-4 warm-up. During both the cold start and the hot start garage tests the fuel tank temp did not change significantly. This data is shown in Figure 15. The oil pan thermocouple was not located properly so no data was obtained. No temperature data was collected on the 0°C and 24°C cold start tests.

Figure 14. Typical catalyst temperatures for the Garage test at -10°C.

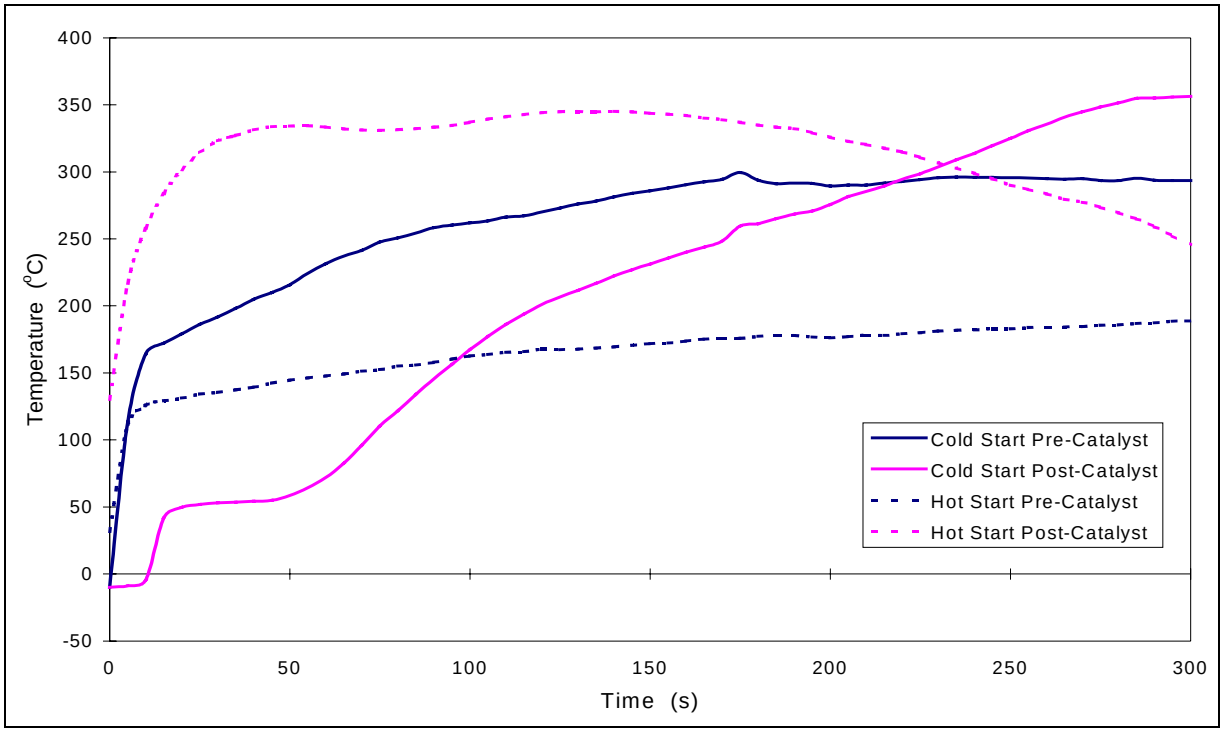
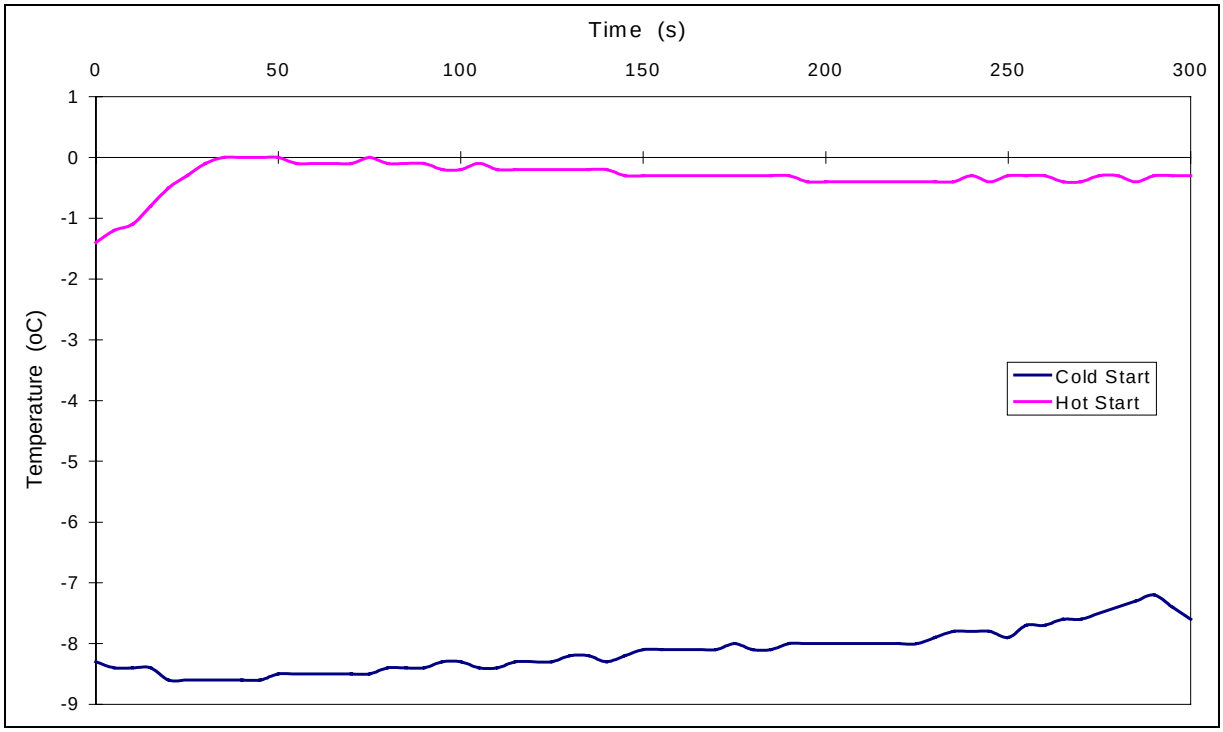


Figure 15. Typical fuel tank temperature profile for Garage tests at -10°C.



5.2 Evaporative Emissions

The evaporative emissions from the vehicle operating on the first test fuel were determined experimentally using the cold SHED procedure described in Section 3.2. The evaporative emissions for operation using the second test fuel were simulated based on the results of the evaporated fuel analyses and the comparison of the evaporated fuel analysis of the first fuel to the actual evaporative emissions. As the fuels had very similar physical characteristics (Reid vapour pressure, density and octane number) the emission rate was not expected to change, just the chemical composition of the emissions.

5.2.1 Test Emissions

The data reported as Test Emissions represents the total mass emissions obtained over the test as obtained experimentally with the vehicle operating using the first test fuel. The VOC profile shows the mass emitted for each compound over the test. An average emission rate g/hr was obtained by dividing the corrected total mass emitted by the length of the test in hours. The evaporative emissions test was conducted only at -10°C and only on the first test fuel. The evaporative emission VOC profile was estimated based on fuel composition for the second test fuel.

5.2.1.1 Gaseous Emissions

The average total hydrocarbon mass emissions and an average emission rate (g/hr) with their corresponding standard deviations for three tests are reported in Table 13. The data is corrected for leakage from the SHED as measured by the tracer gas retention analysis. The emission rate changes over the test as will be shown in the Modal Emissions section below. Thus, this emission rate is an average over the duration of the test. The complete data set is given in Appendix 1.

Table 13. Mass emissions and emission rate of total hydrocarbons for evaporative emissions tests.

	HC Emissions (g/test)	**HC Emissions (g/hr)**
Average	0.28	0.15
Std. Dev.	0.015	0.005

5.2.1.2 Volatile Organic Compounds

The average and standard deviation for the volatile organic compound mass emissions and emission rate for the evaporative emissions tests are given in Table 14. The full data set is given in Appendix 1. Emissions of compounds lighter than propane are likely from tailpipe emissions remaining in the exhaust system and diffusing out as the SHED air is mixed. They are not expected in the fuel in the vehicle gas tank. Emissions of the heavier hydrocarbons (heavier than n-decane) are low as would be expected from their vapour pressures and from the temperature of the fuel tank. Accordingly, the emission rates are also more variable. The data reported in Table 14 is the average and standard deviation for three tests. Instances of non-detects were not included in the calculation of the average. Where no standard deviation is reported, the value reported as average is the amount from only one sample that was found above the detection limit.

The mass emissions and the emission rates for the volatile organic compounds were corrected for SHED leakage as measured using the SF_6 tracer. The fraction of the SHED atmosphere lost due to leakage (*f*) as measured by the SF_6 tracer is determined by the difference between the initial and final SF_6 concentrations divided by the initial SF_6 concentration as given in Equation 1. In the following equations, the notation $[SF_6]$ indicates concentration of SF_6.

$$f = \frac{[SF_6]_{initial} - [SF_6]_{final}}{[SF_6]_{initial}} \qquad \textbf{Equation 1}$$

The actual final concentration measured is lower than the true final concentration that would be expected had there been no leakage by an amount proportional to the true final concentration as given in Equation 2.

$$[SF_6]_{final,true} = f \cdot [SF_6]_{final,true} + [SF_6]_{final,actual} \qquad \textbf{Equation 2}$$

Therefore, the corrected final concentration is equal to the true final concentration, given by rearranging Equation 2 to get Equation 3. This corrected concentration is used in the emission rate calculation.

$$[SF_6]_{corrected} = [SF_6]_{final,actual} \cdot \left(\frac{1}{1-f} \right)$$ **Equation 3**

Table 14. Mass emissions for VOCs for evaporative emissions tests using the first test fuel.

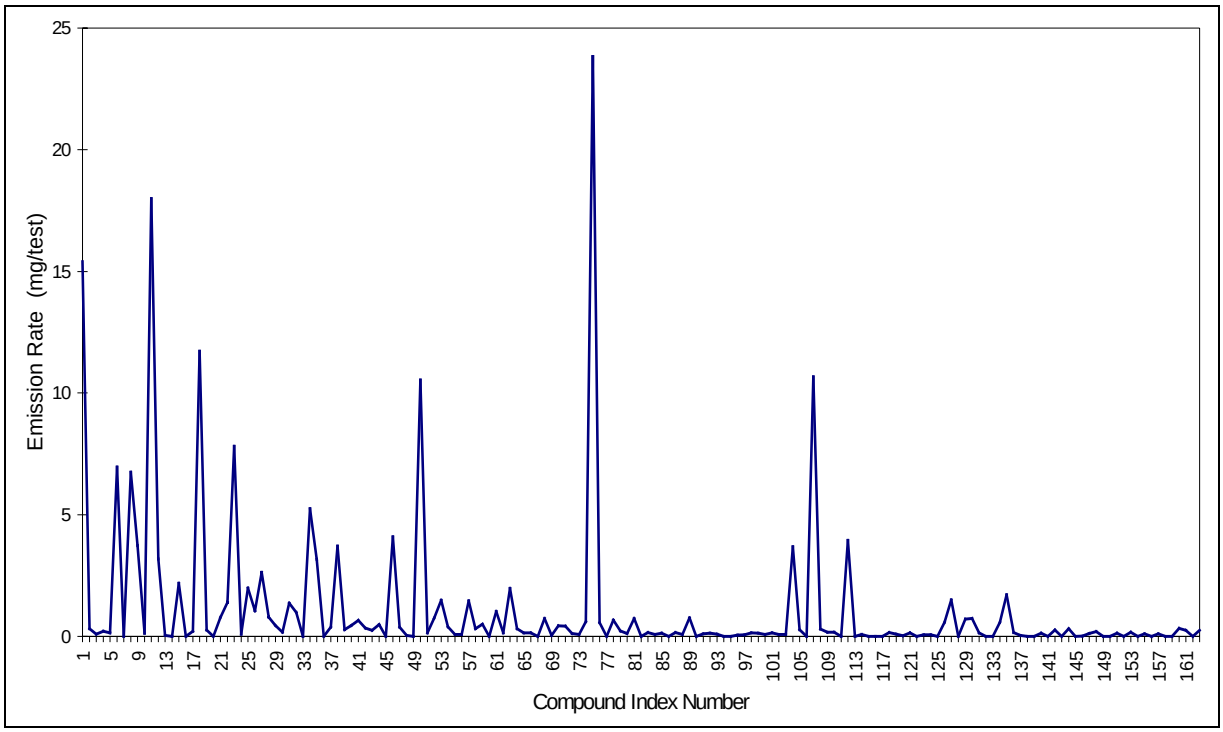
Index		Mass Emissions (mg/test)		Emission Rate (mg/hr)	
		Average	Std. Dev.	Average	Std. Dev.
1	methane	15.41	5.04	8.33	2.55
2	ethylene	0.32	0.20	0.17	0.10
3	acetylene	0.09	0.03	0.05	0.01
4	ethane	0.21	0.05	0.12	0.03
5	propylene	0.15	0.07	0.08	0.04
6	propane	6.96		3.61	
7	propyne				
8	isobutane	6.75	1.46	3.69	1.01
9	isobutene/1-butene	3.73	0.81	2.04	0.55
10	13-butadiene	0.14	0.08	0.07	0.04
11	n-butane	17.99	3.21	9.82	2.24
12	t2-butene	3.19	0.73	1.74	0.47
13	22-dm-propane	0.05	0.00	0.03	0.00
14	1-butyne				
15	c2-butene	2.19	0.46	1.20	0.31
16	12-butadiene				
17	3m1-butene	0.21	0.07	0.11	0.04
18	2m-butane	11.72	1.51	6.37	0.99
19	14-pentadiene	0.27		0.14	
20	2-butyne				
21	1-pentene	0.78	0.10	0.43	0.08
22	2m1-butene	1.39	0.25	0.76	0.18
23	n-pentane	7.81	1.11	4.26	0.78
24	2m-13-butadiene	0.10	0.03	0.05	0.02
25	t2-pentene	1.99	0.31	1.09	0.20
26	c2-pentene	1.05	0.16	0.57	0.11
27	2m2-butene	2.63	0.40	1.43	0.27
28	22-dm-butane	0.79	0.10	0.43	0.06
29	cyclopentene	0.45	0.06	0.24	0.04
30	4m1 & 3m1-pentene	0.17	0.04	0.09	0.02
31	cyclopentane	1.37	0.20	0.75	0.14
32	23-dm-butane	0.99	0.11	0.54	0.06
33	c/t-4m2-pentene				
34	2m-pentane	5.24	0.58	2.85	0.40
35	3m-pentane	3.18	0.35	1.73	0.24
36	2m1-pentene				
37	1-hexene	0.38	0.09	0.21	0.04
38	n-hexane	3.71	0.46	2.02	0.32
39	c/t-3-hexene	0.28	0.04	0.15	0.03
40	t2-hexene	0.45	0.04	0.24	0.04
41	2m2-pentene	0.65	0.09	0.36	0.06
42	t-3m2-pentene	0.35	0.05	0.19	0.03
43	c2-hexene	0.25	0.05	0.14	0.03
44	c-3m2-pentene	0.49	0.08	0.27	0.05
45	22-dm-pentane				
46	m-cyclopentane	4.09	0.56	2.23	0.41

