

# Air Emissions Test of Dynamometer Test Cells

**Roush Industries**  
36630 Commerce Street  
Livonia, Michigan

# **ROUSH**®

*Prepared for*  
**Roush Industries**  
Livonia, Michigan

Bureau Veritas Project No. 11016-000063.00  
June 13, 2016



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RENEWABLE OPERATING PERMIT  
REPORT CERTIFICATION

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Authorized by 1994 P.A. 451, as amended. Failure to provide this information may result in civil and/or criminal penalties.

Reports submitted pursuant to R 336.1213 (Rule 213), subrules (3)(c) and/or (4)(c), of Michigan's Renewable Operating Permit (ROP) program must be certified by a responsible official. Additional information regarding the reports and documentation listed below must be kept on file for at least 5 years, as specified in Rule 213(3)(b)(ii), and be made available to the Department of Environmental Quality, Air Quality Division upon request.

Source Name Roush Industries County Wayne

Source Address 36630 Commerce City Livonia

AQD Source ID (SRN) M4780 ROP No. M4780-2016 ROP Section No. D

Please check the appropriate box(es):

Annual Compliance Certification (Pursuant to Rule 213(4)(c))

Reporting period (provide inclusive dates): From \_\_\_\_\_ To \_\_\_\_\_

- 1. During the entire reporting period, this source was in compliance with ALL terms and conditions contained in the ROP, each term and condition of which is identified and included by this reference. The method(s) used to determine compliance is/are the method(s) specified in the ROP.
- 2. During the entire reporting period this source was in compliance with all terms and conditions contained in the ROP, each term and condition of which is identified and included by this reference, EXCEPT for the deviations identified on the enclosed deviation report(s). The method used to determine compliance for each term and condition is the method specified in the ROP, unless otherwise indicated and described on the enclosed deviation report(s).

Semi-Annual (or More Frequent) Report Certification (Pursuant to Rule 213(3)(c))

Reporting period (provide inclusive dates): From \_\_\_\_\_ To \_\_\_\_\_

- 1. During the entire reporting period, ALL monitoring and associated recordkeeping requirements in the ROP were met and no deviations from these requirements or any other terms or conditions occurred.
- 2. During the entire reporting period, all monitoring and associated recordkeeping requirements in the ROP were met and no deviations from these requirements or any other terms or conditions occurred, EXCEPT for the deviations identified on the enclosed deviation report(s).

Other Report Certification

Reporting period (provide inclusive dates): From NA To NA

Additional monitoring reports or other applicable documents required by the ROP are attached as described:

Test Report evaluating air emissions from FG-Bldg15Tcells and FG-Bldg16Tcells.

This form shall certify that the testing was conducted in accordance with the

approved test plan and that the facility was operating in compliance with permit

conditions at the maximum routing operating condition.

I certify that, based on information and belief formed after reasonable inquiry, the statements and information in this report and the supporting enclosures are true, accurate and complete

JEFF JOHNSTON

VP

734-779-7601

Name of Responsible Official (print or type)

Title

Phone Number

6/17/16

Signature of Responsible Official

Date



## Executive Summary

Roush Industries retained Bureau Veritas North America, Inc. to test air emissions from engine dynamometer test cells at the Roush Industries facility in Livonia, Michigan. The purpose of the testing was to measure gaseous emissions from engine dynamometer test cells as required by the facility's Michigan Department of Environmental Quality (MDEQ) Renewable Operating Permit (ROP) MI-ROP-M4780-2016, effective January 8, 2016.

The air emission test program was conducted during two mobilizations: (1) April 6 and 7, 2016, and (2) April 20 and 21, 2016. The following sources were tested:

### April 6 and 7, 2016—Building 15

- Dynamometer Test Cells EU-TCelIB15A and EU-TCelIB15K from Flex Group FG-Bld15TCells. Engine emissions from these test cells are exhausted directly to the atmosphere.

### April 20 and 21, 2016—Building 16

- Dynamometer Test Cells EU-TCelIB16A1 and EU-TCelIB16B2 from Flex Group FG-Bld16TCells. Engine emissions from these test cells are exhausted through a catalytic converter.

After the first phase of testing, the engines that were tested were moved from Building 15 to Building 16 to complete the second phase of testing.

The concentrations and mass emission rates of following were measured at the exhaust stacks:

- Carbon dioxide (CO<sub>2</sub>)
- Carbon monoxide (CO)
- 1,3-Butadiene
- Nitrogen oxides (NO<sub>x</sub>)

The testing followed United States Environmental Protection Agency (USEPA) Reference Methods 1A, 2C, 3A, 4, 7E, 10, 18, 19, 205, Compendium Method TO-15, and Occupational Safety and Health Administration (OSHA) Reference Method 56.

In order to represent an average point for engine mapping, the engines were tested while operating at the WorldWide Mapping Point (WWMP) engine cycle. The WWMP engine cycle



[1500 revolution per minute (RPM), 2.62 bar brake mean effective pressure] is used in the automobile industry to characterize engine emissions and efficiency for various engines and applications.

A second engine test mode, representing a higher load power development condition, at approximately half the rated power level and engine speed was also used. This engine operating condition represents the average operation over a full engine load curve.

On April 6 and 7, 2016, Bureau Veritas measured gaseous emissions from engine dynamometer test cells by conducting the following:

- Six 60-minute test runs, at the exhaust of EU-TCellB15A, with a 2.5 liter (L) engine.

Three test runs were conducted at the WWMP cycle and three test runs were conducted at 3750 RPM.

- Six 60-minute test runs, at the exhaust of EU-TCellB15K, with a 4.6 L engine.

Three test runs were conducted at the WWMP cycle and three test runs were conducted at 3500 RPM.

On April 20 and 21, 2016, Bureau Veritas measured gaseous emissions from engine dynamometer test cells by conducting the following:

- Six 60-minute test runs, at the exhaust of EU-TCellB16A1, with a 2.5 L engine.

Three test runs were conducted at the WWMP cycle and three test runs were conducted at 3750 RPM.

- Six 60-minute test runs, at the exhaust of EU-TCellB16B2, on a 4.6 L engine.

Three test runs were conducted at the WWMP cycle and three test runs were conducted at 3500 RPM.

Detailed results of the testing are presented in Tables 1 through 12 after the Tables Tab of this report. The results of the testing are summarized in the following table.



## Engine Dynamometer Test Cell Results

Emission Source	Test Cell	Engine Size (liter)	Engine Load Condition	Average Result		
				Parameter		
				Nitrogen Oxides (lb/gal)	Carbon Monoxide (lb/gal)	1,3-Butadiene (lb/gal)
<b>Building 15 - April 6 and 7, 2016</b>						
EU-TCe11B15A	A	2.5	WWMP	0.18	0.33	<0.0002
			3750 RPM	0.47	0.53	<0.0001
EU-TCe11B15K	K	4.6	WWMP	0.31	0.74	<0.0002
			3500 RPM	0.48	0.51	<0.0001
<b>Building 15 Average Result</b>				<b>0.36</b>	<b>0.53</b>	<b>&lt;0.0002</b>
<b>Building 16 - April 20 and 21, 2016</b>						
EU-TCe11B16A1	A1	2.5	WWMP	0.16	0.33	<0.0001
			3750 RPM	0.16	0	<0.000001
EU-TCe11B16B2	B2	4.6	WWMP	0.30	0.75	<0.0001
			3500 RPM	0.16	0	<0.0000002
<b>Building 16 Average Result</b>				<b>0.20</b>	<b>0.27</b>	<b>&lt;0.00005</b>

RPM: revolution per minute

WWMP: WorldWide Mapping Point (1500 RPM, 2.62 bar brake mean effective pressure)

lb/gal: pound of pollutant per gallon of fuel consumed



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# 1.0 Introduction

## 1.1 Summary of Test Program

Roush Industries retained Bureau Veritas North America, Inc. to test air emissions from engine dynamometer test cells at the Roush Industries facility in Livonia, Michigan. Roush Industries is an engineering consulting firm. Roush Industries operates engine dynamometer test cells to conduct automotive testing and development of engine components.

The purpose of the testing was to measure gaseous emissions from engine dynamometer test cells as required by the facility's Michigan Department of Environmental Quality (MDEQ) Renewable Operating Permit (ROP) MI-ROP-M4780-2016, effective January 8, 2016.

The air emission test program was conducted during two mobilizations: (1) April 6 and 7, 2016, and (2) April 20 and 21, 2016. The following sources were tested:

### **April 6 and 7, 2016—Building 15**

- Dynamometer Test Cells EU-TCe11B15A and EU-TCe11B15K from Flex Group FG-B1d15TCe11s. Engine emissions from these test cells are exhausted directly to the atmosphere.

### **April 20 and 21, 2016—Building 16**

- Dynamometer Test Cells EU-TCe11B16A1 and EU-TCe11B16B2 from Flex Group FG-B1d16TCe11s. Engine emissions from these test cells are exhausted through a catalytic converter.

After the first phase of testing, the engines that were tested were moved from Building 15 to Building 16 to complete the second phase of testing.

