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40 CFR Part 60 Subpart JJJJ & 40 CFR Part 63 Subpart ZZZZ Test Report

EUENGINE3-1, EUENGINE3-2, EUENGINE3-3, EUENGINE3-4 & EUENGINE3-5

Consumers Energy Company
Freedom Compressor Station
12201 Pleasant Lake Rd,
Manchester, Michigan 48158
SRN: N3920

July 18, 2023

Test Date: May 23 - 25, 2023

Test Performed by the Consumers Energy Company
Regulatory Compliance Testing Section
Air Emissions Testing Body
Laboratory Services Section
Work Orders: 41494633, 41494634,
41494512,41494514,
41494515
Version No.: 1.0

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EXECUTIVE SUMMARY

Consumers Energy Regulatory Compliance Testing Section (RCTS) conducted continuous compliance testing on EUENGINE3-1, EUENGINE3-2, EUENGINE3-3, EUENGINE3-4 & EUENGINE3-5 at the Freedom Compressor Station in Manchester, Michigan on June 23-25, 2023.

The facility is classified as a major source of hazardous air pollutants (HAP) and the engines are natural gas-fired, 4-stroke lean-burn (4SLB), spark-ignited (SI), reciprocating internal combustion engines (RICE), each of which are >500 horsepower that powers a compressor used to maintain pressure in pipelines transporting natural gas from main lines to storage facilities located in Michigan or local distribution companies. The engines are part of FGENGINES-P3, FGNSPSJJJJ, and FGNESHAPZZZZ flexible groups within the Michigan Department of Environment, Great Lakes and Energy (EGLE), renewable operating permit (ROP) MI-ROP-N3920-2022a.

The test program was conducted to satisfy performance test requirements and evaluate compliance with 40 CFR Part 60, Subpart JJJJ, "Standards of Performance for Stationary Spark Ignition Internal Combustion Engines," (aka NSPS SI ICE), 40 CFR Part 63, Subpart ZZZZ, "National Emission Standards for Hazardous Air Pollutants (NESHAP), as noted in the Facility EGLE ROP MI-ROP-N3920-2022a.

Three, 60-minute nitrogen oxides (NO_x), carbon monoxide (CO), and volatile organic compounds (VOC's), and oxygen (O2) were conducted at the oxidation catalyst outlet following the procedures in United States Environmental Protection Agency (USEPA) Reference Methods (RM) 1, 3A, 4, 7E, 10, 19, and 25A in 40 CFR Part 60, Appendix A. CO was also measured at the oxidation catalyst inlet to calculate percent CO reduction efficiency. There were no deviations from the approved stack test protocol submitted on March 23, 2023, or associated USEPA RM.

The test results summarized in Tables E-1 and E-2 indicate FGENGINES-P3 are operating in continuous compliance with 40 CFR Part 60, Subpart JJJJ and 40 CFR Part 63, Subpart ZZZZ, as specified in MI-ROP-N3920-2022. Detailed results are presented in Appendix Table 1. Sample calculations and field data sheets are presented in Appendices A and B. Engine operating data and supporting documentation are provided in Appendices C and D.

Table E-1
Summary of Test Results

Engine/ Parameter	NO_x		CO			VOC		
	ppmvd at 15% O_2	g/hp-hr	ppmvd at 15% O_2	g/hp-hr	% Reduction	ppmvd at 15% O_2[1]	g/hp-hr[1]	g/hp-hr[2]
EUENGINE3-1	39.9	0.44	7.7	0.05	96.6	46.0	0.49	0.15
EUENGINE3-2	46.7	0.52	11.0	0.07	95.3	42.3	0.45	0.07
EUENGINE3-3	38.8	0.45	9.0	0.06	96.2	42.6	0.48	0.08
EUENGINE3-4	39.3	0.44	8.7	0.06	96.1	17.4	0.19	0.07
EUENGINE3-5	40.8	0.48	3.9	0.03	98.3	45.8	0.51	0.09
JJJJ[3] Limits	82	1.0	270	2.0		60	0.7	
ZZZZ Limits					≥93			
ROP Limits	82	0.6		0.14	≥93	60		0.2

[1] Non-methane organic compounds (NMOC), as propane
[2] Non-methane, non-ethane organic compounds (NMNEOC), as propane
[3] Requirements for non-emergency engines greater than 500 brake HP, commencing construction after June 12, 2006 and manufactured on or after July 1, 2010