Index		Mass Emissions (mg/test)		Emission Rate (mg/hr)	
		Average	Std. Dev.	Average	Std. Dev.
47	24-dm-pentane	0.38	0.04	0.20	0.03
48	223-tm-butane	0.04		0.02	
49	1m-cyclopentene				
50	benzene	10.53	1.08	5.72	0.71
51	33-dm-pentane	0.14	0.01	0.08	0.01
52	cyclohexane	0.75	0.13	0.41	0.08
53	2m-hexane	1.49	0.14	0.81	0.11
54	23-dm-pentane	0.40	0.04	0.21	0.02
55	11-dm-cyP	0.08	0.01	0.04	0.00
56	cyclohexene	0.08	0.00	0.04	0.00
57	3m-hexane	1.46	0.13	0.80	0.11
58	c-13-dm-cyP	0.31	0.03	0.17	0.03
59	3e-pentane/t-13-dm-cyP	0.50	0.05	0.27	0.04
60	t-12-dm-cyP				
61	224-tm-pentane/1-heptene	1.04	0.19	0.56	0.08
62	t3-heptene	0.14	0.01	0.08	0.01
63	n-heptane	1.97	0.18	1.07	0.15
64	c3-heptane	0.32	0.04	0.17	0.03
65	t2-heptene	0.15	0.00	0.08	0.01
66	c2-heptene	0.14	0.01	0.08	0.00
67	22-dm-hexane				
68	m-cyH/c12-dm-cyP/113-tm-cyP	0.74	0.23	0.40	0.11
69	12-dm-cyH	0.04	0.00	0.02	0.00
70	25-dm-hexane/e-cyP	0.44	0.05	0.24	0.03
71	24-dm-hexane/223-tm-pentane	0.42	0.04	0.23	0.02
72	33-dm-hexane/ctc-124-tm-cyP	0.12	0.00	0.06	0.01
73	ctc-123-tm-cyP	0.09	0.01	0.05	0.00
74	234-tm-pentane	0.60	0.15	0.32	0.07
75	toluene/233-tm-pentane	23.84	0.36	13.17	1.33
76	23-dm-hexane/2m3e-pentane	0.56		0.30	
77	112-tm-cyP				
78	2m-heptane	0.67	0.08	0.36	0.06
79	4m-C7/3m3e-C5/1m-cyHexene	0.23	0.03	0.12	0.02
80	34-dm-hexane	0.11	0.02	0.06	0.02
81	3m-heptane	0.73	0.10	0.40	0.07
82	3e-hexane				
83	cct-124-tm-cyP/c-13-dm-cyH	0.16	0.03	0.09	0.02
84	t-14-dm-cyH	0.08	0.01	0.04	0.00
85	225-tm-hexane	0.14	0.02	0.08	0.01
86	11-dm-cyH				
87	1-octene	0.16	0.01	0.09	0.01
88	1e1m-cyP	0.09	0.00	0.05	0.00
89	n-octane/t-12-dm-cyH	0.77	0.05	0.42	0.05
90	224-tm-hexane				
91	t2-octene	0.11	0.01	0.06	0.00
92	ccc-123-tm-cyP	0.14	0.02	0.08	0.01
93	244-tm-hexane	0.09	0.01	0.05	0.01
94	c2-octene				
95	ip-cyP				
96	235-tm-hexane	0.06	0.03	0.03	0.01
97	44&22-dm-heptane	0.06	0.04	0.03	0.02
98	24-dm-heptane	0.15	0.01	0.08	0.01
99	26-dm-heptane/c-12-dm-cyH	0.14	0.02	0.08	0.01
100	np-cyP/ccc-135-tm-cyH/e-cyH	0.08	0.01	0.04	0.00

Index		Mass Emissions (mg/test)		Emission Rate (mg/hr)	
		Average	Std. Dev.	Average	Std. Dev.
101	25-dm-heptane	0.14	0.05	0.08	0.03
102	33-dm-heptane	0.08		0.04	
103	114-tm-cyH	0.07		0.04	
104	e-benzene	3.69	0.34	2.00	0.17
105	ctt-124-tm-cyH	0.28	0.04	0.15	0.03
106	35-dm-heptane				
107	m&p-xylene/23-dm-heptane	10.67	0.22	5.80	0.52
108	34-dm-heptane/4m-octane	0.31	0.02	0.17	0.01
109	2m-octane/246-tm-hexane	0.17	0.06	0.09	0.03
110	ctc-124-tm-cyH	0.17		0.09	
111	3m-octane/33-de-C5/3e-C7				
112	o-xylene	3.94	0.13	2.14	0.22
113	112-tm-cyH				
114	1-nonene	0.08	0.01	0.04	0.01
115	t3-nonene				
116	ib-cyP				
117	c3-nonene				
118	n-nonane	0.16	0.03	0.09	0.03
119	t2-nonene	0.10		0.05	
120	c2-nonene	0.03	0.00	0.02	0.00
121	ip-benzene	0.14	0.09	0.08	0.04
122	22-dm-octane				
123	ip-cyH	0.06		0.03	
124	nb-cyP	0.07	0.01	0.04	0.01
125	33-dm-octane				
126	np-benzene	0.58	0.06	0.31	0.03
127	3e-toluene	1.50	0.18	0.81	0.12
128	23-dm-octane				
129	4e-toluene	0.72	0.01	0.40	0.03
130	135-tm-benzene	0.74	0.08	0.40	0.06
131	2m-nonane	0.15	0.04	0.08	0.03
132	3e-octane				
133	3m-nonane				
134	2e-toluene	0.58	0.15	0.32	0.10
135	124-tm&tb-benzene/1-decene	1.71	0.12	0.93	0.05
136	ib-cyH	0.16		0.08	
137	n-decane	0.05	0.03	0.03	0.02
138	ib-benzene				
139	sb-benzene				
140	3-ip-toluene	0.13	0.12	0.07	0.06
141	123-tm-benzene				
142	4-ip-toluene	0.26	0.20	0.14	0.11
143	indan				
144	2-ip-toluene	0.32	0.20	0.18	0.12
145	13-de-benzene				
146	14-de-benzene	0.01		0.01	
147	3-np-toluene	0.13	0.02	0.07	0.00
148	4-np-toluene/nb-&13dm-5e-benz	0.20	0.03	0.11	0.02
149	12-de-benzene				
150	2-np-toluene				
151	14-dm-2e-benzene	0.13	0.02	0.07	0.00
152	13-dm-4e-benzene				
153	12-dm-4e-benzene	0.16	0.08	0.09	0.05
154	13-dm-2e-benzene				

Index		Mass Emissions (mg/test)		Emission Rate (mg/hr)	
		Average	Std. Dev.	Average	Std. Dev.
155	n-undecane/12-dm-3e-benzene	0.11	0.15	0.06	0.08
156	1245-ttm-benzene				
157	2mb-benzene	0.10		0.05	
158	tb-2m-benzene				
159	1234-ttm-benzene				
160	n-pentylbenzene	0.33		0.17	
161	tb-35-dm-benzene	0.25		0.13	
162	tb-4e-benzene				
163	n-dodecane	0.25	0.30	0.13	0.15

Figure 16. VOC profile for evaporative emissions tests using the first test fuel.



In Figure 16, the Compound Index Number corresponds to the order in which the compounds are listed in Table 13.

5.2.2 Modal Emissions

The data reported at Modal Emissions shows the cumulative mass emissions of total hydrocarbons (HC) over the test when the vehicle was operated using the first test fuel. From this data, the variation in emission rate can be determined. This data is not expected to change when the vehicle is operated on the second test fuel.

5.2.2.1 Emission Rate Profiles

Figure 17 shows a typical profile for the cumulative mass emission of hydrocarbons over the evaporative emissions test. These data are not corrected for leakage as only a total leakage measurement over the entire test was measured. The mass emitted appears to approach a constant amount after about 2 hours. Figure 18 shows the change in HC emission rate through the test. As observed above, the emission rate appears to approach zero after 2 hours.

Figure 17. Cumulative HC mass emissions for the evaporative emissions test for the first test fuel.

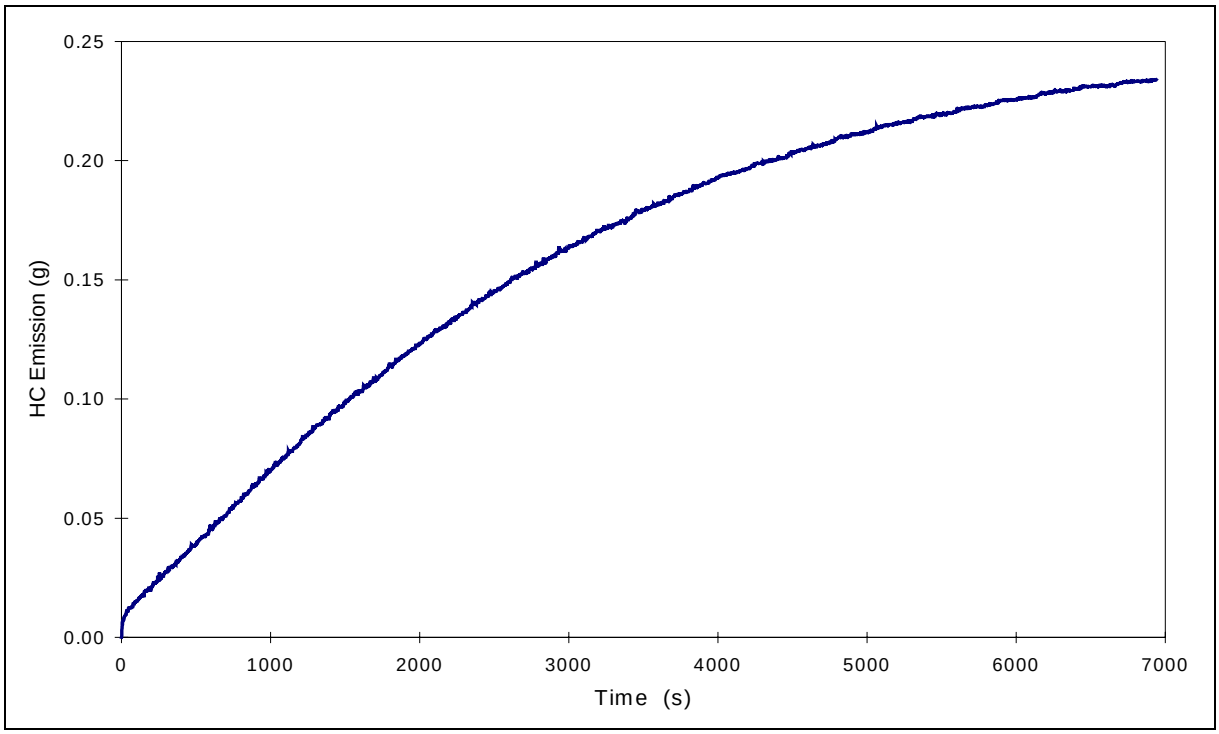
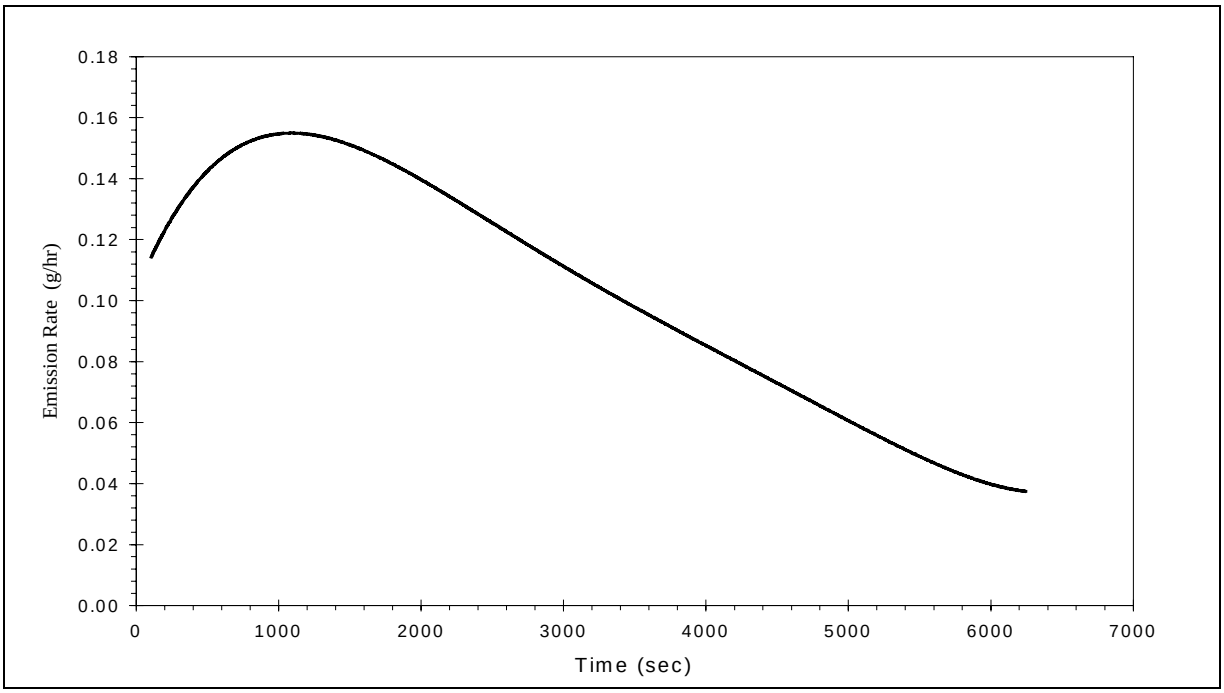