The concentrations and mass emission rates of following were measured at the exhaust stacks:

- Carbon dioxide (CO<sub>2</sub>)
- Carbon monoxide (CO)
- 1,3-Butadiene
- Nitrogen oxides (NO<sub>x</sub>)



The testing followed United States Environmental Protection Agency (USEPA) Reference Methods 1A, 2C, 3A, 4, 7E, 10, 18, 19, 205, Compendium Method TO-15, and Occupational Safety and Health Administration (OSHA) Reference Method 56.

In order to represent an average point for engine mapping, the engines were tested while operating at the WorldWide Mapping Point (WWMP) engine cycle. The WWMP engine cycle [1500 revolutions per minute (RPM), 2.62 bar brake mean effective pressure] is used in the automobile industry to characterize engine emissions and efficiency for various engines and applications.

A second engine test mode, representing a higher load power development condition, at approximately half the rated power level and engine speed was also used. This engine operating condition represents the average operation over a full engine load curve.

On April 6 and 7, 2016, Bureau Veritas measured gaseous emissions from engine dynamometer test cells by conducting the following:

- Six 60-minute test runs, at the exhaust of EU-TCe11B15A, with a 2.5 liter (L) engine.

Three test runs were conducted at the WWMP cycle and three test runs were conducted at 3750 RPM.

- Six 60-minute test runs, at the exhaust of EU-TCe11B15K, with a 4.6 L engine.

Three test runs were conducted at the WWMP cycle and three test runs were conducted at 3500 RPM.

On April 20 and 21, 2016, Bureau Veritas measured gaseous emissions from engine dynamometer test cells by conducting the following:

- Six 60-minute test runs, at the exhaust of EU-TCe11B16A1, with a 2.5 L engine.

Three test runs were conducted at the WWMP cycle and three test runs were conducted at 3750 RPM.

- Six 60-minute test runs, at the exhaust of EU-TCe11B16B2, on a 4.6 L engine.

Three test runs were conducted at the WWMP cycle and three test runs were conducted at 3500 RPM.

Table 1-1 summarizes the sources, parameters, and test dates.



**Table 1-1**  
**Sources Tested, Parameters, and Test Dates**

<b>Source Identification</b>	<b>Test Runs</b>	<b>Test Parameters</b>	<b>Test Date</b>
<b>Building 15 – uncontrolled cells</b>			
EU-TCellB15A	1 through 6	NO <sub>x</sub> , CO, 1,3-Butadiene, CO <sub>2</sub>	April 6, 2016
EU-TCellB15K	1 through 6	NO <sub>x</sub> , CO, 1,3-Butadiene, CO <sub>2</sub>	April 7, 2016
<b>Building 16 – catalytic converter controlled cells</b>			
EU-TCellB16A1	1 through 6	NO <sub>x</sub> , CO, 1,3-Butadiene, CO <sub>2</sub>	April 20, 2016
EU-TCellB16B2	1 through 6	NO <sub>x</sub> , CO, 1,3-Butadiene, CO <sub>2</sub>	April 21, 2016

NO<sub>x</sub>: Nitrogen oxides  
CO: Carbon monoxide  
CO<sub>2</sub>: Carbon dioxide

## **1.2 Key Personnel**

Key personnel involved in this test program are listed in Table 1-2. Mr. Thomas Schmelter, Senior Project Manager with Bureau Veritas, directed the air emissions testing program. Mr. Robert Mullenax, Manager, and Mr. Jeffrey Carter, B15 Dynamometer Supervisor, with Roush Industries provided process coordination and arranged for facility operating parameters to be recorded.

The testing was witnessed by Mr. Terseer Hemben, Environmental Engineer, and Messrs. David Patterson and Mark Dziadosz, Environmental Quality Analysts, with MDEQ.





**Table 1-2  
Key Personnel**

<b>Facility Contact</b>	
<p>Robert Mullenax Manager <b>Roush Industries</b> 36630 Commerce Street Livonia, Michigan 48150 Telephone: 734.779.7647 Facsimile: 734.779.7915 robert.mullenax@roush.com</p>	<p>Jeffrey Carter B15 Dynamometer Supervisor <b>Roush Industries</b> 36630 Commerce Street Livonia, Michigan 48150 Telephone: 734.779.7639 Facsimile: 734.779.7915 jeffrey.carter@roush.com</p>
<b>Emission Testing Project Manager</b>	
<p>Thomas Schmelter, QSTI Senior Project Manager <b>Bureau Veritas North America, Inc.</b> 22345 Roethel Drive Novi, Michigan 48375 Telephone: 248.344.2661 Facsimile: 248.344.2656 thomas.schmelter@us.bureauveritas.com</p>	
<b>Regulatory Agency</b>	
<p>Terseer Hemben, DM Environmental Engineer <b>Michigan Department of Environmental Quality</b> Air Quality Division Cadillac Place 3058 West Grand Boulevard Suite 2-300 Detroit, Michigan 48202 Telephone: 313.456.4677 Facsimile: 313.456.4692 hembent@michigan.gov</p>	<p>David Patterson Environmental Quality Analyst <b>Michigan Department of Environmental Quality</b> Air Quality Division – Technical Programs Unit Constitution Hall 2<sup>nd</sup> Floor South Tower 525 West Allegan Street Lansing, Michigan 48909 Telephone: 517.284.6782 Facsimile: 517.335.3122 pattersond2@michigan.gov</p>
<p>Mark Dziadosz Environmental Quality Analyst <b>Michigan Department of Environmental Quality</b> Air Quality Division Southeast Michigan District 27700 Donald Court Warren, Michigan 48092-2793 Telephone: 586.753.3745 Facsimile: 586.753.3731 dziadoszm@michigan.gov</p>	



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## 2.0 Source and Sampling Locations

### 2.1 Process Description

Roush Industries is an engineering consulting firm. Roush Industries operates engine dynamometer test cells to conduct automotive testing and development of engine components. The test cells have the capability of firing a variety of specific fuels. The tests cells that were evaluated during this test program are located in Buildings 15 and 16. Emissions from these test cells are regulated by a single MDEQ ROP (MI-ROP-M4780-2016).

A total of 12 test cells are located in Building 15 and are grouped as FG-Bld15TCells within the MDEQ ROP. Five sets of single-ended test cells and seven sets of double-ended test cells are located in Building 15. Some of the test cells in Building 15 may incorporate catalytic converters to control air emissions. Test Cells EU-TCe11B15A and EU-TCe11B15K, which were tested during this test program, are not controlled by catalytic oxidizers.

A total of seven test cells are located in Building 16 and are grouped as FG-Bld16TCells within the MDEQ ROP. Five sets of single-ended test cells and two sets of double-ended test cells are located in Building 16. The two sets of double-ended test cells in Building 16 are not controlled by catalytic oxidizers. The remaining five test cells in Building 16 incorporate catalytic converters to control air emissions including Test Cells EU-TCe11B16A1 and EU-TCe11B16B2, which were tested during this test program.

The two engines tested, Ford manufactured 2.5L V6 and 4.6L V8, are representative of modern engine design and of those currently tested at the facility. The engines are similar to a 3.0L V6 engine that was used for initial emission rate estimated during the permitting process.

Unleaded gasoline with 10% ethanol (E10) was used to fuel the engines within the dynamometer test cells during the emissions testing program. Fuel use, fuel analysis, and engine operating parameters recorded during testing are included in Appendix F. Table 2-1 summarizes the operating parameters.



**Table 2-1  
Summary of Process Operating Parameters**

Emission Source	Test Run	Engine Size (liter)	Engine Load Condition	Average Total Fuel Consumption	
				lb/hr	gal/hr
<b>Building 15 - April 6 and 7, 2016</b>					
EU-TCe11B15A	1	2.5	WWMP	5.87	0.98
	2			5.89	0.98
	3			5.89	0.98
	4	2.5	3750 RPM	35.35	5.89
	5			35.16	5.86
	6			35.10	5.85
EU-TCe11B15K	1	4.6	WWMP	11.4	1.9
	2			11.3	1.9
	3			11.1	1.8
	4	4.6	3500 RPM	60.2	10.0
	5			59.6	9.9
	6			59.9	10.0
<b>Building 16 - April 20 and 21, 2016</b>					
EU-TCe11B16A1	1	2.5	WWMP	5.41	0.90
	2			5.34	0.89
	3			5.31	0.88
	4	2.5	3750 RPM	34.36	5.73
	5			34.26	5.71
	6			34.11	5.68
EU-TCe11B16B2	1	4.6	WWMP	10.85	1.81
	2			10.89	1.81
	3			10.84	1.81
	4	4.6	3500 RPM	58.65	9.77
	5			59.05	9.84
	6			59.16	9.86

RPM: revolution per minute

WWMP: WorldWide Mapping Point (1500 RPM, 2.62 bar brake mean effective pressure)

lb/hr: pound per hour

gal/hr: gallon per hour



## 2.2 Control Equipment

Some of the engine dynamometer test cells exhaust uncontrolled directly to the atmosphere. Other test cells are controlled by catalytic converters. During this emissions testing program the test cells tested in Building 15 (EU-TCe11B15A and EU-TCe11B15K) were not equipped with catalytic converters and emissions tested from the test cells in Building 16 (EU-TCe11B16A1 and EU-TCe11B16B2) were controlled with catalytic converters.