Table E-2
Summary of Operating Results

Engine/Parameter	Catalyst Inlet Temp.[1] (°F)	Catalyst Press. Drop (inches)	Initial Catalyst Press. Drop (inches)
EUENGINE3-1	776	2.0	1.3
EUENGINE3-2	795	2.0	1.8
EUENGINE3-3	774	2.0	2.1
EUENGINE3-4	790	2.0	2.0
EUENGINE3-5	791	2.0	2.0
ZZZZ Limits	**450-1350**	**±2 (from initial)**	
ROP Limits	**450-1350**	**±2 (from initial)**	

[1] Compliance with the catalyst inlet temperature operating range is based on a 4-hour rolling average

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1.0 INTRODUCTION

This report summarizes compliance air emission results from tests conducted May 23-25, 2023, at the Consumers Energy Freedom Compressor Station (FCS) in Manchester, Michigan.

1.1 Identification, Location, and Dates of Tests

Consumers Energy Regulatory Compliance Testing Section (RCTS) conducted nitrogen oxides (NO_x), carbon monoxide (CO), and volatile organic compound (VOC) testing of five (5) natural gas-fired 4-stroke lean burn (4SLB), Waukesha Model 12V275GL reciprocating internal combustion engines (RICE) designated as EUENGINE3-1, EUENGINE3-2, EUENGINE3-3, EUENGINE3-4 & EUENGINE3-5 at the Freedom Compressor Station in Manchester, Michigan.

A test protocol outlining the proposed testing and data quality objectives was submitted to EGLE on March 22, 2023, and subsequently approved by Mr. Andrew Riley, Environmental Quality Analyst, in a letter dated May 12, 2023. There were no deviations from the approved stack test protocol or associated USEPA RM.

1.2 Purpose of Testing

The purpose of the test program was to satisfy performance test requirements and evaluate compliance with 40 CFR Part 60, Subpart JJJJ, "Standards of Performance for Stationary Spark Ignition Internal Combustion Engines," 40 CFR Part 63, Subpart ZZZZ, "National Emission Standards for Hazardous Air Pollutants (NESHAP) for Stationary Reciprocating Internal Combustion Engines", and EGLE ROP MI-ROP-N3920-2022. EUENGINE3-1, EUENGINE3-2, EUENGINE3-3, EUENGINE3-4 & EUENGINE3-5 are associated emissions unit of FGENGINES-P3, FGNSPSJJJJ, and FGNESHAPZZZZ flexible groups within the ROP. The applicable emission limits and associated operating requirements are shown in Table 1-1 and Table 1-2.

Table 1-1
FGENGINES-P3 Emission Limits

Parameter	Emission Limit	Units	Applicable Requirement[1,2,3]
NO_x	0.6	g/HP-hr	MI-ROP-N3920-2022a, FGENGINES-P3
	2.0	g/HP-hr	40 CFR Part 60, Subpart JJJJ, Table 1
	160	ppmvd at 15% O_2	40 CFR Part 60, Subpart JJJJ, Table 1
CO	0.14	g/HP-hr	MI-ROP-N3920-2022a, FGENGINES-P3
	4.0	g/HP-hr	40 CFR Part 60, Subpart JJJJ, Table 1
	540	ppmvd at 15% O_2	40 CFR Part 60, Subpart JJJJ, Table 1
VOC	0.2	g/HP-hr	MI-ROP-N3920-2022a, FGENGINES-P3
	1.0	g/HP-hr	40 CFR Part 60, Subpart JJJJ, Table 1
	86	ppmvd at 15% O_2	40 CFR Part 60, Subpart JJJJ, Table 1

1 Owners and operators of stationary non-certified SI engines may choose to comply with the emission standards in units of either g/HP-hr or ppmvd at 15 percent O_2
2 Owners and operators of new lean burn SI stationary engines with a site rating ≥250 brake HP located at a major source that are meeting the requirements of 40 CFR Part 63, Subpart ZZZZ, Table 2a do not have to comply with the CO emission standards in 40 CFR Part 60, Subpart JJJJ, Table 1.
3 Emissions limits from MI-ROP-N3920-2022, Flexible Group Conditions: FGENGINES-P3, FGNSPSJJJJ, and FGNESHAPZZZZ.