Figure 18. Change in HC emission rate for the evaporative emissions test.



5.2.2.2 Temperature Profiles

The test cell and SHED were maintained at a temperature appropriate to wintertime conditions expected in garages. The chiller was set to maintain the cell at an average temperature of -10 °C but varied by ±2 °C over the course of the vehicle characterisations.

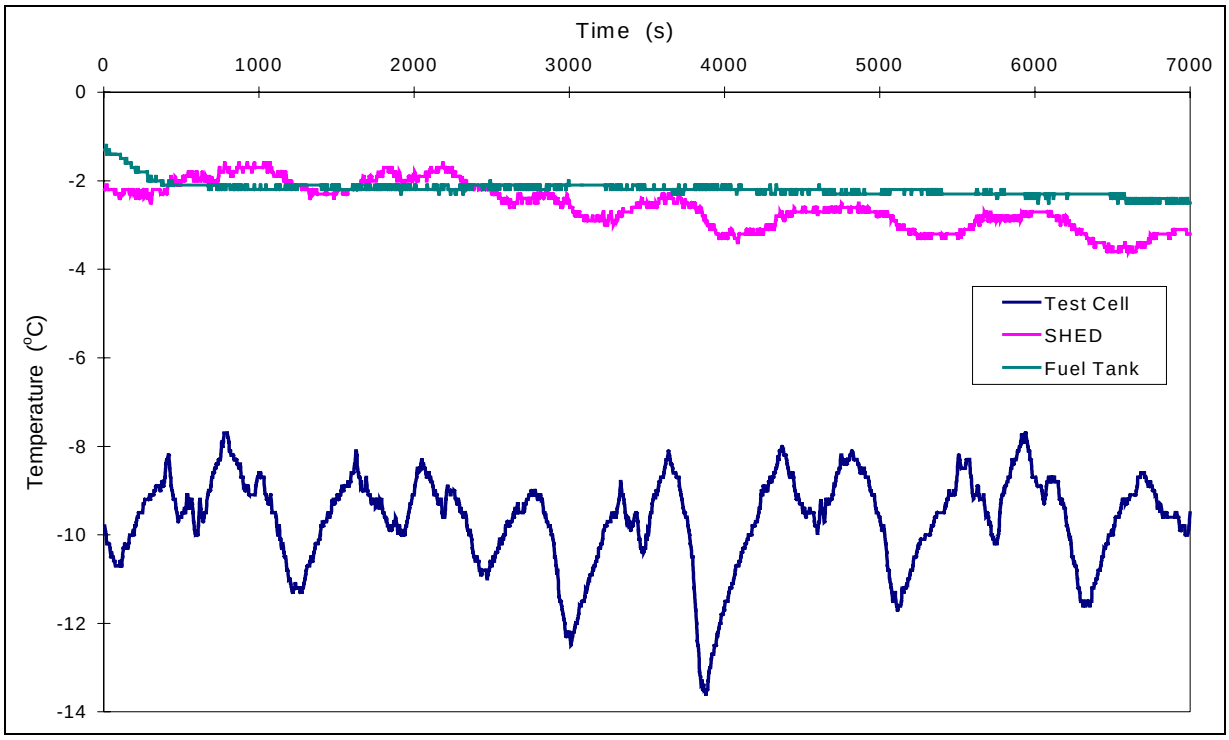
The cold test cell is equipped with two chiller units, one large and one small. The small chiller is used to maintain the cell temperature when no heat load is present in the cell, i.e. the vehicle is not operating. The larger chiller cycles on and off when there is a heat load and thus the cell temperature oscillates somewhat when the larger chiller is operating. This is seen in the cell temperature traces of Figure 19. The SHED temperature is more uniform due to the sheltering effect of the walls of the enclosure. The temperatures monitored during the SHED tests are summarised in Table 15.

The vehicle was pushed into the cold SHED as quickly as possible therefore the temperature of the fuel tank will still be warm due to the driving cycle. Although during the driving cycle the temperatures for all three runs followed very similar temperature profiles, the initial temperature of the fuel tank is dependent primarily on the time between the end of the driving cycle and the beginning of the SHED test.

Table 15. Measured temperatures for evaporative emissions tests.

	3 Dec	5 Dec	9 Dec
Average Cell Temperature (°C)	-9.7	-9.2	-9.9
Average SHED Temperature (°C)	-2.6	-3.2	-2.0
Initial Fuel Tank Temperature (°C)	-1.3	0.9	0.2
Final Fuel Tank Temperature (°C)	-2.5	-2.1	-1.2

Figure 19. Typical temperature profiles for the evaporative emissions test.



5.2.3 Evaporative Emission Profile for Second Test Fuel

To obtain an evaporative emission profile for the second fuel, samples of both fuels were evaporated into evacuated SUMMA canisters, pressurised with ultra-high purity Nitrogen and analysed using the same method as the VOC samples collected from the vehicle tests. These samples are referred to as evaporated whole gas samples. A comparison was made between the actual evaporative emissions and the evaporated whole gas sample for the first fuel. Compounds from propane through n-dodecane were compared between the two samples as compounds lighter than propane are not expected to be present in the liquid fuel. The concentration profiles were normalized over this set of compounds to produce the two VOC profiles shown in Figure 20. The two normalized evaporated whole gas profiles are compared in Figure 21.

Figure 20. Comparison of evaporative emissions and evaporated whole gas sample profiles.

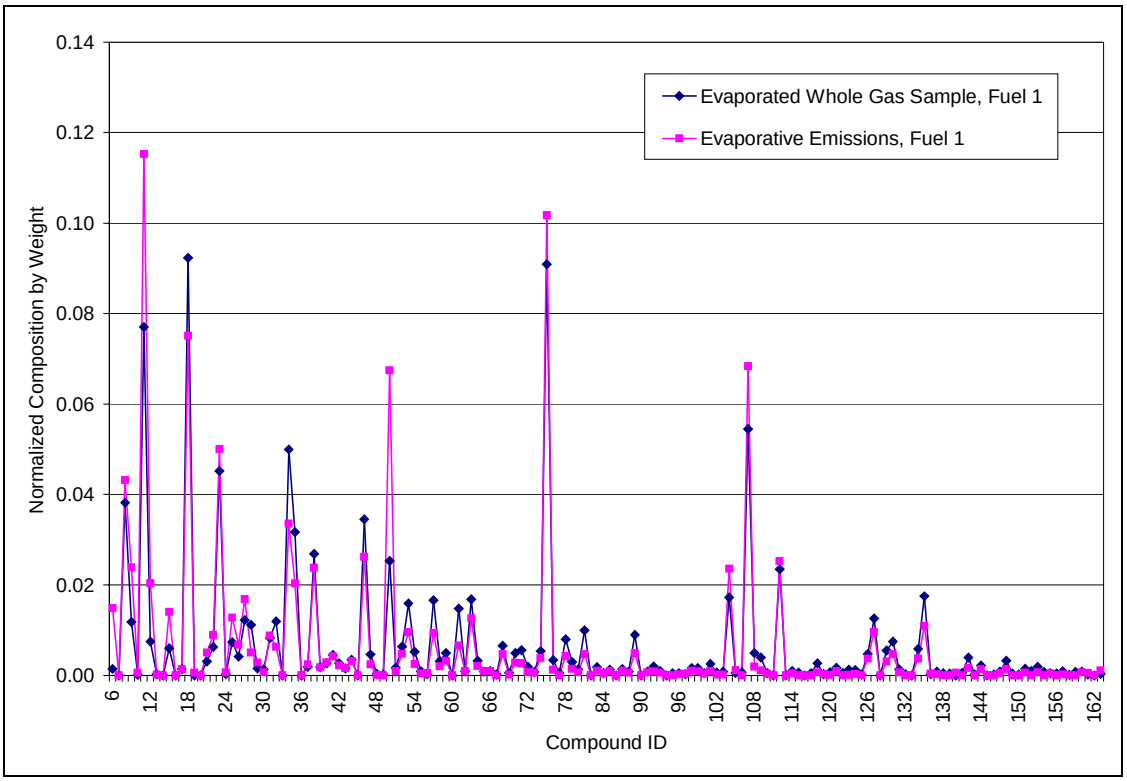
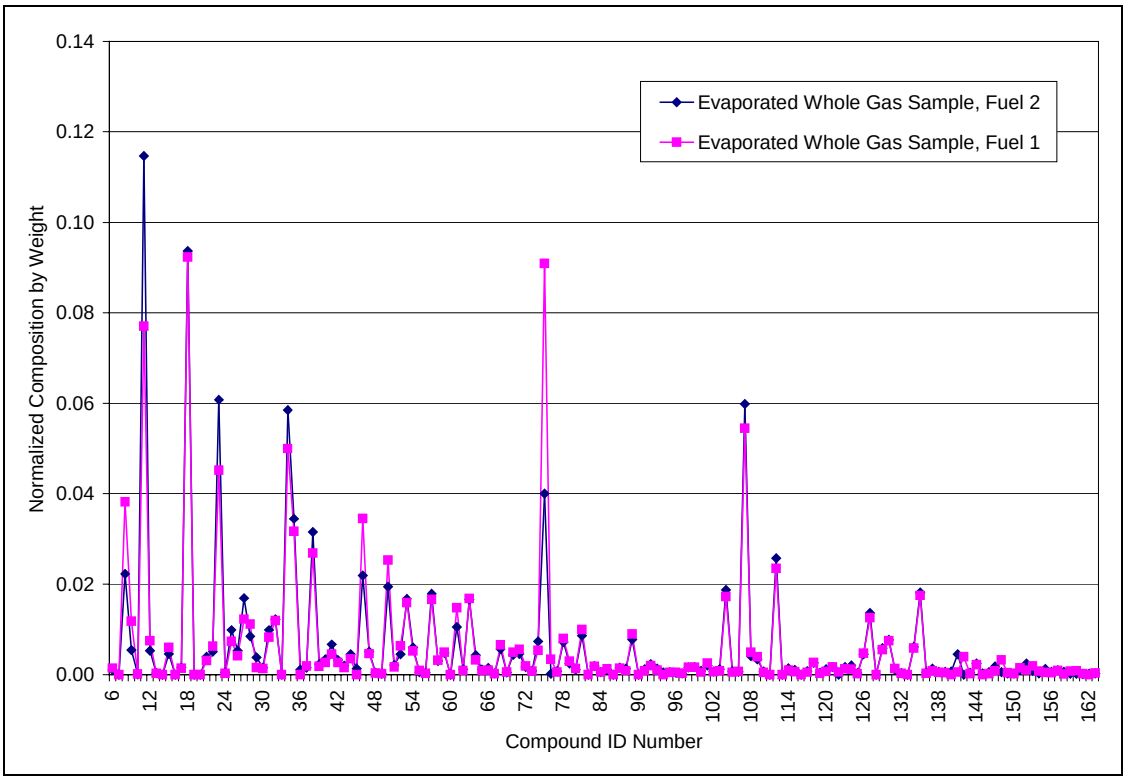


Figure 21. Comparison of evaporated whole gas samples for the two test fuels.