## 2.3 Exhaust Gas Sampling Locations

Figures 1 and 2 in the Appendix (after the Figures Tab) depict the test cell emission source sampling ports and traverse point locations. Descriptions of each sampling location are presented in Sections 2.3.1 and 2.3.2.

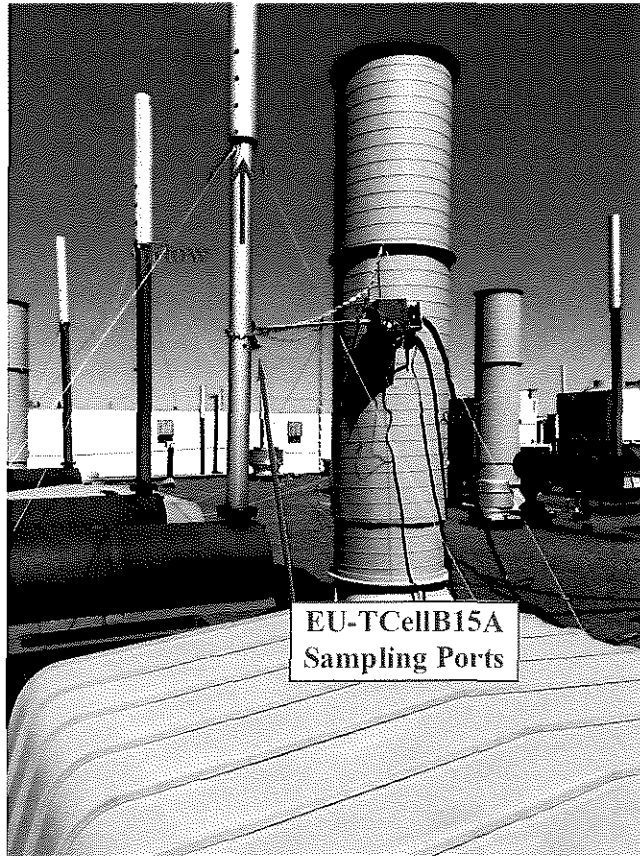
### 2.3.1 EU-TCe11B15A and EU-TCe11B15K

Test Cells EU-TCe11B15A and EU-TCe11B15K are configured similarly. The exhaust stacks are 5.625 inches in diameter and have three sampling ports. Only two ports (located 90° apart) were necessary to conduct the testing. Four traverse points for each of the two sampling ports were used to measure stack gas velocity and calculate volumetric flowrates. The ports are located:

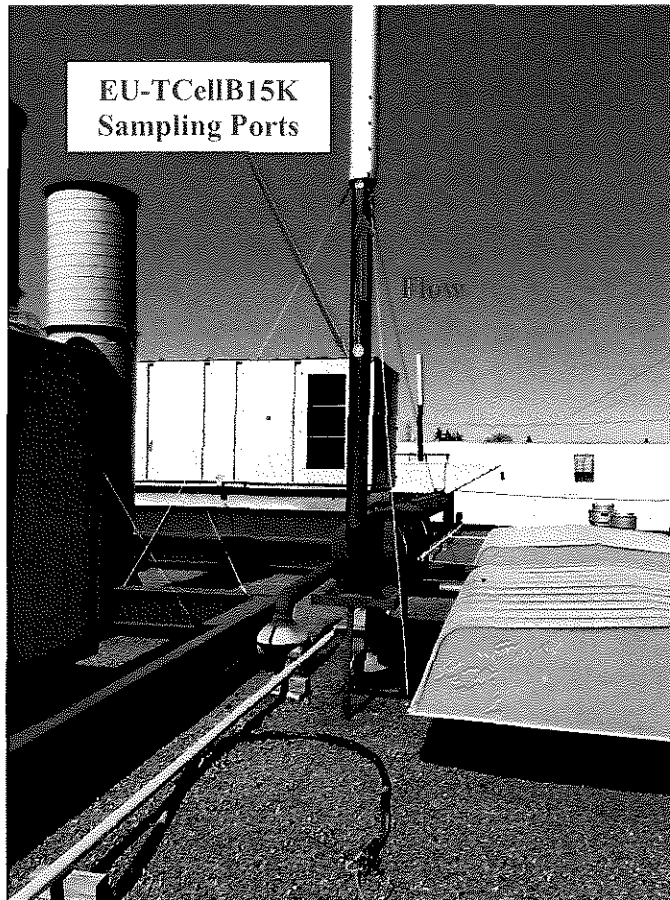
- Approximately 48 inches (8.5 duct diameters) from the nearest downstream disturbance (exhaust to atmosphere).
- Approximately 43 inches (7.6 duct diameters) from the nearest upstream disturbance (duct confluence where flue gas enters exhaust stack).

The sampling ports are accessible via the rooftop where the exhaust stacks exit the building.

Figures 2-1 and 2-2 are photographs of the EU-TCe11B15A and EU-TCe11B15K exhaust sampling locations. Figure 1 in the Appendix depicts the EU-TCe11B15A and EU-TCe11B15K sampling and traverse point locations.



**Figure 2-1. EU-TCellB15A Sampling Location**



**Figure 2-2. EU-TCCellB15K Sampling Location**

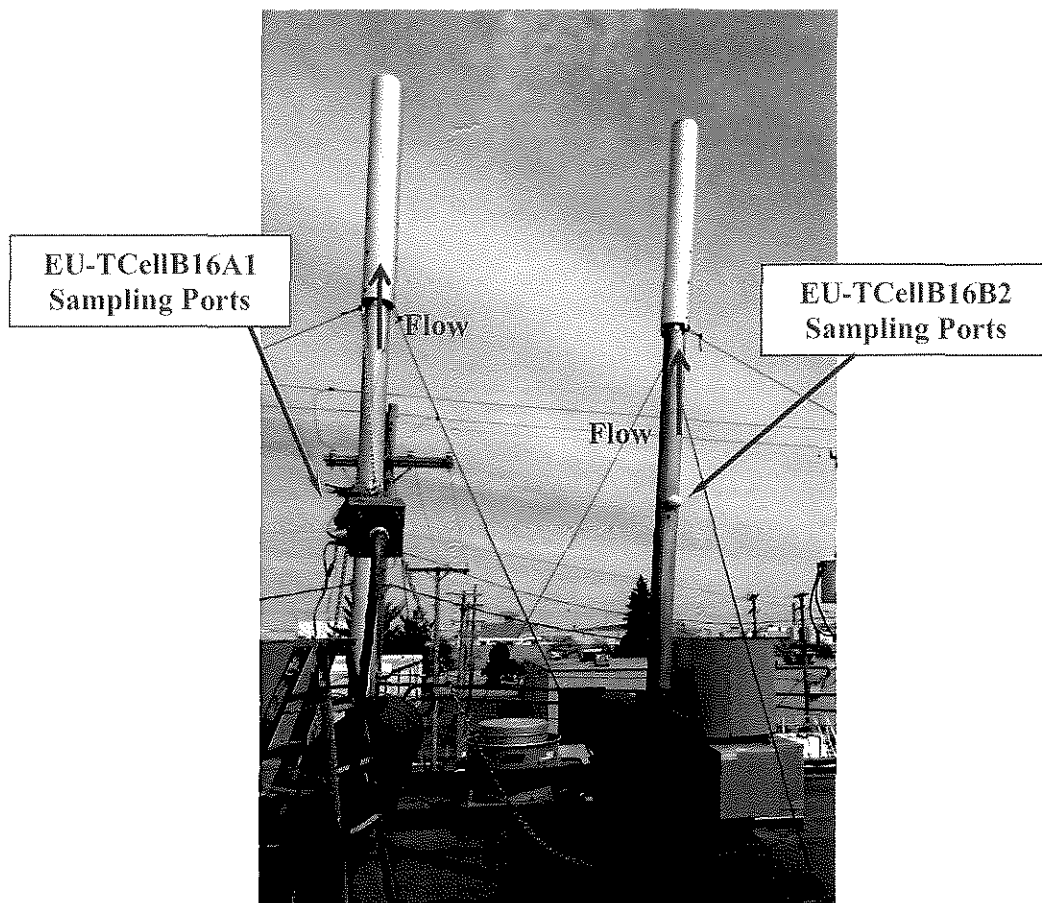
### **2.3.2 EU-TCCellB16A1 and EU-TCCell B16B2**

Test Cells EU-TCCellB16A1 and EU-TCCellB16B2 are configured similarly. The exhaust stacks are 5.625 inches in diameter and have two sampling ports. Four traverse points for each of the two sampling ports were used to measure stack gas velocity and calculate volumetric flowrates. The ports are located:

- Approximately 48 inches (8.5 duct diameters) from the nearest downstream disturbance (exhaust to atmosphere).
- Approximately 60 inches (10.5 duct diameters) from the nearest upstream disturbance (duct confluence where flue gas enters exhaust stack).

The sampling ports are accessible via the rooftop where the exhaust stacks exit the building.

Figure 2-3 is a photograph of the EU-TCellB16A1 and EU-TCellB16B2 exhaust sampling locations. Figure 2 in the Appendix depicts the EU-TCellB16A1 and EU-TCellB16B2 sampling and traverse point locations.