As can be seen in Figure 20, the evaporative emission profile obtained from vehicle testing is very similar to the evaporated whole gas sample. The evaporative emissions profile shows slightly higher contributions from the lighter and mid-range hydrocarbons (the more volatile compounds – lower compound ID number) while the evaporated whole gas sample shows slightly higher contributions from the heavier compounds – higher compound ID number).

The comparison between the two fuels shows many similarities, but one notable difference. The toluene composition of the first test fuel is substantially greater than the second fuel.

In order to obtain an estimated evaporative emissions profile for the second fuel, a ratio was calculated by dividing the evaporative emissions normalized composition by the evaporated whole gas sample normalized composition for each of the components. The ratios for each compound are shown in Figure 22. The simulated evaporative emissions profile for the second fuel was then obtained by multiplying the normalized composition amount for each compound in the evaporated whole gas sample for test fuel 2 by the respective ratio in Figure 22. This ratio can be thought of as a "transfer function" on the fuel as it evaporates through the emission control system of the vehicle. The simulated evaporative emissions profile for the second test fuel is shown in Figure 23. The complete sample analysis results are presented in Appendix 1.

Figure 22. Ratio of Evaporative emissions to evaporated whole gas sample composition.

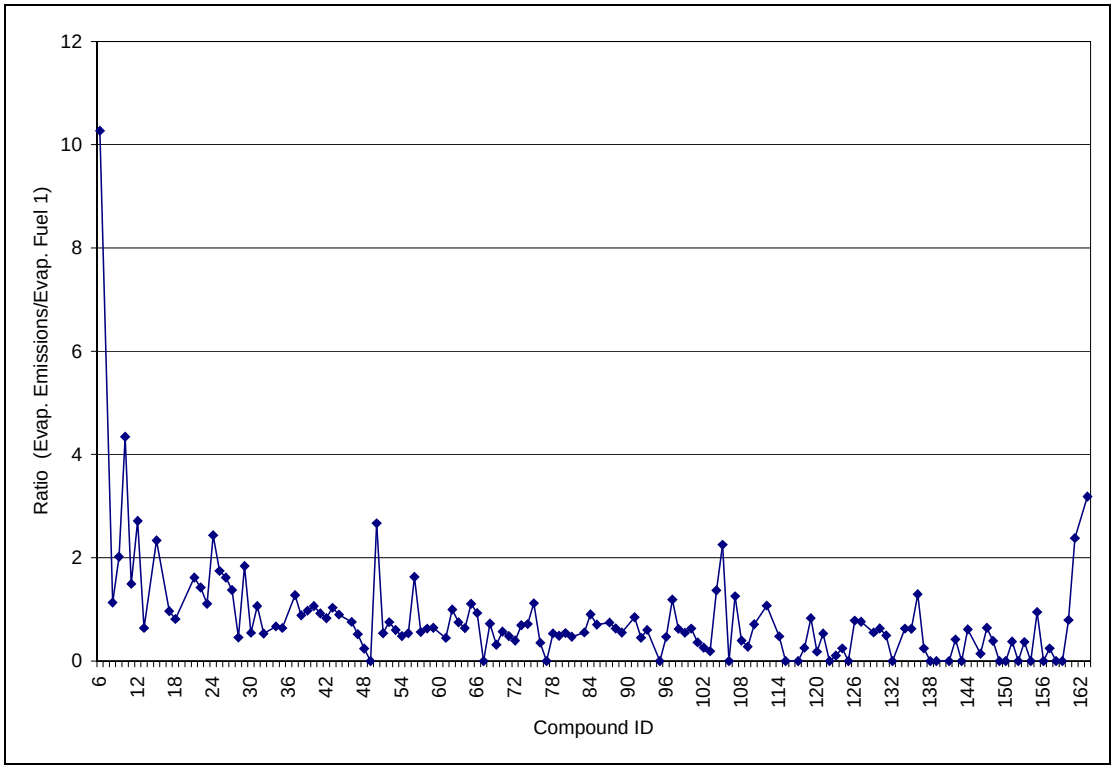
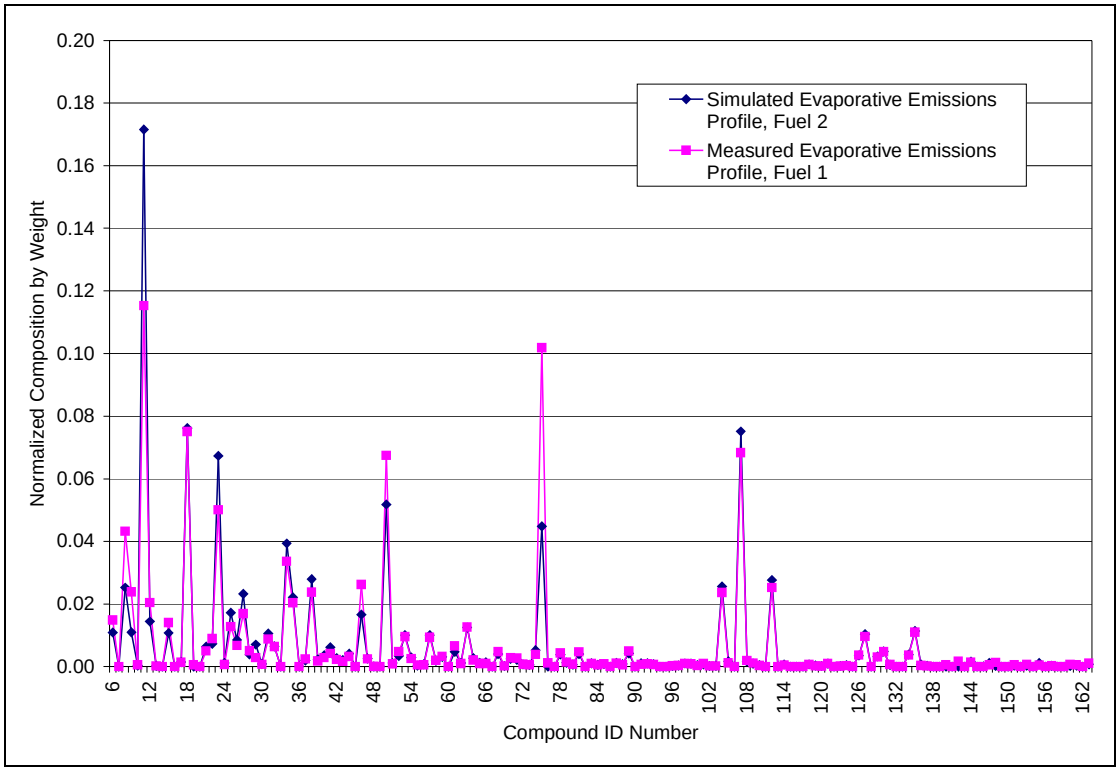


Figure 23. Comparison of measured evaporative emissions profile for Fuel 1 to simulated evaporative emissions profile for Fuel 2.



6. Conclusions

As expected, the cold start tailpipe emissions are significantly higher than the corresponding hot start tailpipe emissions. CO is 32 times greater, CO_2 is twice, NO_X is 10 times greater and HC is 18 times greater for the cold start test over hot start test. Emissions of carbonyl compounds were also greater for the cold start over the hot start. The confidence in the hot start carbonyl emissions is not high as only one of the two samples showed measurable levels of the two dominant species, formaldehyde and acetaldehyde.

The VOC profiles are different between cold start and hot start tailpipe emissions. The cold start profile is dominated by products of incomplete combustion (unsaturated hydrocarbons) while the hot start profile shows more unburned fuel components. This results from two different events, the fuel enrichment needed to start the combustion process and the following period of rich combustion needed to maintain the combustion process until the engine warms up and the inactivity of the catalyst for the first minute or so of the cold start. The fuel enrichment is much less on a hot start and the catalyst is much closer to operating temperature, thus reducing the total HC emissions and changing the distribution of the hydrocarbons to those more indicative of unburned fuel passing through the exhaust system.

As seen in the modal emissions profiles for the cold start and hot start tailpipe emissions, the engine crank accounts for a large portion of the total emissions of CO, CO_2 and HC. The modal NO_X emissions indicates that the catalyst begins to operate about 30 seconds into the test cycle. The initial injection of tailpipe emissions into the garage atmosphere is approximately 110 seconds in length.

For the evaporative emissions tests, the mass emitted appears to approach a level amount after about 2 hours. The emission rate appears to approach a limiting rate of 0.033 mg/min at that time.

The VOC profile for the evaporative emissions is different from either of the tailpipe emission profiles. The expected increase in concentration of evaporative emissions compounds in each individual residential garage can be obtained by

dividing the mass emitted over a specified time interval by the garage volume. By adding this concentration increase to the initial VOC profile of the garage, the concentration profile of the garage air infiltrating the house can be estimated.

The cold start tailpipe emissions obtained at 0°C and 24°C on the first test fuel show a similar chemical profile to that obtained at -10°C, but with a decrease in emission rate as the temperature increases. The cold start tailpipe emissions from the second test fuel at 0°C show very similar results for the gaseous emissions (CO, CO_2, NO_X and THC). This was expected based on the similar physical fuel characteristics. Differences were observed in the VOC profiles for the two fuels. This was also expected as the two fuels were produced approximately 2 years apart.

These fuel differences were also seen in the evaporated whole gas samples analysed in order to estimate the evaporative emission profile for the second fuel.

Appendix 1

Detailed reports for all tailpipe and evaporative emissions tests. In all tables, missing values indicate compound not present above detection limits reported in the main document.

Gaseous Emissions total mass emissions at –10 °C for the first test fuel (g/test).

	CO	CO_2	NO_X	HC
Cold Start -10°C				
3-Dec	73.4	666	4.48	9.35
5-Dec	40.2	606	1.20	6.58
9-Dec	34.9	572	1.01	4.81
Hot Start -10°C				
5-Dec	2.42	317	0.32	0.46
9-Dec	0.73	294	0.13	0.30

Gaseous Emissions total mass emissions at 0 °C and 24 °C for the first test fuel (g/test).

	CO	CO_2	NO_X	HC
Cold Start 0°C				
2-Apr	32.0	487	0.55	3.80
3-Apr	25.2	489	0.58	3.32
Cold Start 24°C				
23-Apr	14.6	428	1.08	2.61
24-Apr	15.8	370	0.14	2.13

Gaseous Emissions total mass emissions at 0 °C for the second test fuel (g/test).

	CO	CO_2	NO_X	HC
Cold Start 0°C				
4-May	30.59	466	0.38	3.51
5-May	31.06	466	0.36	3.72

Mass emissions for volatile organic compounds at –10 °C for the first test fuel (mg/test).

		Cold Start -10°C			Hot Start -10°C	
ID	Compound Name	3-Dec	5-Dec	9-Dec	5-Dec	9-Dec
1	methane	506.14	379.38	295.57	60.97	64.62
2	ethylene	631.66	476.75	391.41	40.59	23.30
3	acetylene	336.34	269.58	204.51	3.81	3.26
4	ethane	68.69	60.42	49.50	15.50	18.22
5	propylene	295.50	220.32	188.07	20.61	
6	propane				0.65	1.05
7	propyne	33.28	22.39	19.10		
8	isobutane	91.04	74.78	57.99	7.04	5.07
9	isobutene/1-butene	128.45	99.87	83.55	10.00	5.46
10	13-butadiene	53.68	52.62	44.52	3.14	
11	n-butane	192.74	156.24	119.82	14.66	9.49
12	t2-butene	34.37	26.76	21.01	2.51	1.21
13	22-dm-propane	0.93	0.80	0.67	0.23	0.11
14	1-butyne	1.02	1.07	0.76		
15	c2-butene	32.77	25.45	17.75	2.62	1.27

ID	Compound Name	Cold Start -10°C			Hot Start -10°C	
		3-Dec	5-Dec	9-Dec	5-Dec	9-Dec
16	12-butadiene					
17	3m1-butene	8.60	6.26	5.68	0.59	0.30
18	2m-butane	270.28	208.14	158.64	14.19	9.38
19	14-pentadiene	2.20	1.12	2.00	0.61	0.12
20	2-butyne	2.10	1.48	1.58		
21	1-pentene	15.98	12.03	10.20	0.76	0.38
22	2m1-butene	20.99	17.94	14.15	1.35	0.68
23	n-pentane	145.45	109.91	83.59	7.71	4.31
24	2m-13-butadiene	9.67	15.12	12.12	1.26	0.78
25	t2-pentene	25.13	19.38	15.95	1.32	0.70
26	c2-pentene	14.39	10.96	9.02	0.74	0.40
27	2m2-butene	24.80	29.71	24.57	2.19	1.11
28	22-dm-butane	41.38	33.16	24.91	2.66	1.63
29	cyclopentene	0.07		6.49	0.56	0.29
30	4m1 & 3m1-pentene	5.08	3.99	3.24	0.07	0.14
31	cyclopentane	30.65	22.65	16.84	1.39	0.82
32	23-dm-butane	45.02	33.90	25.11	2.19	1.14
33	c/t-4m2-pentene					
34	2m-pentane	199.53	151.43	111.10	9.68	5.01
35	3m-pentane	131.00	98.63	72.04	6.23	3.32
36	2m1-pentene	6.66		4.09		
37	1-hexene	6.74	4.84	4.30	0.25	0.15
38	n-hexane	124.74	92.92	68.43	5.54	2.97
39	c/t-3-hexene	6.93	6.03	4.21	0.33	0.16
40	t2-hexene	10.64	6.85	6.67	0.35	0.27
41	2m2-pentene	14.66	11.01	10.18	0.68	0.38
42	t-3m2-pentene	4.65	7.14	6.31	0.45	0.24
43	c2-hexene	5.91	4.10	3.51	0.21	0.12
44	c-3m2-pentene	9.47	8.06	7.45	0.41	0.27
45	22-dm-pentane					0.19
46	m-cyclopentane	168.01	125.19	90.65	7.26	3.50
47	24-dm-pentane	16.79	13.44	10.14	0.85	0.54
48	223-tm-butane	1.49	1.39	1.07	0.17	0.11
49	1m-cyclopentene	1.27	1.20		0.12	
50	benzene	345.29	232.87	220.25	18.56	16.05
51	33-dm-pentane	7.92	5.55	4.77	0.36	0.21
52	cyclohexane	33.78	25.78	17.90	1.49	0.69
53	2m-hexane	82.15	55.24	47.37	3.82	2.27
54	23-dm-pentane	25.07	17.76	14.68	1.32	0.74
55	11-dm-cyP	4.81	3.92	2.96	0.48	0.19
56	cyclohexene	2.63	1.69	1.75	0.30	0.11
57	3m-hexane	85.70	57.95	49.30	4.17	2.40
58	c-13-dm-cyP	16.95	12.35	9.77	1.00	0.45
59	3e-pentane/t-13-dm-cyP	28.27	19.87	16.32	1.43	0.74
60	t-12-dm-cyP			10.32		
61	224-tm-pentane/1-heptene	62.97	41.24	27.14	2.54	2.12
62	t3-heptene	4.96	3.14	2.73	0.23	0.12
63	n-heptane	94.60	60.77	54.66	3.92	2.51
64	c3-heptane	11.95	7.37	7.31	0.42	0.26
65	t2-heptene	4.87	2.86	2.83	0.20	0.13
66	c2-heptene	4.38	2.82	2.66	0.18	0.17
67	22-dm-hexane	1.36	0.90	0.80		
68	m-cyH/c12-dm-cyP/113-tm-cyP	38.65	27.34	22.12	1.37	1.07

ID	Compound Name	Cold Start -10°C			Hot Start -10°C	
		3-Dec	5-Dec	9-Dec	5-Dec	9-Dec
69	12-dm-cyH	3.43	2.27	1.94	0.25	0.09
70	25-dm-hexane/e-cyP	28.53	18.28	16.16	1.13	0.82
71	24-dm-hexane/223-tm-pentane	30.57	18.75	17.60	1.21	0.93
72	33-dm-hexane/ctc-124-tm-cyP	11.60	8.02	6.68	0.18	0.34
73	ctc-123-tm-cyP	4.87	3.71	2.91	0.32	0.21
74	234-tm-pentane	23.72	22.29	14.68	0.87	0.67
75	toluene/233-tm-pentane	879.77	962.51	506.59	101.43	26.66
76	23-dm-hexane/2m3e-pentane	0.98	0.79	0.56		
77	112-tm-cyP	2.95	1.67	1.57		
78	2m-heptane	52.66	33.19	30.10	3.02	1.52
79	4m-C7/3m3e-C5/1m-cyHexene	19.84	12.51	11.11	1.29	0.57
80	34-dm-hexane	8.11	5.31	4.83	0.89	0.25
81	3m-heptane	66.19	41.62	37.55	3.60	1.88
82	3e-hexane					
83	cct-124-tm-cyP/c-13-dm-cyH	12.78	8.18	7.37	0.97	0.44
84	t-14-dm-cyH	3.73	2.36	2.25	0.50	0.19
85	225-tm-hexane	8.67	5.18	5.04	0.94	0.21
86	11-dm-cyH					
87	1-octene	9.58	6.06	5.55	0.94	0.47
88	1e1m-cyP	5.04	2.60	2.58	0.89	0.15
89	n-octane/t-12-dm-cyH	65.44	41.37	36.43	2.58	1.80
90	224-tm-hexane					
91	t2-octene	5.25	3.06	2.95	0.26	0.15
92	ccc-123-tm-cyP	13.75	8.16	7.58		0.77
93	244-tm-hexane	4.33	2.76	2.75		
94	c2-octene	2.38	1.23	1.28		
95	ip-cyP	3.54	2.00	2.01		0.17
96	235-tm-hexane	3.51	2.02	1.94		
97	44&22-dm-heptane	2.41	1.28	1.19		0.06
98	24-dm-heptane	12.04	6.96	6.74	0.85	0.40
99	26-dm-heptane/c-12-dm-cyH	12.89	7.55	7.13	0.58	0.46
100	np-cyP/ccc-135-tm-cyH/e-cyH	4.19	2.35	2.19		
101	25-dm-heptane	20.10	16.04	10.77	0.56	0.48
102	33-dm-heptane	5.20	4.76	2.60		
103	114-tm-cyH	6.02	4.76	3.28		0.18
104	e-benzene	227.10	143.66	125.76	7.83	8.35
105	ctt-124-tm-cyH	5.17	3.99	3.12	0.28	0.87
106	35-dm-heptane	5.96		3.33		0.56
107	m&p-xylene/23-dm-heptane	744.34	465.83	391.50	23.12	19.83
108	34-dm-heptane/4m-octane	45.36	28.94	24.17		1.92
109	2m-octane/246-tm-hexane	34.97	22.55	18.63	1.22	1.09
110	ctc-124-tm-cyH	37.05	28.92	23.19	0.57	1.38
111	3m-octane/33-de-C5/3e-C7	2.89				
112	o-xylene	313.74	195.85	162.87	10.75	8.08
113	112-tm-cyH					
114	1-nonene	9.65	6.14	5.03		0.24
115	t3-nonene	5.97	3.53	2.89		
116	ib-cyP					
117	c3-nonene	4.23	2.53	2.13		
118	n-nonane	26.82	18.91	13.83	0.80	0.76
119	t2-nonene	2.38	2.32	1.11		
120	c2-nonene	5.82	4.29	3.22		
121	ip-benzene	19.35	13.54	10.68	0.68	0.55

ID	Compound Name	Cold Start -10°C			Hot Start -10°C	
		3-Dec	5-Dec	9-Dec	5-Dec	9-Dec
122	22-dm-octane	6.95	4.32	3.67		
123	ip-cyH	12.47	7.68	6.46		0.39
124	nb-cyP	14.51	14.28	8.19	0.29	1.20
125	33-dm-octane	0.96	1.70	1.26		0.25
126	np-benzene	62.55	42.65	31.57	3.48	1.62
127	3e-toluene	197.56	145.48	98.78	5.35	5.24
128	23-dm-octane					
129	4e-toluene	85.61	61.22	42.33	1.52	2.14
130	135-tm-benzene	105.11	81.12	52.04	2.44	2.64
131	2m-nonane	14.97	11.48	7.78		0.52
132	3e-octane	3.18	3.22	1.87		
133	3m-nonane					
134	2e-toluene	83.77	69.38	44.12		3.64
135	124-tm&tb-benzene/1-decene	276.48	225.14	133.63	6.41	5.64
136	ib-cyH	0.50				
137	n-decane	6.94		5.15	0.42	0.35
138	ib-benzene	6.14		2.81		
139	sb-benzene	5.21		2.64	0.97	
140	3-ip-toluene			1.46		1.05
141	123-tm-benzene	12.50		4.16		
142	4-ip-toluene	57.23		30.13	2.48	1.46
143	indan	0.47		1.20	3.62	
144	2-ip-toluene	35.12		15.11		1.32
145	13-de-benzene					
146	14-de-benzene	28.98		13.89	4.08	0.98
147	3-np-toluene	9.96		6.88	0.69	0.87
148	4-np-toluene/nb-&13dm-5e-benz	47.12		25.48		1.66
149	12-de-benzene	4.91		2.81	1.67	
150	2-np-toluene			1.17	2.65	
151	14-dm-2e-benzene	25.71		11.17		0.78
152	13-dm-4e-benzene	17.69		8.60	1.99	0.34
153	12-dm-4e-benzene	28.93		14.30	2.15	0.69
154	13-dm-2e-benzene	9.40		4.92	1.61	0.38
155	n-undecane/12-dm-3e-benzene			3.49	1.88	0.34
156	1245-ttm-benzene	6.14		3.37	1.35	
157	2mb-benzene	12.87		5.99	0.56	0.44
158	tb-2m-benzene	1.22		1.23		
159	1234-ttm-benzene	8.87		4.51	0.96	
160	n-pentylbenzene	9.66		4.53	0.87	0.26
161	tb-35-dm-benzene	1.53		0.76	0.18	
162	tb-4e-benzene				1.19	
163	n-dodecane			1.47	5.32	0.65

Mass emissions for volatile organic compounds at 0 °C and 24 °C for the first test fuel (mg/test).

ID	Compound Name	Cold Start 0 °C		Cold Start 24 °C	
		2-Apr	3-Apr	23-Apr	24-Apr
1	methane	204.93	178.88	100.86	117.21
2	ethylene	353.31	295.46	257.29	282.46
3	acetylene	136.65	118.77	47.82	68.07
4	ethane	46.56	43.61	31.34	40.52
5	propylene	167.57	147.62	141.21	134.18

ID	Compound Name	Cold Start 0 °C		Cold Start 24 °C	
		2-Apr	3-Apr	23-Apr	24-Apr
6	propane				2.97
7	propyne	12.07	9.53	7.84	
8	isobutane	47.05	41.26	44.18	30.05
9	isobutene/1-butene	75.93	64.22	66.05	56.82
10	13-butadiene	41.15	33.79	28.04	33.00
11	n-butane	96.37	87.84	87.69	60.95
12	t2-butene	19.05	15.86	16.71	12.42
13	22-dm-propane	0.75	0.46	0.44	0.33
14	1-butyne	0.69	0.61	0.30	0.37
15	c2-butene	17.59	12.79	12.85	11.20
16	12-butadiene				
17	3m1-butene	4.76	4.22	4.63	3.48
18	2m-butane	129.20	111.79	107.96	74.29
19	14-pentadiene	1.50	3.74	3.98	3.50
20	2-butyne	1.18	1.01	0.78	1.16
21	1-pentene	8.20	7.33	7.61	5.51
22	2m1-butene	10.30	8.51	11.81	7.35
23	n-pentane	66.40	57.72	53.32	37.93
24	2m-13-butadiene	12.13	9.30	7.85	8.72
25	t2-pentene	12.65	11.17	10.36	7.81
26	c2-pentene	7.62	6.58	5.94	4.64
27	2m2-butene	22.02	19.26	13.45	12.92
28	22-dm-butane	20.36	17.77	16.30	12.38
29	cyclopentene	5.57	4.72	4.68	3.68
30	4m1 & 3m1-pentene	2.83	1.04	2.37	0.93
31	cyclopentane	13.56	11.70	10.22	7.30
32	23-dm-butane	19.69	17.31	15.47	10.88
33	c/t-4m2-pentene				
34	2m-pentane	87.92	75.33	65.86	47.11
35	3m-pentane	56.44	48.56	42.10	30.03
36	2m1-pentene	2.79	2.22	2.69	1.57
37	1-hexene	3.49	2.93	3.19	2.38
38	n-hexane	52.17	44.44	36.99	26.41
39	c/t-3-hexene	3.37	2.65	2.34	1.71
40	t2-hexene	5.20	4.15	3.80	2.76
41	2m2-pentene	8.45	7.02	5.57	4.42
42	t-3m2-pentene	5.32	4.19	2.36	3.01
43	c2-hexene	2.82	2.27	1.94	1.43
44	c-3m2-pentene	6.05	4.84	3.60	3.01
45	22-dm-pentane				
46	m-cyclopentane	70.88	59.99	49.15	35.16
47	24-dm-pentane	9.07	7.16	5.45	4.47
48	223-tm-butane	1.59	0.86	0.66	0.80
49	1m-cyclopentene				
50	benzene	173.25	126.16	97.62	97.64
51	33-dm-pentane	3.80	3.02	2.57	1.96
52	cyclohexane	14.44	12.32	9.40	6.64
53	2m-hexane	36.92	29.45	23.86	16.91
54	23-dm-pentane	11.40	9.31	7.70	5.45
55	11-dm-cyP	2.33	1.96	1.58	1.13
56	cyclohexene	1.54	1.22	1.32	0.90
57	3m-hexane	38.63	30.85	24.77	17.61
58	c-13-dm-cyP	7.66	6.33	4.92	3.48