**Figure 2-3. EU-TCellB16A1 and EU-TCellB16B2 Sampling Locations**

## 2.4 Process Sampling Locations

A process sample is a sample that is analyzed for operational parameters, such as calorific value of a fuel (e.g., natural gas, coal), organic compound content (e.g., paint coatings), or composition (e.g., polymers).

Roush Industries collected a sample of the gasoline, used to fuel the dynamometer engine test cells, for laboratory analysis. The results of the gasoline analysis are included in Appendix F.



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## 3.0 Summary and Discussion of Results

### 3.1 Objectives and Test Matrix

The purpose of the testing was to measure gaseous emissions from engine dynamometer test cells as required by the facility's MDEQ ROP MI-ROP-M4780-2016, effective January 8, 2016.

Table 3-1 presents the sampling and analytical matrix.

**Table 3-1  
Test Matrix**

Sampling Location	Test Date (2016)	Engine Size (liter)	Engine Load Condition	No. of Test Runs and Duration	Sample/Type of Pollutant	Sampling Method
EU-TCelB15A (Building 15)	Apr. 6	2.5	WWMP	Three 60-minute runs	O <sub>2</sub> , CO <sub>2</sub> , NO <sub>x</sub> , CO, 1,3-Butadiene	USEPA 1A, 2C, 3A, 4, 7E, 10, 18, 19, 205, TO-15, and OSHA 56
			3750 RPM	Three 60-minute runs		
EU-TCelB15K (Building 15)	Apr. 7	4.6	WWMP	Three 60-minute runs	O <sub>2</sub> , CO <sub>2</sub> , NO <sub>x</sub> , CO, 1,3-Butadiene	USEPA 1A, 2C, 3A, 4, 7E, 10, 18, 19, 205, TO-15, and OSHA 56
			3500 RPM	Three 60-minute runs		
EU-TCelB16A1 (Building 16)	Apr. 20	2.5	WWMP	Three 60-minute runs	O <sub>2</sub> , CO <sub>2</sub> , NO <sub>x</sub> , CO, 1,3-Butadiene	USEPA 1A, 2C, 3A, 4, 7E, 10, 18, 19, 205, TO-15, and OSHA 56
			3750 RPM	Three 60-minute runs		
EU-TCelB16B2 (Building 16)	Apr. 21	4.6	WWMP	Three 60-minute runs	O <sub>2</sub> , CO <sub>2</sub> , NO <sub>x</sub> , CO, 1,3-Butadiene	USEPA 1A, 2C, 3A, 4, 7E, 10, 18, 19, 205, TO-15, and OSHA 56
			3500 RPM	Three 60-minute runs		

RPM: revolution per minute

WWMP: WorldWide Mapping Point (1500 RPM, 2.62 bar brake mean effective pressure)

### 3.2 Field Test Changes and Issues

Communication between Roush Industries and Bureau Veritas allowed the testing to be completed with the changes described in Sections 3.2.1 through 3.2.5.





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### 3.2.1 Volumetric Flowrate Measurements

Bureau Veritas measured engine flue gas velocity within the exhaust stack following USEPA Method 2 guidelines; however, these measurements do not agree with theoretical stoichiometric estimates and appear to be biased. The bias was observed when comparing the measured volumetric flowrates to those calculated using stoichiometric conditions following USEPA Method 19 procedures. The stoichiometric volumetric flowrate was calculated using the measured CO<sub>2</sub> concentration, fuel analysis, and fuel-specific CO<sub>2</sub> F<sub>c</sub> factor.

The bias of the measured volumetric flowrates appears to be the result of engine exhaust pulsation and low Pitot tube differential pressure measurements (i.e., <0.1 inch of H<sub>2</sub>O). Refer to Table 3-2 for a comparison of the measured and estimated stoichiometric volumetric flowrates.

Engine exhaust gas pulsation is due in part to engine design. Each cylinder of a spark ignition engine intermittently emits combustion gases after the air and fuel mixture is compressed and ignited in the combustion chamber. After the combustion gases are exhausted, fresh air and fuel are drawn into the engine combustion chamber. During this time, air is not exhausted from the cylinder. Once the fuel and air mixture has been introduced, the piston compresses the mixture and it is ignited by the spark plug. The energy from combustion pushes the piston down the cylinder and rotates the crankshaft. This process repeats causing frequent pulses of pressure and combustion gases to be exhausted.

Although, Bureau Veritas presents the measured volumetric flowrates and calculated mass emission rates in the results tables, the pollutant mass emission rates and emission factors were calculated using the USEPA Method 19 equations presented in Section 4.15 and in the Appendix B.



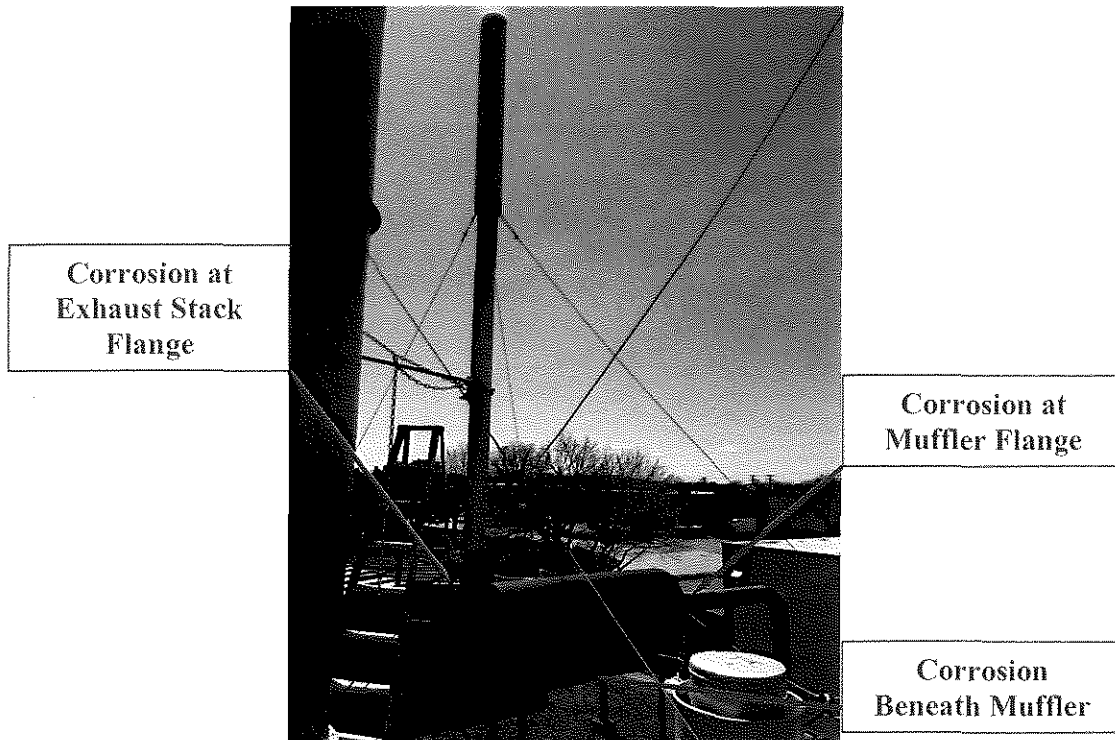
**Table 3-2  
Comparison of Volumetric Flowrate Results**

Sampling Location	Test Date (2016)	Engine Size (liter)	Engine Load Condition	Run	Flowrate (dcfm)			
					Method 2	Method 19	% Difference	Average
EU-TCe11B15A (Building 15)	Apr. 6	2.5	WWMP	1	148	20	152	84
				2	107	20	137	64
				3	92	20	129	56
			3750 RPM	4	80	114	35	97
				5	88	113	25	101
				6	104	108	4	106
EU-TCe11B15K (Building 15)	Apr. 7	4.6	WWMP	1	132	43	102	88
				2	128	42	101	85
				3	87	42	70	65
			3500 RPM	4	140	196	33	168
				5	114	197	53	156
				6	122	192	45	157
EU-TCe11B16A1 (Building 16)	Apr.20	2.5	WWMP	1	29	22	27	26
				2	29	25	15	27
				3	31	36	15	34
			3750	4	83	104	23	94
				5	93	104	11	99
				6	92	103	11	98
EU-TCe11B16B2 (Building 16)	Apr. 21	4.6	WWMP	1	48	54	12	51
				2	46	52	12	49
				3	46	61	28	54
			3500 RPM	4	78	193	85	136
				5	81	195	83	138
				6	79	194	84	137
<b>Average</b>					<b>87</b>	<b>94</b>	<b>54</b>	<b>90</b>

### 3.2.2 Exhaust Duct Deterioration

At the conclusion of the test program, Bureau Veritas identified corrosion within the exhaust stacks and connecting ductwork. At some locations, the corrosion resulted in holes in the metal of the duct and stack. Because the air emission sampling locations were downstream of the deteriorated metal, fugitive emissions and/or ambient air entrainment may have occurred and affected the measurements. However, because the measured emissions results are consistent

with historic test data, the effect of the corroded metal appears to be minimal. Refer to Figure 3-1 for a photograph of the corroded metal ductwork.



**Figure 3-1. Areas of Observed Metal Ductwork Corrosion**

### **3.2.3 EU-TCe116B2 – Sample Container Broken During Transit**

The 40-milliliter volatile organic analysis (VOA) vial containing the contents of 1,3-butadiene impinger sample EU-TCe116B2, Run 6 Normal broke during transport to the laboratory and could not be analyzed.

Because the volume of condensate collected was less than 1 milliliter and 1,3-butadiene was not detected in each of the impinger samples collected, the non-detectable value of 1.6 microgram per liter was used to calculate the USEPA Method 18 1,3-butadiene emissions result. It is Bureau Veritas opinion that the broken sample container did not significantly affect the calculation of emissions results.



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### 3.2.4 EU-TCell16A1 and EU-TCell16B2– Carbon Monoxide Concentrations

The carbon monoxide concentrations measured during Test Runs 4, 5, and 6 for the 2.5 L Engine at 3750 RPM and the 4.6 L engine at 3500 RPM are reported as zero. Although, the analyzer passed the applicable data quality control objectives for calibration error, system bias, and drift, the measured carbon monoxide concentrations ranged from -0.3 to 1 parts per million by volume (ppmv). When the USEPA Method 7E analyzer drift corrections were applied the corrected concentration was a negative value; therefore, Bureau Veritas reported the carbon monoxide concentrations as “not detected.” Refer to Tables 8 and 11 after the Tables Tab of this report and calibration data in Appendix A for this data.

### 3.2.5 1,3-Butadiene Measurements

As a precautionary measure, Bureau Veritas collected secondary samples for 1,3-butadiene in evacuated canisters following USEPA Compendium Method TO-15, “Determination of Volatile Organic Compounds (VOCs) in Air Collected in Specially-Prepared Canisters and Analyzed by Gas Chromatography/Mass Spectrometry (GC/MS). These samples were collected to provide additional data in the event USEPA Method 18 data quality objectives were not met.

USEPA Compendium Method TO-15 typically provides a more accurate and sensitive measurement of organic compounds because the sample is extracted from the stack directly into a canister and then injected into the GC/MS. In comparison, 4-tert-butylcatechol coated charcoal sorbent tubes and impingers are used to collect the USEPA Method 18 samples and the samples are desorbed with carbon disulfide prior to analysis by GC with a flame ionization detector. USEPA Method 18 is the default method for measuring specified organic compounds from stack emissions when known interferences such as water limit measurements by Fourier transform infrared spectroscopy or other analysis. Due to USEPA Compendium Method TO-15 laboratory procedures, the spike recovery data quality objects of USEPA Method 18 are typically not performed.

The 1,3-butadiene samples collected using USEPA Method 18 procedures and analyzed by OSHA Reference Method 56 did not meet the data quality spike recovery criteria of the Method; therefore, Bureau Veritas has presented the results of the USEPA Compendium Method TO-15 measurements. USEPA Compendium Method TO-15 samples were collected for Test Runs 1, 2, 4, and 5 on April 6 and 7, 2016 and Test Runs 1 through 6 on April 20 and 21, 2016. Refer to Section 5.0 for further discussion of the quality assurance/quality control (QA/QC) activities.



### 3.3 Summary of Results

The results of the testing are summarized in Table 3-3. Detailed results of the testing are presented in Tables 1 through 12 after the Tables Tab of this report. Graphs of O<sub>2</sub>, CO<sub>2</sub>, NO<sub>x</sub>, and CO concentrations during testing are provided after the Graphs Tab in the Appendix. Sample calculations are presented in Appendix B.

In order to represent an average point for engine mapping, the engines were tested while operating at the WWMP, as well as, being tested at a second engine test mode, representing higher load power development at approximately half the rated power level and rated engine speed.

**Table 3-3  
Summary of Air Emission Test Results**

Emission Source	Test Cell	Engine Size (liter)	Engine Load Condition	Average Result		
				Parameter		
				Nitrogen Oxides (lb/gal)	Carbon Monoxide (lb/gal)	1,3-Butadiene (lb/gal)
<b>Building 15 - April 6 and 7, 2016</b>						
EU-TCelB15A	A	2.5	WWMP	0.18	0.33	<0.0002
			3750 RPM	0.47	0.53	<0.0001
EU-TCelB15K	K	4.6	WWMP	0.31	0.74	<0.0002
			3500 RPM	0.48	0.51	<0.0001
<b>Building 15 Average Result</b>				<b>0.36</b>	<b>0.53</b>	<b>&lt;0.0002</b>
<b>Building 16 - April 20 and 21, 2016</b>						
EU-TCelB16A1	A1	2.5	WWMP	0.16	0.33	<0.0001
			3750 RPM	0.16	0	<0.000001
EU-TCelB16B2	B2	4.6	WWMP	0.30	0.75	<0.0001
			3500 RPM	0.16	0	<0.0000002
<b>Building 16 Average Result</b>				<b>0.20</b>	<b>0.27</b>	<b>&lt;0.00005</b>

RPM: revolution per minute

WWMP: WorldWide Mapping Point (1500 RPM, 2.62 bar brake mean effective pressure)

lb/gal: pound of pollutant per gallon of fuel consumed



## 4.0 Sampling and Analytical Procedures

### 4.1 Test Methods

Bureau Veritas measured emissions in accordance with the USEPA and OSHA Methods listed in Table 4-1. Descriptions of the sampling methods and analysis procedures are presented in the following sections.

**Table 4-1  
Sampling Methods**

Parameter	Sources				Method	USEPA Reference
	EU-TCe11B15A	EU-TCe11B15K	EU-TCe11B16A1	EU-TCe11B16B2		Title
Sampling ports and traverse points	•	•	•	•	1A	Sample and Velocity Traverses for Stationary Sources with Small Stacks or Ducts
Velocity and flowrate	•	•	•	•	2C	Determination of Stack Gas Velocity and Volumetric Flow Rate in Small Stacks or Ducts (Standard Pitot Tube)
Molecular weight (O <sub>2</sub> and CO <sub>2</sub> )	•	•	•	•	3A	Determination of Oxygen and Carbon Dioxide Concentrations in Emissions, from Stationary Sources (Instrumental Analyzer Procedure)
Moisture content	•	•	•	•	4	Determination of Moisture Content in Stack Gas
Nitrogen oxides (NO <sub>2</sub> , NO, NO <sub>x</sub> )	•	•	•	•	7E	Determination of Nitrogen Oxides Emissions from Stationary Sources
Carbon monoxide (CO)	•	•	•	•	10	Determination of Carbon Monoxide Emissions by Gas Chromatography
1,3-Butadiene	•	•	•	•	TO-15	Determination of Volatile Organic Compounds (VOCs) in Air Collected in Specially-Prepared Canisters and Analyzed by Gas Chromatography/Mass Spectrometry (GC/MS)
1,3-Butadiene	•	•	•	•	18	Measurement of Gaseous Organic Compound Emissions by Gas Chromatography
Emission rate (lb/gal)	•	•	•	•	19	Determination of Sulfur Dioxide Removal Efficiency, and Particulate Matter, Sulfur Dioxide, and Nitrogen Oxide Emission Rates
1,3-Butadiene	•	•	•	•	OSHA 56	OSHA Sampling and Analytical Procedure for 1,3-Butadiene
Gas dilution	•	•	•	•	205	Verification of Gas Dilution Systems for Field Instruments Calibrations



#### **4.1.1 Volumetric Flowrate (USEPA Methods 1A and 2C)**

USEPA Method 1A, “Sample and Velocity Traverses for Stationary Sources with Small Stacks or Ducts,” from the Code of Federal Regulations, Title 40, Part 60 (40 CFR 60), Appendix A, was used to evaluate the sampling location and the number of traverse points for the measurement of velocity profiles. Figures 1 and 2 (see Figures Tab) depicts the sampling locations and traverse points.

Method 2C, “Determination of Stack Gas Velocity and Volumetric Flow Rate in Small Stacks or Ducts (Standard Pitot Tube),” was used to measure flue gas velocity and calculate volumetric flowrate. Standard Pitot tubes and thermocouple assemblies, meeting the requirements outlined in Section 6.7 of USEPA Method 2 were used and a baseline Pitot tube coefficient of 0.99 (dimensionless) was assigned. The Pitot tube inspection and calibration sheets are included in Appendix A.

**Cyclonic Flow Check.** Bureau Veritas evaluated whether cyclonic flow was present at the sampling locations.

Cyclonic flow is defined as a flow condition with an average null angle greater than 20°. The direction of flow can be determined by aligning the Pitot tube to obtain zero (null) velocity head readings—the direction would be parallel to the Pitot tube face openings or perpendicular to the null position. By measuring the angle of the Pitot tube face openings in relation to the stack wall when a null angle is obtained, the direction of flow is measured. If the absolute average of the flow direction angles is greater than 20°, the flue gas flow is considered to be cyclonic at that sampling location and an alternative location should be used.

The measured traverse point flue gas velocity null angle was 0° at the each test cell sampling location. The measurements indicate the absence of cyclonic flow at the test cell sampling locations.

Field data sheets are included in Appendix C. Computer-generated field data sheets are included in Appendix D.