ID	Compound Name	Cold Start 0 °C		Cold Start 24 °C	
		2-Apr	3-Apr	23-Apr	24-Apr
59	3e-pentane/t-13-dm-cyP	12.64	10.27	8.35	5.75
60	t-12-dm-cyP				
61	224-tm-pentane/1-heptene	27.72	22.09	18.10	12.62
62	t3-heptene	2.12	1.57	1.26	0.76
63	n-heptane	42.45	32.44	25.27	18.27
64	c3-heptane	5.72	4.27	3.00	2.21
65	t2-heptene	2.09	1.54	1.29	0.86
66	c2-heptene	2.21	1.53	1.17	0.89
67	22-dm-hexane	0.66	0.50	0.48	0.34
68	m-cyH/c12-dm-cyP/113-tm-cyP	17.29	13.99	10.67	7.61
69	12-dm-cyH	1.61	1.27	1.04	0.86
70	25-dm-hexane/e-cyP	12.40	9.53	7.50	5.23
71	24-dm-hexane/223-tm-pentane	13.55	10.30	7.75	5.35
72	33-dm-hexane/ctc-124-tm-cyP	5.22	3.97	3.21	2.35
73	ctc-123-tm-cyP	2.43	1.75	1.41	1.00
74	234-tm-pentane	11.49	8.19	6.12	4.41
75	toluene/233-tm-pentane	366.91	240.48	205.40	167.71
76	23-dm-hexane/2m3e-pentane	0.49		0.27	
77	112-tm-cyP	1.21	0.75	0.65	0.48
78	2m-heptane	22.72	16.94	13.13	9.40
79	4m-C7/3m3e-C5/1m-cyHexene	8.59	6.45	5.14	3.57
80	34-dm-hexane	3.72	2.84	2.35	1.70
81	3m-heptane	28.38	21.23	16.46	11.63
82	3e-hexane				
83	cct-124-tm-cyP/c-13-dm-cyH	5.52	4.24	3.25	2.30
84	t-14-dm-cyH	1.75	1.32	1.05	0.74
85	225-tm-hexane	3.51	2.57	2.25	1.36
86	11-dm-cyH				
87	1-octene	4.36	3.24	2.60	1.88
88	1e1m-cyP	1.85	1.31	0.85	0.60
89	n-octane/t-12-dm-cyH	26.34	19.13	14.58	10.26
90	224-tm-hexane				
91	t2-octene	2.10	1.50	1.24	0.84
92	ccc-123-tm-cyP	5.75	4.36	4.24	2.96
93	244-tm-hexane	1.83	1.26		
94	c2-octene			0.55	
95	ip-cyP	1.51	1.11	0.94	0.64
96	235-tm-hexane	1.45	1.05	0.92	0.65
97	44&22-dm-heptane	1.05	0.64	0.77	0.58
98	24-dm-heptane	4.94	3.69	2.97	2.08
99	26-dm-heptane/c-12-dm-cyH	5.20	3.87	3.14	2.24
100	np-cyP/ccc-135-tm-cyH/e-cyH	1.64	1.20	0.96	0.64
101	25-dm-heptane	7.76	5.83	4.52	3.15
102	33-dm-heptane	2.12	1.51	1.31	0.90
103	114-tm-cyH	2.36	1.73	1.42	0.95
104	e-benzene	86.29	55.62	47.56	37.55
105	ctt-124-tm-cyH	2.54	2.09	1.60	0.74
106	35-dm-heptane	2.45	1.91	1.51	0.80
107	m&p-xylene/23-dm-heptane	253.20	157.52	137.94	107.19
108	34-dm-heptane/4m-octane	16.60	12.37	9.90	6.86
109	2m-octane/246-tm-hexane	13.47	10.96	8.14	5.96
110	ctc-124-tm-cyH	0.89	1.28	9.06	8.67
111	3m-octane/33-de-C5/3e-C7				

ID	Compound Name	Cold Start 0 °C		Cold Start 24 °C	
		2-Apr	3-Apr	23-Apr	24-Apr
112	o-xylene	108.59	70.05	61.50	47.03
113	112-tm-cyH				
114	1-nonene	3.60	3.27	2.27	1.61
115	t3-nonene	1.94	1.83	1.00	0.65
116	ib-cyP				
117	c3-nonene	1.46	1.42	0.86	0.61
118	n-nonane	9.35	7.18	5.07	3.75
119	t2-nonene	0.73	0.84		
120	c2-nonene	2.23	2.47	1.32	0.91
121	ip-benzene	7.34	5.46	4.34	3.10
122	22-dm-octane	0.62	2.11	1.04	0.31
123	ip-cyH	4.23	3.79	2.03	1.55
124	nb-cyP	5.02	3.73	3.58	1.99
125	33-dm-octane	0.98	0.85	0.67	0.30
126	np-benzene	19.34	12.87	11.51	8.49
127	3e-toluene	64.61	37.53	36.60	26.80
128	23-dm-octane				
129	4e-toluene	26.01	15.90	14.31	10.40
130	135-tm-benzene	34.77	22.20	19.35	14.69
131	2m-nonane	4.44	3.36	1.59	0.95
132	3e-octane	0.94	0.98	0.33	0.38
133	3m-nonane				
134	2e-toluene	29.33	19.41	17.12	13.04
135	124-tm&tb-benzene/1-decene	85.78	51.41	47.97	37.36
136	ib-cyH				
137	n-decane	3.36	2.67	1.58	1.43
138	ib-benzene	1.92	1.52	0.76	0.53
139	sb-benzene	1.76	1.41	0.97	0.70
140	3-ip-toluene	1.06	0.95	1.33	1.32
141	123-tm-benzene	2.70	1.97	1.74	1.20
142	4-ip-toluene	19.26	11.77	11.28	8.37
143	indan	0.82	0.84	0.65	0.43
144	2-ip-toluene	9.72	6.01	5.67	4.08
145	13-de-benzene				
146	14-de-benzene	6.61	0.77	0.58	2.51
147	3-np-toluene	4.16	3.22	2.91	2.23
148	4-np-toluene/nb-&13dm-5e-benz	16.06	10.32	9.27	7.52
149	12-de-benzene	1.88	1.34	1.15	0.84
150	2-np-toluene	0.83	0.60	0.51	0.38
151	14-dm-2e-benzene	8.03	5.38	5.16	4.02
152	13-dm-4e-benzene	5.84	3.59	3.58	2.83
153	12-dm-4e-benzene	9.36	5.75	5.55	4.21
154	13-dm-2e-benzene	3.08	2.23	2.03	1.49
155	n-undecane/12-dm-3e-benzene	2.19	1.52	1.41	1.34
156	1245-ttm-benzene	2.18	1.06	1.11	0.67
157	2mb-benzene	3.50	2.27	2.32	1.76
158	tb-2m-benzene	0.67	0.48	0.53	0.34
159	1234-ttm-benzene	2.52	1.60	1.78	1.23
160	n-pentylbenzene	2.54	1.27	1.80	1.28
161	tb-35-dm-benzene	0.46	0.39	0.56	0.44
162	tb-4e-benzene				
163	n-dodecane	1.16	1.06	0.89	1.33

Mass emissions for volatile organic compounds at 0 °C for the second test fuel (mg/test).

ID	Compound Name	Cold Start 0°C	
		4-May	5-May
1	methane	199.39	195.47
2	ethylene	385.73	409.83
3	acetylene	115.16	125.16
4	ethane	49.34	57.24
5	propylene	188.91	193.58
6	propane	*	144.85
7	propyne	11.00	14.70
8	isobutane	25.36	33.03
9	isobutene/1-butene	51.42	69.68
10	13-butadiene	29.79	37.59
11	n-butane	134.28	164.58
12	t2-butene	12.92	15.86
13	22-dm-propane	0.53	0.63
14	1-butyne	0.33	0.58
15	c2-butene	12.54	13.48
16	12-butadiene		
17	3m1-butene	4.01	5.06
18	2m-butane	108.41	142.61
19	14-pentadiene	1.05	2.36
20	2-butyne	1.26	1.10
21	1-pentene	7.10	8.46
22	2m1-butene	9.25	12.60
23	n-pentane	68.72	88.30
24	2m-13-butadiene	9.50	10.62
25	t2-pentene	12.52	14.61
26	c2-pentene	6.96	8.08
27	2m2-butene	20.74	23.37
28	22-dm-butane	11.53	14.97
29	cyclopentene	5.73	6.97
30	4m1 & 3m1-pentene	0.57	0.86
31	cyclopentane	11.17	14.87
32	23-dm-butane	14.47	19.04
33	c/t-4m2-pentene		
34	2m-pentane	70.88	91.80
35	3m-pentane	42.03	54.31
36	2m1-pentene	2.13	2.94
37	1-hexene	2.45	2.99
38	n-hexane	36.68	47.55
39	c/t-3-hexene	2.31	2.80
40	t2-hexene	3.53	4.25
41	2m2-pentene	6.14	7.18
42	t-3m2-pentene	3.99	4.67
43	c2-hexene	1.93	2.32
44	c-3m2-pentene	4.18	4.96
45	22-dm-pentane	1.74	2.04
46	m-cyclopentane	27.27	35.64
47	24-dm-pentane	6.06	7.28
48	223-tm-butane	0.76	0.83
49	1m-cyclopentene	0.71	0.68
50	benzene	64.06	84.52

ID	Compound Name	Cold Start 0°C	
		4-May	5-May
51	33-dm-pentane	2.41	2.87
52	cyclohexane	5.82	7.55
53	2m-hexane	21.68	26.37
54	23-dm-pentane	7.70	9.51
55	11-dm-cyP	0.80	0.97
56	cyclohexene	0.85	1.06
57	3m-hexane	22.96	28.02
58	c-13-dm-cyP	4.14	4.98
59	3e-pentane/t-13-dm-cyP	7.05	8.52
60	t-12-dm-cyP		
61	224-tm-pentane/1-heptene	13.53	16.60
62	t3-heptene	1.12	1.20
63	n-heptane	20.39	25.15
64	c3-heptane	3.34	3.75
65	t2-heptene	1.07	1.22
66	c2-heptene	1.37	1.57
67	22-dm-hexane	0.47	0.54
68	m-cyH/c12-dm-cyP/113-tm-cyP	8.07	9.84
69	12-dm-cyH	0.76	0.93
70	25-dm-hexane/e-cyP	6.06	7.43
71	24-dm-hexane/223-tm-pentane	6.46	7.72
72	33-dm-hexane/ctc-124-tm-cyP	2.44	2.95
73	ctc-123-tm-cyP	1.16	1.37
74	234-tm-pentane	8.11	9.54
75	toluene/233-tm-pentane	73.67	88.87
76	23-dm-hexane/2m3e-pentane	0.12	
77	112-tm-cyP	0.80	0.79
78	2m-heptane	10.07	11.83
79	4m-C7/3m3e-C5/1m-cyHexene	3.57	4.22
80	34-dm-hexane	1.70	1.95
81	3m-heptane	12.21	14.35
82	3e-hexane		
83	cct-124-tm-cyP/c-13-dm-cyH	2.97	3.62
84	t-14-dm-cyH	0.85	1.08
85	225-tm-hexane	1.89	2.26
86	11-dm-cyH		
87	1-octene	2.28	2.68
88	1e1m-cyP	1.08	1.15
89	n-octane/t-12-dm-cyH	9.87	11.63
90	224-tm-hexane		
91	t2-octene	1.28	1.41
92	ccc-123-tm-cyP	3.17	3.76
93	244-tm-hexane	1.15	1.22
94	c2-octene	0.55	0.62
95	ip-cyP	0.91	1.05
96	235-tm-hexane	0.72	0.81
97	44&22-dm-heptane	0.48	0.60
98	24-dm-heptane	2.38	2.71
99	26-dm-heptane/c-12-dm-cyH	2.49	2.84
100	np-cyP/ccc-135-tm-cyH/e-cyH	1.04	1.22
101	25-dm-heptane	2.98	11.92
102	33-dm-heptane	1.06	3.16
103	114-tm-cyH	1.55	3.38

ID	Compound Name	Cold Start 0°C	
		4-May	5-May
104	e-benzene	30.37	36.93
105	ctt-124-tm-cyH	1.06	1.65
106	35-dm-heptane		
107	m&p-xylene/23-dm-heptane	98.84	116.26
108	34-dm-heptane/4m-octane	6.34	7.69
109	2m-octane/246-tm-hexane	5.27	6.35
110	ctc-124-tm-cyH	0.86	1.09
111	3m-octane/33-de-C5/3e-C7		
112	o-xylene	45.79	52.40
113	112-tm-cyH		
114	1-nonene	2.47	2.81
115	t3-nonene	1.33	1.07
116	ib-cyP		
117	c3-nonene	1.08	1.21
118	n-nonane	3.78	4.35
119	t2-nonene	0.68	0.66
120	c2-nonene	2.05	1.96
121	ip-benzene	3.13	3.23
122	22-dm-octane		0.91
123	ip-cyH	2.32	2.38
124	nb-cyP	3.92	3.50
125	33-dm-octane	0.48	0.54
126	np-benzene	7.03	7.23
127	3e-toluene	22.14	27.71
128	23-dm-octane		
129	4e-toluene	10.10	11.87
130	135-tm-benzene	14.85	15.57
131	2m-nonane	1.44	1.74
132	3e-octane	1.35	1.00
133	3m-nonane		
134	2e-toluene	12.76	12.94
135	124-tm&tb-benzene/1-decene	32.76	34.98
136	ib-cyH		0.24
137	n-decane	1.97	1.37
138	ib-benzene		
139	sb-benzene	1.11	0.69
140	3-ip-toluene	0.11	0.70
141	123-tm-benzene	8.52	8.18
142	4-ip-toluene		
143	indan	0.66	0.40
144	2-ip-toluene	3.76	3.76
145	13-de-benzene	3.25	0.57
146	14-de-benzene	2.17	2.15
147	3-np-toluene	3.67	3.67
148	4-np-toluene/nb-&13dm-5e-benz	1.08	0.80
149	12-de-benzene	0.58	0.38
150	2-np-toluene	3.70	3.57
151	14-dm-2e-benzene	2.75	2.92
152	13-dm-4e-benzene	5.13	5.30
153	12-dm-4e-benzene	1.83	1.77
154	13-dm-2e-benzene	1.72	1.58
155	n-undecane/12-dm-3e-benzene	1.63	1.47
156	1245-ttm-benzene	1.60	1.65

ID	Compound Name	Cold Start 0°C	
		4-May	5-May
157	2mb-benzene	2.38	2.51
158	tb-2m-benzene	1.20	1.31
159	1234-ttm-benzene	0.89	0.40
160	n-pentylbenzene	1.34	1.19
161	tb-35-dm-benzene	0.40	0.38
162	tb-4e-benzene	2.89	1.39
163	n-dodecane	0.96	0.96

* contamination of test cell air with propane invalidated this result.