#### **4.1.2 Carbon Dioxide, Nitrogen Oxides, and Carbon Monoxide (USEPA Methods 3A, 7E, and 10)**

USEPA Method 3A, “Determination of Oxygen and Carbon Dioxide Concentrations in Emissions from Stationary Sources (Instrument Analyzer Procedure),” was used to measure the oxygen and carbon dioxide concentrations of the flue gas. Oxides of nitrogen concentrations were measured using USEPA Method 7E, “Determination of Nitrogen Oxides Emissions from Stationary Sources.” Carbon monoxide concentrations were measured using USEPA Method 10, “Determination of Carbon Monoxide Emissions from Stationary Sources.” Figure 3 depicts the USEPA Methods 3A, 7E, and 10 sampling train.



The sampling trains for USEPA Methods 3A, 7E, and 10 are similar and the flue gas was extracted from the stack through:

- A stainless-steel probe.
- Heated Teflon® sample line to prevent condensation.
- A chilled Teflon impinger train with peristaltic pump to remove moisture from the sampled gas stream prior to entering the analyzers via separate sampling lines.
- Oxygen, carbon dioxide, oxides of nitrogen, and carbon monoxide gas analyzers.

The flue gas was extracted and continuously introduced into the paramagnetic (O<sub>2</sub>), chemiluminescence (NO<sub>x</sub>), and infrared (CO and CO<sub>2</sub>) gas analyzers to measure pollutant concentrations. Data were recorded at 1-second intervals on a computer equipped with data acquisition software. Recorded concentrations were reported in 1-minute averages over the duration of each test run.

A pollutant stratification test was not performed because emissions from engines are generally too temporally variable to render a stratification test meaningful. In addition, the sampling duct is 5.6 inches in diameter, which does not lend itself well to stratification tests.

An NO/NO<sub>2</sub> conversion check was performed using an approximate 50-ppmv NO<sub>2</sub> calibration gas. The NO concentration was greater than 90% of the introduced NO<sub>2</sub> calibration standard.

A calibration error check was performed by introducing zero-, mid-, and high-level calibration gases directly into the analyzers. The calibration error check was performed to evaluate the analyzers' response within the acceptable  $\pm 2\%$  range of the calibration span.

Before each test run, a system-bias test was performed where known concentrations of calibration gases were introduced at the probe tip to measure if the analyzers' responses were within  $\pm 5\%$  of the calibration span. At the conclusion of each test run, an additional system-bias check was performed to evaluate the percent drift from pre- and post-test system-bias checks. If percent drift was less than 3.0% of span, the test is considered valid.

USEPA Method 19 equations were used to calculate volumetric flowrates and NO<sub>x</sub> and CO emission rates in lb NO<sub>x</sub>/gal of fuel and lb CO/gal of fuel.

Calibration data along with the USEPA Protocol 1 certification sheets for the calibration gases used are included in Appendix A.





### 4.1.3 Moisture Content (USEPA Method 4)

The moisture content of the flue gas was measured using USEPA Method 4, "Determination of Moisture Content in Stack Gases." Bureau Veritas' modular USEPA Method 4 stack sampling system consists of:

- A stainless steel probe.
- Tygon<sup>®</sup> umbilical line connecting the probe to the impingers.
- A set of four Greenburg-Smith (GS) impingers with the configuration shown in Table 4-2 situated in a chilled ice bath.
- A sample line.
- An Environmental Supply<sup>®</sup> control case equipped with a pump, dry-gas meter, and calibrated orifice.

**Table 4-2  
USEPA Method 4 Impinger Configuration**

Impinger	Type	Contents	Amount
1	Modified	Water	~100 milliliters
2	Greenburg Smith	Water	~100 milliliters
3	Modified	Empty	0 milliliters
4	Modified	Silica desiccant	~300 grams

Before starting a test run, the sampling train was leak-checked by capping the probe tip and applying a vacuum of approximately 15 inches of mercury to the sampling train. The dry-gas meter was monitored for approximately 1 minute to demonstrate that the sample train leak rate was less than 0.02 cubic feet per minute (cfm). The sampling probe was inserted into the sampling port and positioned near the centroid of the stack in preparation for sampling. Flue gas was extracted at a constant rate from the stack, with moisture removed from the sample stream by the chilled impingers.

At the conclusion of the test run, a post-test leak check was conducted and the impinger train was carefully disassembled. The weight of liquid or silica gel in each impinger was measured with a scale capable of measuring  $\pm 0.5$  gram. The weight of water collected within the impingers and volume of flue gas sampled were used to calculate the moisture content. Figure 4 after the Figures Tab depicts the USEPA Method 4 sampling train.



#### 4.1.4 1,3-Butadiene (USEPA Method 18 and OSHA Method 56)

The 1,3-butadiene concentration was measured according to procedures outlined in USEPA Method 18, "Measurement of Gaseous Organic Compound Emissions by Gas Chromatography" and OSHA Method 56 "Sampling and Analytical Procedure for 1,3-butadiene." Sorbent tubes containing charcoal coated with 4-tert-butylcatechol were used. The mass of 1,3-butadiene collected on the sampling media was measured using gas chromatography with flame ionization detector.

The USEPA Method 18 and OSHA Method 56 sampling train passes flue gas in the exhaust stack through charcoal sorbent tubes in series. The sorbent tubes are inserted into critical orifices (Gemini® twin-port sampler) connected to a rotameter and sampling pump. The rotameter is used to continuously monitor the sampling rate. A similar sampling train using spiked sorbent tubes is placed in parallel to the unspiked sorbent tubes for QA/QC purposes.

Based on the expected concentrations and analytical detection limits, the USEPA Method 18 sampling trains were setup to collect approximately 3 L of sample, at a rate of 0.05 L per minute, for a 60-minute test run. The mass of 1,3-butadiene on the spiked sample media was targeted to be 40 to 60% of the expected mass to be collected at each sampling location.

Before testing, the flowrate through each set of sorbent tubes was measured using a rotameter and verified with a BIOS International drycal® calibrator. The critical orifices were adjusted to ensure the sample flowrate was within 20% of the specified sample rate of 0.05 L per minute. The pre-test flowrates were recorded on a test run data sheet. After the sampling rate was verified, the sampling train was positioned to sample the flue gas.

Flue gas was sampled into the sorbent tubes for 60 minutes per test run. At the conclusion of each test run, the sample train flowrate was measured using the drycal calibrator. The averages of the pre-test and post-test flowrates were used to calculate total sample volume for the test duration.

During the second test program mobilization, on April 20 and 21, 2016, Bureau Veritas placed a series of two impingers upstream of the sorbent media in an attempt to reduce the flue gas temperature and remove water and other water soluble organic compounds. Refer to Table 4-3 for the impinger configuration. At the conclusion of the test, the contents of the impingers were collected and the surfaces of the impingers were rinsed with HPLC water and added to the sample container.



**Table 4-3  
USEPA Method 18 Impinger Configuration**

Impinger	Type	Contents	Amount
1	Midget	Water	10 milliliters
2	Midget	Empty	—

The sorbent tube sample media was placed in a freezer and the impinger samples in a refrigerator immediately after sampling. The media was transported in a chilled cooler to the laboratory. The sorbent tube samples were analyzed by Bureau Veritas' laboratory in Novi, Michigan, using gas chromatography with flame ionization detector and the impinger samples were analyzed by Pace Analytical Services, Inc.'s laboratory in St. Rose, Louisiana.

Because mass is collected on co-located unspiked and spiked sorbent media, spike recovery calculations were completed for QA/QC information. The spike recovery calculation compares the concentration measured by the unspiked and spiked sorbent tubes and corrects the results based on the fraction of spiked compound recovered.

Chains of custody and laboratory analytical results are included in Appendix F.

#### **4.1.5 Carbon Monoxide and Nitrogen Oxide Emission Rate (USEPA Method 19)**

USEPA Method 19, "Determination of Sulfur Dioxide Removal Efficiency and Particulate Matter, Sulfur Dioxide, and Nitrogen Oxide Emission Rates," was used to calculate CO and NO<sub>x</sub> emission rates in the units lb NO<sub>x</sub>/gal of fuel and lb CO/gal of fuel. Carbon dioxide concentrations and appropriate F factors (ratios of combustion gas volumes to heat inputs) were used to calculate NO<sub>x</sub> and CO emission rates from measured NO<sub>x</sub> and CO<sub>2</sub> concentrations.

Equation 19-7 from the method was used:

$$E = C_d F_c \left( \frac{100}{\%CO_{2d}} \right)$$

Where:

E = Pollutant Emission Rate (lb/mmBtu)

C<sub>d</sub> = Pollutant concentration, dry basis (lb/dscf)

%CO<sub>2d</sub> = Concentration of carbon dioxide on a dry basis (%)



$F_c$  = Volumes of combustion components per unit of heat content,  
 $F_c$  is calculated by Equation 19-15

#### **4.1.6 Gas Dilution (USEPA Method 205)**

A gas dilution system was used to introduce known values of calibration gases into the analyzers. The gas dilution system consists of calibrated orifices or mass flow controls and dilutes a high-level calibration gas to within  $\pm 2\%$  of predicted values. The gas divider is capable of diluting gases at set increments and was evaluated for accuracy in the field in accordance with USEPA Method 205, "Verification of Gas Dilution Systems for Field Instrument Calibrations."

Before testing, the gas divider dilutions were measured to evaluate that they were within  $\pm 2\%$  of predicted values. Three sets of three dilutions of the high-level calibration gas were performed. In addition, a certified mid-level calibration gas was introduced into an analyzer; this calibration gas concentration was within  $\pm 10\%$  of a gas divider dilution concentration.

### **4.2 Procedures for Obtaining Process Data**

Process data were recorded by Roush Industries personnel and included the following information:

- Volume of gasoline used.
- Size and type of engine being tested.
- Engine running conditions.

Refer to Section 2.1 and 2.2 for discussions of process and control device data and Appendix F for the operating parameters recorded during testing.

### **4.3 Sampling Identification and Custody**

Applicable Chain of Custody procedures followed guidelines outlined within ASTM D4840-99 (Reapproved 2010), "Standard Guide for Sample Chain-of-Custody Procedures." Detailed sampling and recovery procedures are described in Section 4.1. For each sample collected, sample identification and custody procedures were completed as follows:

- Containers will be sealed with Teflon tape to prevent contamination.
- Containers will be labeled with test number, location, and test date.



- 
- The level of fluid will be marked on outside of sample containers to identify if leakage had occurred before delivery of the samples to the laboratory.
  - Containers will be placed in a cooler for storage.
  - Samples will be logged using guidelines outlined in ASTM D4840-99 (Reapproved 2010), “Standard Guide for Sample Chain-of-Custody Procedures.”
  - Samples will be delivered to the laboratory under chain of custody.

Chains of custody and laboratory analytical results are included in Appendix E.



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## **5.0 QA/QC Activities**

Equipment used in this emissions test program passed QA/QC procedures. Refer to Appendix A for equipment calibrations and inspection sheets documents. Field data sheets are presented in Appendix C. Computer-generated Data Sheets are presented within Appendix D

### **5.1 Pretest QA/QC Activities**

Before testing, the sampling equipment was cleaned, inspected, and calibrated according to procedures outlined in the applicable USEPA sampling method and USEPA's "Quality Assurance Handbook for Air Pollution Measurement Systems, Volume and Principles: Volume III, Stationary Source Specific Methods."

### **5.2 QA/QC Audits**

The results of select sampling and equipment QA/QC audits and the acceptable USEPA tolerance are presented in the following sections. Analyzer calibration and gas certification sheets are presented in Appendix A.

#### **5.2.1 Sampling Train QA/QC Audits**

The sampling trains described in Section 4.1 were audited for measurement accuracy and data reliability. Table 5-1 summarizes the QA/QC audits conducted for the Method 4 sampling train.



**Table 5-1  
Method 4 Sampling Train QA/QC Audits**

Parameter	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Method Requirement	Comment
<b>EU-TCe11B15A</b>	2.5 L at WWMP			2.5 L at 3750 RPM				
Sampling train leak check post-test	0 ft <sup>3</sup> for 1 min at 5 in Hg	0 ft <sup>3</sup> for 1 min at 9 in Hg	0 ft <sup>3</sup> for 1 min at 5 in Hg	0 ft <sup>3</sup> for 1 min at 6 in Hg	0 ft <sup>3</sup> for 1 min at 5 in Hg	0 ft <sup>3</sup> for 1 min at 5 in Hg	<0.020 ft <sup>3</sup> for 1 minute at ≥ sample vacuum recorded during test	Valid
Sampling vacuum (in Hg)	1	1	1	1	1	1		
<b>EU-TCe11B15K</b>	4.6 L at WWMP			4.6 L at 3500 RPM				
Sampling train leak check post-test	0 ft <sup>3</sup> for 1 min at 9 in Hg	0 ft <sup>3</sup> for 1 min at 5 in Hg	0 ft <sup>3</sup> for 1 min at 5 in Hg	0 ft <sup>3</sup> for 1 min at 5 in Hg	0 ft <sup>3</sup> for 1 min at 5 in Hg	0 ft <sup>3</sup> for 1 min at 5 in Hg	<0.020 ft <sup>3</sup> for 1 minute at ≥ sample vacuum recorded during test	Valid
Sampling vacuum (in Hg)	1	1	1	1	1	1		
<b>EU-TCe11B16A1</b>	2.5 L at WWMP			2.5 L at 3750 RPM				
Sampling train leak check post-test	0.005 ft <sup>3</sup> for 1 min at 8 in Hg	0.005 ft <sup>3</sup> for 1 min at 10 in Hg	0 ft <sup>3</sup> for 1 min at 5 in Hg	0 ft <sup>3</sup> for 1 min at 10 in Hg	0 ft <sup>3</sup> for 1 min at 10 in Hg	0 ft <sup>3</sup> for 1 min at 10 in Hg	<0.020 ft <sup>3</sup> for 1 minute at ≥ sample vacuum recorded during test	Valid
Sampling vacuum (in Hg)	1	1	1	1	1	1		
<b>EU-TCe11B16B2</b>	4.6 L at WWMP			4.6 L at 3500 RPM				
Sampling train leak check post-test	0 ft <sup>3</sup> for 1 min at 7 in Hg	0 ft <sup>3</sup> for 1 min at 10 in Hg	0 ft <sup>3</sup> for 1 min at 10 in Hg	0 ft <sup>3</sup> for 1 min at 12 in Hg	0 ft <sup>3</sup> for 1 min at 12 in Hg	0 ft <sup>3</sup> for 1 min at 10 in Hg	<0.020 ft <sup>3</sup> for 1 minute at ≥ sample vacuum recorded during test	Valid
Sampling vacuum (in Hg)	1	1	1	6	4 to 6	5		

### 5.2.2 Dry-Gas Meter QA/QC Audits

Table 5-2 summarizes the dry-gas meter (DMG) calibration checks in comparison to the acceptable USEPA tolerance. Refer to Appendix A for DMG calibrations.



**Table 5-2  
Dry-Gas Meter Calibration QA/QC Audit**

<b>Meter Box</b>	<b>Pre-test DGM Calibration Factor (Y) (dimensionless)</b>	<b>Post-test DGM Calibration Check Value (Y) (dimensionless)</b>	<b>Absolute Difference Between Pre- and Post-test DGM Calibrations</b>	<b>Acceptable Tolerance</b>	<b>Calibration Result</b>
7	1.014 March 10, 2016	1.028 April 27, 2016	0.014	≤0.05	Valid

### **5.2.3 Instrument Analyzer QA/QC Audits**

The Methods 3A, 7E, and 10 sampling described in Section 4.1 was audited for measurement accuracy and data reliability. The analyzers passed the applicable calibration criteria. Table 5-3 summarizes gas cylinders used during this test program. Refer to Appendix A for additional calibration data.





**Table 5-3  
Calibration Gas Cylinder Information**

Parameter	Gas Vendor	Cylinder Serial Number	Cylinder Value	Expiration Date
Carbon Dioxide (CO <sub>2</sub> ) Oxygen (O <sub>2</sub> ) Nitrogen (N)	Airgas	CC307809	11.20% (CO <sub>2</sub> ) 10.91% (O <sub>2</sub> ) Balance (N)	2/17/23
		XC018136B	19.94% (CO <sub>2</sub> ) 20.09% (O <sub>2</sub> ) Balance (N)	2/26/23
Carbon Monoxide (CO) Nitrogen (N)	The American Gas Group	EB0022434	945 ppm (CO) Balance (N)	10/3/19
	Airgas	XC032359B	4,408 ppm Balance (N)	10/30/22
		CC312641	9,110 ppm Balance (N)	12/10/23
		XC023394B	9,110 ppm Balance (N)	12/10/23
Nitrogen (N)	Airgas	CC173587	99.9995%	3/18/24
Nitrogen Dioxide (NO <sub>2</sub> ) Oxygen (O <sub>2</sub> ) Nitrogen (N)	Airgas	CC500773	50.18 ppm (NO <sub>2</sub> ) 1,000 ppm (O <sub>2</sub> ) Balance (N)	11/11/17
Nitric Oxide (NO) Nitrogen Oxides (NO <sub>x</sub> ) Nitrogen (N)	Air Liquide America Specialty Gases LLC	ALM039013	4,500 ppm (NO) 4,510 ppm (NO <sub>x</sub> ) Balance (N)	10/14/23

#### 5.2.4 USEPA Method 18 Field Testing QA/QC Audits

USEPA Method 18 requires a spike recovery study be performed as a quality assurance audit of the sampling. Two identical sampling trains are setup with one designated as the spiked train and the other the unspiked normal train. A mass of the pollutant of interest is injected onto the adsorbent media in the spiked sorbent tube before sampling. Stack gas is then sampled into the normal and spiked sample trains. The spike recovery measures the fraction of spike compound recovered and corrects the unspiked sample result based on this recovery. The USEPA Method 18 spike recovery quality assurance results are provided in Table 5-4.