Mass emissions for carbonyl compounds at –10 °C on the first test fuel (mg/test).

	Cold Start			Hot Start	
	3-Dec	5-Dec	9-Dec	5-Dec	9-Dec
Formaldehyde	152	130	162		8.1
Acetaldehyde	350	242	301		27
2-3 butandione					
Acrolein		22			
Acetone	138	89	77		
Propionaldehyde	26	22	26		
Methoxyacetone					
Crotonaldehyde					
Methyl Vinyl Ketone					
Methacrolein	34				
Methyl Ethyl Ketone	33				
Isobutyraldehyde & Butyraldehyde					
Benzaldehyde	97				
Isovaleraldehyde					
Trimethylacetaldehyde & 3m2-Butanone					
Valeraldehyde					
Acetophenone					
o-Tolualdehyde					
m&p-Tolualdehyde					
Methyl isobutyl Ketone					
Pinacolone					
Hexanaldehyde					

Mass emissions for carbonyl compounds at 0 °C and 24 °C on the first test fuel (mg/test).

	Cold Start 0 °C		Cold Start 24 °C	
	2-Apr	3-Apr	23-Apr	24-Apr
Formaldehyde				
Acetaldehyde				
2-3 butandione				
Acrolein				
Acetone		145.98		5.32
Propionaldehyde				
Methoxyacetone				
Crotonaldehyde				
Methyl Vinyl Ketone				

	Cold Start 0 °C		Cold Start 24 °C	
	2-Apr	3-Apr	23-Apr	24-Apr
Methacrolein				
Methyl Ethyl Ketone		90.37	4.23	
Isobutyraldehyde & Butyraldehyde				
Benzaldehyde				
Isovaleraldehyde				
Trimethylacetaldehyde & 3m2-Butanone		41.61		
Valeraldehyde				
Acetophenone				
o-Tolualdehyde				
m&p-Tolualdehyde				
Methyl isobutyl Ketone				
Pinacolone				
Hexanaldehyde				

Total Hydrocarbon Hot Soak Evaporative Emissions

	HC Emissions (g/test)	HC Emission Rate (g/hr)	Time (min)	Average Temperature (°C)
3-Dec	0.30	0.15	116	-2.7
5-Dec	0.28	0.15	115	-3.9
9-Dec	0.27	0.16	102	-3.7

Volatile Organic Compound Hot Soak Evaporative Emissions on first test fuel (mg/test).

		Hot Soak Evaporative Emissions		
ID	Compound Name	3-Dec	5-Dec	9-Dec
1	methane	11.61	21.12	13.50
2	ethylene	0.36	0.49	0.10
3	acetylene	0.06	0.12	0.08
4	ethane	0.16	0.23	0.25
5	propylene	0.17	0.22	0.07
6	propane	6.96		
7	propyne			
8	isobutane	5.16	7.07	8.01
9	isobutene/1-butene	2.81	4.03	4.35
10	13-butadiene		0.19	0.08
11	n-butane	14.31	19.43	20.23
12	t2-butene	2.35	3.57	3.64
13	22-dm-propane		0.05	0.04
14	1-butyne			
15	c2-butene	1.66	2.41	2.50
16	12-butadiene			
17	3m1-butene	0.13	0.25	0.25
18	2m-butane	10.09	13.07	12.00
19	14-pentadiene		0.27	
20	2-butyne			
21	1-pentene	0.67	0.79	0.87
22	2m1-butene	1.11	1.48	1.59
23	n-pentane	6.53	8.54	8.37
24	2m-13-butadiene	0.07	0.10	0.13
25	t2-pentene	1.65	2.22	2.12
26	c2-pentene	0.87	1.16	1.13

ID	Compound Name	Hot Soak Evaporative Emissions		
		3-Dec	5-Dec	9-Dec
27	2m2-butene	2.18	2.95	2.77
28	22-dm-butane	0.69	0.89	0.79
29	cyclopentene	0.38	0.49	0.48
30	4m1 & 3m1-pentene	0.14	0.20	
31	cyclopentane	1.14	1.50	1.47
32	23-dm-butane	0.89	1.10	0.97
33	c/t-4m2-pentene			
34	2m-pentane	4.62	5.77	5.34
35	3m-pentane	2.80	3.49	3.24
36	2m1-pentene			
37	1-hexene	0.48	0.36	0.31
38	n-hexane	3.19	4.06	3.89
39	c/t-3-hexene	0.27	0.25	0.32
40	t2-hexene	0.41	0.45	0.49
41	2m2-pentene	0.56	0.74	0.67
42	t-3m2-pentene	0.30	0.39	0.36
43	c2-hexene	0.20	0.29	0.26
44	c-3m2-pentene	0.40	0.55	0.52
45	22-dm-pentane			
46	m-cyclopentane	3.44	4.38	4.45
47	24-dm-pentane	0.33	0.41	0.38
48	223-tm-butane			0.04
49	1m-cyclopentene			
50	benzene	9.45	11.61	10.54
51	33-dm-pentane	0.16	0.13	0.13
52	cyclohexane	0.60	0.85	0.79
53	2m-hexane	1.34	1.59	1.55
54	23-dm-pentane	0.36	0.43	0.39
55	11-dm-cyP	0.07	0.08	0.08
56	cyclohexene	0.08	0.08	0.08
57	3m-hexane	1.31	1.56	1.52
58	c-13-dm-cyP	0.28	0.33	0.33
59	3e-pentane/t-13-dm-cyP	0.45	0.52	0.54
60	t-12-dm-cyP			
61	224-tm-pentane/1-heptene	1.05	1.22	0.84
62	t3-heptene	0.14	0.13	0.15
63	n-heptane	1.76	2.09	2.05
64	c3-heptane	0.28	0.35	0.33
65	t2-heptene	0.14	0.15	0.15
66	c2-heptene	0.14	0.16	0.14
67	22-dm-hexane			
68	m-cyH/c12-dm-cyP/113-tm-cyP	0.57	0.99	0.65
69	12-dm-cyH	0.04		0.04
70	25-dm-hexane/e-cyP	0.39	0.47	0.46
71	24-dm-hexane/223-tm-pentane	0.39	0.47	0.41
72	33-dm-hexane/ctc-124-tm-cyP	0.11	0.12	0.12
73	ctc-123-tm-cyP	0.08	0.10	0.08
74	234-tm-pentane	0.53	0.77	0.50
75	toluene/233-tm-pentane	23.58	na*	24.09
76	23-dm-hexane/2m3e-pentane		0.56	
77	112-tm-cyP			
78	2m-heptane	0.57	0.70	0.73
79	4m-C7/3m3e-C5/1m-cyHexene	0.19	0.24	0.24
80	34-dm-hexane	0.09	0.11	0.14

ID	Compound Name	Hot Soak Evaporative Emissions		
		3-Dec	5-Dec	9-Dec
81	3m-heptane	0.63	0.77	0.81
82	3e-hexane			
83	cct-124-tm-cyP/c-13-dm-cyH	0.13	0.16	0.19
84	t-14-dm-cyH	0.08	0.09	0.08
85	225-tm-hexane	0.12	0.16	0.14
86	11-dm-cyH			
87	1-octene	0.15	0.16	0.17
88	1e1m-cyP	0.09	0.09	0.08
89	n-octane/t-12-dm-cyH	0.72	0.78	0.81
90	224-tm-hexane			
91	t2-octene	0.12	0.10	0.11
92	ccc-123-tm-cyP	0.12	0.14	0.15
93	244-tm-hexane	0.09	0.09	0.10
94	c2-octene			
95	ip-cyP			
96	235-tm-hexane	0.04	0.07	
97	44&22-dm-heptane	0.09	0.07	0.01
98	24-dm-heptane	0.14	0.16	0.16
99	26-dm-heptane/c-12-dm-cyH	0.14	0.12	0.15
100	np-cyP/ccc-135-tm-cyH/e-cyH		0.08	0.07
101	25-dm-heptane	0.10	0.14	0.19
102	33-dm-heptane		0.08	
103	114-tm-cyH			0.07
104	e-benzene	4.08	3.45	3.53
105	ctt-124-tm-cyH	0.25		0.30
106	35-dm-heptane			
107	m&p-xylene/23-dm-heptane	10.49	10.60	10.91
108	34-dm-heptane/4m-octane	0.33	0.30	0.29
109	2m-octane/246-tm-hexane	0.11	0.20	0.20
110	ctc-124-tm-cyH		0.17	
111	3m-octane/33-de-C5/3e-C7			
112	o-xylene	3.81	3.93	4.08
113	112-tm-cyH			
114	1-nonene	0.08	0.07	0.08
115	t3-nonene			
116	ib-cyP			
117	c3-nonene			
118	n-nonane		0.14	0.18
119	t2-nonene	0.10		
120	c2-nonene	0.03	0.03	
121	ip-benzene	0.24	0.07	0.13
122	22-dm-octane			
123	ip-cyH		0.06	
124	nb-cyP		0.06	0.07
125	33-dm-octane			
126	np-benzene	0.64	0.54	0.54
127	3e-toluene	1.30	1.66	1.54
128	23-dm-octane			
129	4e-toluene	0.72		0.71
130	135-tm-benzene	0.65	0.80	0.76
131	2m-nonane	0.12		0.18
132	3e-octane			
133	3m-nonane			
134	2e-toluene	0.42	0.59	0.72

ID	Compound Name	Hot Soak Evaporative Emissions		
		3-Dec	5-Dec	9-Dec
135	124-tm&tb-benzene/1-decene	1.69	1.84	1.60
136	ib-cyH	0.16		
137	n-decane		0.07	0.02
138	ib-benzene			
139	sb-benzene			
140	3-ip-toluene		0.22	0.05
141	123-tm-benzene			
142	4-ip-toluene	0.03	0.38	0.37
143	indan			
144	2-ip-toluene		0.18	0.45
145	13-de-benzene			
146	14-de-benzene	0.01		
147	3-np-toluene		0.14	0.11
148	4-np-toluene/nb-&13dm-5e-benz	0.18	0.23	0.19
149	12-de-benzene			
150	2-np-toluene			
151	14-dm-2e-benzene		0.14	0.12
152	13-dm-4e-benzene			
153	12-dm-4e-benzene		0.11	0.22
154	13-dm-2e-benzene			
155	n-undecane/12-dm-3e-benzene		0.21	0.00
156	1245-ttm-benzene			
157	2mb-benzene		0.10	
158	tb-2m-benzene			
159	1234-ttm-benzene			
160	n-pentylbenzene	0.33		
161	tb-35-dm-benzene		0.25	
162	tb-4e-benzene			
163	n-dodecane		0.46	0.04

na* sample contaminated with toluene from cleaning bag fittings.

Evaporated Fuel Volatile Organic Compound profiles for Fuel 1 and Fuel 2 (wt. normalised).

ID	Compound Name	Normalized Composition			
		Evaporated Fuel 1	Actual Evaporative Emissions Fuel 1	Evaporated Fuel 2	Simulated Evaporative Emissions Fuel 2
6	propane	0.0014	0.0149	0.0011	0.0109
7	propyne	0.0000	0.0000	0.0000	0.0000
8	isobutane	0.0382	0.0432	0.0223	0.0252
9	isobutene/1-butene	0.0118	0.0239	0.0054	0.0110
10	13-butadiene	0.0001	0.0006	0.0001	0.0003
11	n-butane	0.0770	0.1153	0.1147	0.1716
12	t2-butene	0.0075	0.0204	0.0053	0.0144
13	22-dm-propane	0.0003	0.0002	0.0004	0.0002
14	1-butyne	0.0000	0.0000	0.0000	0.0000
15	c2-butene	0.0060	0.0140	0.0046	0.0107
16	12-butadiene	0.0000	0.0000	0.0000	0.0000
17	3m1-butene	0.0014	0.0013	0.0016	0.0015
18	2m-butane	0.0923	0.0751	0.0937	0.0762
19	14-pentadiene	0.0000	0.0006	0.0000	0.0000
20	2-butyne	0.0000	0.0000	0.0000	0.0000
21	1-pentene	0.0031	0.0050	0.0040	0.0064
22	2m1-butene	0.0063	0.0089	0.0051	0.0073
23	n-pentane	0.0452	0.0501	0.0608	0.0674

ID	Compound Name	Normalized Composition			
		Evaporated Fuel 1	Actual Evaporative Emissions Fuel 1	Evaporated Fuel 2	Simulated Evaporative Emissions Fuel 2
24	2m-13-butadiene	0.0003	0.0006	0.0005	0.0012
25	t2-pentene	0.0073	0.0128	0.0099	0.0172
26	c2-pentene	0.0042	0.0067	0.0053	0.0085
27	2m2-butene	0.0123	0.0169	0.0169	0.0233
28	22-dm-butane	0.0112	0.0051	0.0085	0.0039
29	cyclopentene	0.0016	0.0029	0.0038	0.0071
30	4m1 & 3m1-pentene	0.0013	0.0007	0.0016	0.0009
31	cyclopentane	0.0082	0.0088	0.0099	0.0105
32	23-dm-butane	0.0120	0.0063	0.0122	0.0065
33	c/t-4m2-pentene	0.0000	0.0000	0.0000	0.0000
34	2m-pentane	0.0500	0.0336	0.0585	0.0393
35	3m-pentane	0.0317	0.0204	0.0345	0.0221
36	2m1-pentene	0.0000	0.0000	0.0011	0.0000
37	1-hexene	0.0019	0.0025	0.0016	0.0020
38	n-hexane	0.0269	0.0238	0.0316	0.0279
39	c/t-3-hexene	0.0018	0.0018	0.0024	0.0023
40	t2-hexene	0.0027	0.0029	0.0034	0.0036
41	2m2-pentene	0.0045	0.0042	0.0067	0.0062
42	t-3m2-pentene	0.0027	0.0022	0.0033	0.0027
43	c2-hexene	0.0016	0.0016	0.0020	0.0020
44	c-3m2-pentene	0.0035	0.0032	0.0046	0.0041
45	22-dm-pentane	0.0000	0.0000	0.0013	0.0000
46	m-cyclopentane	0.0345	0.0262	0.0219	0.0166
47	24-dm-pentane	0.0046	0.0024	0.0051	0.0026
48	223-tm-butane	0.0003	0.0001	0.0004	0.0001
49	1m-cyclopentene	0.0002	0.0000	0.0002	0.0000
50	benzene	0.0253	0.0675	0.0194	0.0518
51	33-dm-pentane	0.0017	0.0009	0.0021	0.0011
52	cyclohexane	0.0064	0.0048	0.0045	0.0034
53	2m-hexane	0.0159	0.0096	0.0167	0.0101
54	23-dm-pentane	0.0052	0.0025	0.0060	0.0029
55	11-dm-cyP	0.0009	0.0005	0.0005	0.0003
56	cyclohexene	0.0003	0.0005	0.0004	0.0007
57	3m-hexane	0.0166	0.0094	0.0179	0.0101
58	c-13-dm-cyP	0.0032	0.0020	0.0030	0.0019
59	3e-pentane/t-13-dm-cyP	0.0050	0.0032	0.0048	0.0031
60	t-12-dm-cyP	0.0000	0.0000	0.0000	0.0000
61	224-tm-pentane/1-heptene	0.0148	0.0066	0.0105	0.0047
62	t3-heptene	0.0009	0.0009	0.0012	0.0012
63	n-heptane	0.0168	0.0126	0.0166	0.0125
64	c3-heptane	0.0032	0.0021	0.0043	0.0027
65	t2-heptene	0.0008	0.0009	0.0011	0.0012
66	c2-heptene	0.0010	0.0009	0.0015	0.0014
67	22-dm-hexane	0.0002	0.0000	0.0003	0.0000
68	m-cyH/c12-dm-cyP/113-tm-cyP	0.0065	0.0047	0.0056	0.0041
69	12-dm-cyH	0.0006	0.0002	0.0005	0.0002
70	25-dm-hexane/e-cyP	0.0049	0.0028	0.0044	0.0025
71	24-dm-hexane/223-tm-pentane	0.0056	0.0027	0.0046	0.0022
72	33-dm-hexane/ctc-124-tm-cyP	0.0019	0.0007	0.0017	0.0007
73	ctc-123-tm-cyP	0.0008	0.0006	0.0008	0.0006
74	234-tm-pentane	0.0054	0.0038	0.0074	0.0053
75	toluene/233-tm-pentane	0.0909	0.1018	0.0400	0.0448

ID	Compound Name	Normalized Composition			
		Evaporated Fuel 1	Actual Evaporative Emissions Fuel 1	Evaporated Fuel 2	Simulated Evaporative Emissions Fuel 2
76	23-dm-hexane/2m3e-pentane	0.0034	0.0012	0.0002	0.0001
77	112-tm-cyP	0.0006	0.0000	0.0007	0.0000
78	2m-heptane	0.0080	0.0043	0.0072	0.0038
79	4m-C7/3m3e-C5/1m-cyHexene	0.0030	0.0014	0.0025	0.0012
80	34-dm-hexane	0.0013	0.0007	0.0012	0.0006
81	3m-heptane	0.0099	0.0047	0.0086	0.0041
82	3e-hexane	0.0000	0.0000	0.0000	0.0000
83	cct-124-tm-cyP/c-13-dm-cyH	0.0018	0.0010	0.0019	0.0010
84	t-14-dm-cyH	0.0006	0.0005	0.0006	0.0005
85	225-tm-hexane	0.0013	0.0009	0.0011	0.0008
86	11-dm-cyH	0.0000	0.0000	0.0000	0.0000
87	1-octene	0.0014	0.0010	0.0016	0.0012
88	1e1m-cyP	0.0009	0.0005	0.0013	0.0008
89	n-octane/t-12-dm-cyH	0.0090	0.0049	0.0078	0.0043
90	224-tm-hexane	0.0000	0.0000	0.0000	0.0000
91	t2-octene	0.0008	0.0007	0.0012	0.0010
92	ccc-123-tm-cyP	0.0020	0.0009	0.0023	0.0010
93	244-tm-hexane	0.0010	0.0006	0.0014	0.0008
94	c2-octene	0.0000	0.0000	0.0005	0.0000
95	ip-cyP	0.0005	0.0000	0.0006	0.0000
96	235-tm-hexane	0.0005	0.0002	0.0004	0.0002
97	44&22-dm-heptane	0.0003	0.0004	0.0003	0.0004
98	24-dm-heptane	0.0016	0.0010	0.0016	0.0010
99	26-dm-heptane/c-12-dm-cyH	0.0016	0.0009	0.0017	0.0009
100	np-cyP/ccc-135-tm-cyH/e-cyH	0.0005	0.0003	0.0008	0.0005
101	25-dm-heptane	0.0025	0.0009	0.0020	0.0007
102	33-dm-heptane	0.0006	0.0002	0.0007	0.0002
103	114-tm-cyH	0.0008	0.0002	0.0012	0.0002
104	e-benzene	0.0173	0.0236	0.0187	0.0256
105	ctt-124-tm-cyH	0.0005	0.0012	0.0007	0.0017
106	35-dm-heptane	0.0007	0.0000	0.0006	0.0000
107	m&p-xylene/23-dm-heptane	0.0545	0.0683	0.0598	0.0751
108	34-dm-heptane/4m-octane	0.0050	0.0020	0.0041	0.0016
109	2m-octane/246-tm-hexane	0.0039	0.0011	0.0034	0.0010
110	ctc-124-tm-cyH	0.0005	0.0004	0.0007	0.0005
111	3m-octane/33-de-C5/3e-C7	0.0000	0.0000	0.0000	0.0000
112	o-xylene	0.0235	0.0252	0.0258	0.0277
113	112-tm-cyH	0.0000	0.0000	0.0000	0.0000
114	1-nonene	0.0010	0.0005	0.0014	0.0007
115	t3-nonene	0.0007	0.0000	0.0010	0.0000
116	ib-cyP	0.0000	0.0000	0.0000	0.0000
117	c3-nonene	0.0005	0.0000	0.0008	0.0000
118	n-nonane	0.0027	0.0007	0.0026	0.0007
119	t2-nonene	0.0003	0.0002	0.0004	0.0004
120	c2-nonene	0.0007	0.0001	0.0012	0.0002
121	ip-benzene	0.0017	0.0009	0.0017	0.0009
122	22-dm-octane	0.0006	0.0000	0.0000	0.0000
123	ip-cyH	0.0013	0.0001	0.0017	0.0002
124	nb-cyP	0.0012	0.0003	0.0021	0.0005
125	33-dm-octane	0.0002	0.0000	0.0004	0.0000
126	np-benzene	0.0047	0.0037	0.0045	0.0035
127	3e-toluene	0.0126	0.0096	0.0137	0.0104

ID	Compound Name	Normalized Composition			
		Evaporated Fuel 1	Actual Evaporative Emissions Fuel 1	Evaporated Fuel 2	Simulated Evaporative Emissions Fuel 2
128	23-dm-octane	0.0000	0.0000	0.0000	0.0000
129	4e-toluene	0.0055	0.0031	0.0059	0.0033
130	135-tm-benzene	0.0075	0.0047	0.0077	0.0049
131	2m-nonane	0.0013	0.0006	0.0011	0.0006
132	3e-octane	0.0003	0.0000	0.0003	0.0000
133	3m-nonane	0.0000	0.0000	0.0000	0.0000
134	2e-toluene	0.0059	0.0037	0.0061	0.0039
135	124-tm&tb-benzene/1-decene	0.0175	0.0110	0.0182	0.0114
136	ib-cyH	0.0003	0.0003	0.0005	0.0007
137	n-decane	0.0008	0.0002	0.0014	0.0003
138	ib-benzene	0.0005	0.0000	0.0006	0.0000
139	sb-benzene	0.0004	0.0000	0.0006	0.0000
140	3-ip-toluene	0.0000	0.0006	0.0007	0.0000
141	123-tm-benzene	0.0006	0.0000	0.0045	0.0000
142	4-ip-toluene	0.0040	0.0017	0.0000	0.0000
143	indan	0.0002	0.0000	0.0004	0.0000
144	2-ip-toluene	0.0022	0.0013	0.0025	0.0015
145	13-de-benzene	0.0000	0.0000	0.0003	0.0000
146	14-de-benzene	0.0002	0.0000	0.0006	0.0001
147	3-np-toluene	0.0008	0.0005	0.0018	0.0012
148	4-np-toluene/nb-&13dm-5e-benz	0.0033	0.0013	0.0006	0.0002
149	12-de-benzene	0.0005	0.0000	0.0003	0.0000
150	2-np-toluene	0.0002	0.0000	0.0003	0.0000
151	14-dm-2e-benzene	0.0015	0.0006	0.0011	0.0004
152	13-dm-4e-benzene	0.0010	0.0000	0.0025	0.0000
153	12-dm-4e-benzene	0.0019	0.0007	0.0008	0.0003
154	13-dm-2e-benzene	0.0007	0.0000	0.0003	0.0000
155	n-undecane/12-dm-3e-benzene	0.0005	0.0005	0.0013	0.0012
156	1245-ttm-benzene	0.0004	0.0000	0.0007	0.0000
157	2mb-benzene	0.0009	0.0002	0.0010	0.0002
158	tb-2m-benzene	0.0001	0.0000	0.0006	0.0000
159	1234-ttm-benzene	0.0008	0.0000	0.0002	0.0000
160	n-pentylbenzene	0.0009	0.0007	0.0002	0.0002
161	tb-35-dm-benzene	0.0002	0.0005	0.0001	0.0003
162	tb-4e-benzene	0.0000	0.0000	0.0002	0.0000
163	n-dodecane	0.0003	0.0011	0.0002	0.0008

Explanation of the conventions used in this document for hydrocarbon compound names.

Abbreviation	Full Name
t2-butene	trans-2-butene
c2-butene	cis-2-butene
2,2-dm-propane	2,2-dimethylpropane
3m1-butene	3-methyl-1-butene
1,1-dm-cyP	1,1-dimethylcyclopentane
e-cyP	ethylcyclopentane
4m-C7	4-methylheptane
3e-C6	3-ethylhexane
cct-1,3,5-tm-cyH	cis-cis-trans-1,3,5-trimethylcyclohexane
ip-	isopropyl-
np-	n-propyl
ib-	isobutyl-
sb-	sec-butyl
tb-	tert-butyl
1,2,4,5-ttm-benzene	1,2,4,5-tetramethylbenzene
1,3-de-benzene	1,3-diethylbenzene