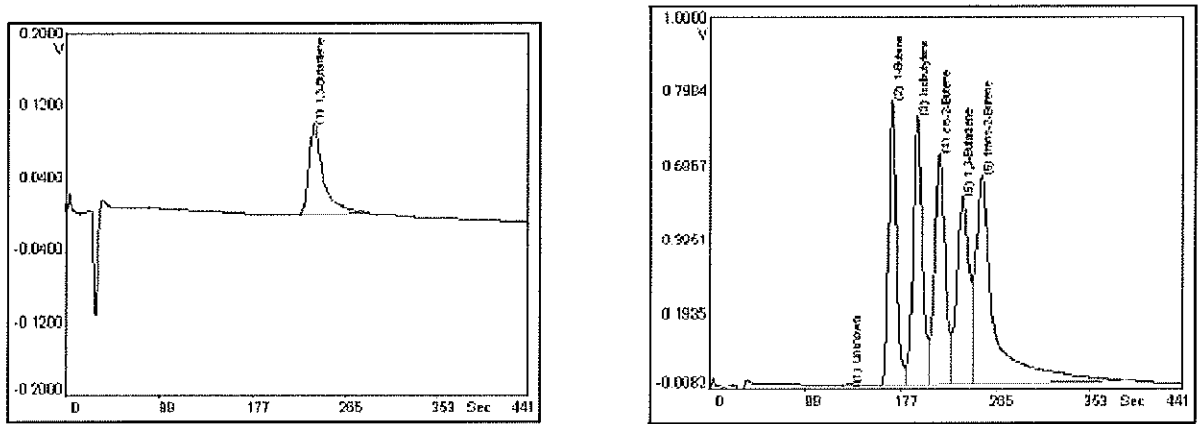


**Table 5-4  
Method 18 Spike Recovery Quality Assurance Results**

Parameter	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Avg.	Criterion
EU-TCeIB15A	2.5 L at WWMP			2.5 L at 3750 RPM				
Spike Recovery	0.21	0.71	0.52	0.02	0.39	0.44	0.38	$0.70 \leq R \leq 1.30$
EU-TCeIB15K	4.6 L at WWMP			4.6 L at 3500 RPM				
Spike Recovery	0.01	0.07	-0.01	0.05	-0.01	0.08	0.03	$0.70 \leq R \leq 1.30$
EU-TCeIB16A1	2.5 L at WWMP			2.5 L at 3750 RPM				
Spike Recovery	0.06	0.26	-0.11	-0.02	0	-0.01	0.03	$0.70 \leq R \leq 1.30$
EU-TCeIB16B1	4.6 L at WWMP			4.6 L at 3500 RPM				
Spike Recovery	0.01	0.003	0.02	-0.003	-0.01	-0.005	0.003	$0.70 \leq R \leq 1.30$

The 1,3-butadiene samples collected using USEPA Method 18 procedures and analyzed by OSHA 56 did not meet the data quality spike recovery criteria of the method. Bureau Veritas suspects the temperature (63 to 552°F), moisture content (2 to 17%), low concentration (<1 ppmv), and presence of interfering pollutants (C4 interferences) in the sampled flue gas affected the spike recovery results.

Pollutant interference peaks were detected in the laboratory gas chromatography analysis. These interferences result in a possible low bias and increased the detection limit of the USEPA Compendium Method TO-15 samples. Examples of interfering peaks are provided in Figure 5-1.



**Figure 5-1. 1,3-Butadiene and C4 Interferences**

Based on the results of the USEPA Method 18 spike recoveries, Bureau Veritas has presented the results of the USEPA Compendium Method TO-15 measurements. USEPA Compendium Method TO-15 samples were collected for Test Runs 1, 2, 4, and 5 on April 6 and 7, 2016 and Test Runs 1 through 6 on April 20 and 21, 2016.

### **5.2.5 Thermocouple QA/QC Audits**

Temperature measurements using thermocouples and digital pyrometers were compared to a reference temperature (i.e., ice water bath, boiling water bath) prior to testing to evaluate accuracy of the equipment. The thermocouples and pyrometers measured temperature within  $\pm 1.5\%$  of reference temperatures and were within USEPA acceptance criteria. Thermocouple calibration sheets are presented in Appendix A.

## **5.3 QA/QC Checks for Data Reduction and Validation**

Bureau Veritas validated the computer spreadsheets onsite. The computer spreadsheets were used to evaluate the accuracy of field calculations. The field data sheets were reviewed to evaluate whether data has been recorded appropriately. The computer data sheets were checked against the field data sheets for accuracy during review of the draft report. Sample calculations were performed to check computer spreadsheet computations.

## **5.4 QA/QC Blanks and Spikes**

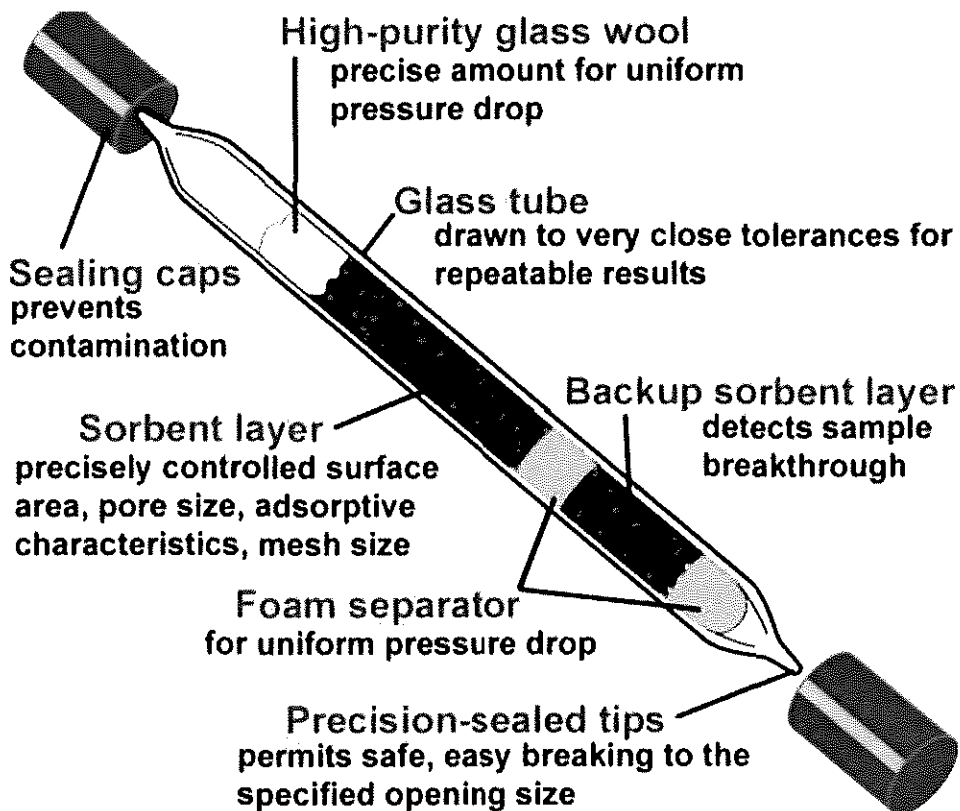
Media blanks and spiked media were analyzed for the parameters of interest. The USEPA Method 18 results are presented in Table 5-5.



**Table 5-5  
USEPA Method 18 Field Spikes and Blanks**

<b>Sample Identification</b>	<b>Result (µg)</b>	<b>Parameter</b>	<b>Comment</b>
1,3-Butadiene Blank 1 April 6, 2016	<1	1,3-Butadiene	1,3-butadiene not detected in blank
1,3-Butadiene Spike Blank 1 April 6, 2016	22	1,3-Butadiene	135% breakthrough detected. Target spike mass was 20 micrograms.
1,3-Butadiene Blank 2 April 7, 2016	<1	1,3-Butadiene	1,3-butadiene not detected in blank
1,3-Butadiene Spike Blank 2 April 7, 2016	21.1	1,3-Butadiene	95.2% breakthrough detected. Target spike mass was 20 micrograms.
1,3-Butadiene Blank 1 April 20, 2016	<1	1,3-Butadiene	1,3-butadiene not detected in blank
1,3-Butadiene Spike Blank 1 April 20, 2016	17.7	1,3-Butadiene	84.7% breakthrough detected. Target spike mass was 20 micrograms.
1,3-Butadiene Blank 1 April 21, 2016	<1	1,3-Butadiene	1,3-butadiene not detected in blank
1,3-Butadiene Spike Blank 1 April 21, 2016	17.5	1,3-Butadiene	88.3% breakthrough detected. Target spike mass was 20 micrograms.

The high breakthrough results of the spike blanks indicate 1,3-butadiene progression within the sorbent media. Ideally, 100% of the 1,3-butadiene mass in the sample would be collected and remain on the primary sorbent layer. Analysis of the spike blanks indicates a significant amount of 1,3-butadiene was measured on the breakthrough section of the sorbent tube. The percent breakthrough measured in the spiked sorbent tubes may have affected the USEPA Method 18 spike recoveries. Refer to Figure 5-2 for a diagram of a sorbent tube sections.



Reference: [https://www.skcinco.com/catalog/product\\_info.php?products\\_id=567](https://www.skcinco.com/catalog/product_info.php?products_id=567)

**Figure 5-2. Sorbent Tube Sections**

## 5.5 QA/QC Problems

Equipment audits and QA/QC procedures demonstrate sample collection accuracy. Measurement issues of volumetric flowrate by USEPA Method 2 resulted in calculation of emission rates calculated using USEPA Method 19 equations. The results of the USEPA Method 18 samples did not meet the spike recovery data quality objectives; therefore, USEPA TO-15 1,3-butadiene results were used to calculate the emission rates.




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## Limitations

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