Table 1-2
FGENGINES-P3 40 CFR Part 63, Subpart ZZZZ Requirements

CO Reduction Efficiency (%)	Oxidation Catalyst Inlet Temperature (°F)	Oxidation Catalyst Pressure Drop Change (Inches Water Gauge)	Applicable Requirement
≥93†	≥450°F and ≤1350°F	±2" from Initial Performance Test	MI-ROP-N3920-2022a, 40 CFR §63.6300(b) and Table 2a

† 40 CFR Part 63, Subpart ZZZZ, Table 2a allows compliance to be demonstrated by limiting the concentration of formaldehyde in the stationary RICE exhaust to 14 ppmvd or less at 15 percent O_2 or reducing CO emissions by ≥93%. Compliance using the CO reduction efficiency emission limit will be evaluated.

1.3 Brief Description of Source

EUENGINE3-1, EUENGINE3-2, EUENGINE3-3, EUENGINE3-4 & EUENGINE3-5 are classified as four-stroke lean burn natural gas-fired, spark-ignition reciprocating internal combustion engines, which are located and operating at the Freedom Compressor Station in Manchester, Michigan. The engines are part of the flexible group FGENGINES-P3 as found in the MI-ROP-N3920-2022a.

1.4 Contact Information

Table 1-3 presents contact information of personnel involved in the test program.

Table 1-3
Contact Information

Program Role	Contact	Address
Regulatory Agency Representative	Mr. Jeremy Howe Technical Programs Supervisor 231-878-6687 howej1@michigan.gov	EGLE Technical Programs Unit 525 W. Allegan, Constitution Hall, 2nd Floor S Lansing, Michigan 48933
State Regulatory Inspector	Mr. Mike Kovalchick Environmental Quality Analyst 517-416-5025 kovalchickm@michigan.gov	EGLE Jackson District 301 East Louis B. Glick Hwy Jackson, Michigan 49201-1556
Responsible Official	Mr. Avelock Robinson Director of Gas Compression Operations 586-716-3326 avelock.robinson@cmsenergy.com	Consumers Energy Company St. Clair Compressor Station 10021 Marine City Highway Ira, Michigan 48023
Corporate Air Quality Contact	Ms. Amy Kapuga Principal Engineer 517-788-2201 amy.kapuga@cmsenergy.com	Consumers Energy Company Environmental Services Department 1945 West Parnall Road Jackson, Michigan 49201
Field Environmental Coordinator	Mr. Frank Rand Senior Environmental Analyst 734-807-0935 frank.randjr@cmsenergy.com	Consumers Energy Company South Monroe Customer Service Center 7116 Crabb Road Temperance, MI 48182
Facility Leader	Ms. Tara Guenther Manager of Compression 734-482-2042 tara.guenther@cmsenergy.com	Consumers Energy Company Freedom Compressor Station 12201 Pleasant Lake Road Manchester, Michigan 48158

Table 1-3
Contact Information

Program Role	Contact	Address
Supervisor	Mr. Zeke Duke Station Supervisor 734-318-4803 zeke.duke@cmsenergy.com	Consumers Energy Company Freedom Compressor Station 12201 Pleasant Lake Road Manchester, Michigan 48158
Test Team Representative	Mr. Thomas Schmelter, QSTI Sr. Engineering Technical Analyst 616-738-3234 thomas.schmelter@cmsenergy.com	Consumers Energy Company L&D Training Center 17010 Croswell Street West Olive, Michigan 49460

2.0 SUMMARY OF RESULTS

2.1 OPERATING DATA

During the performance test the engines fired natural gas and operated within 10% of 100 percent peak (or the highest achievable) load. The performance testing was conducted with the engines operating at an average load >93% torque and >92% horsepower, based on the maximum manufacturer's design capacity at engine and compressor site conditions. Refer to Appendix D for detailed operating data.

2.2 APPLICABLE PERMIT INFORMATION

The Freedom Compressor Station operates in accordance with air permit MI-ROP-N3920-2022a. EUENGINE3-1, EUENGINE3-2, EUENGINE3-3, EUENGINE3-4 & EUENGINE3-5 are the emission unit source identifications and are included in the FGENGINES-P3 flexible group. Incorporated within the permit are the applicable requirements of 40 CFR Part 60, Subpart JJJJ - Standards of Performance for Stationary Spark Ignition Internal Combustion Engines and 40 CFR Part 63, Subpart ZZZZ – National Emission Standards for Hazardous Air Pollutants for Stationary Reciprocating Internal Combustion Engines.

2.3 RESULTS

The test results in Tables 2-1 and 2-2 indicate the engines complies with the applicable emission limits and associated operating requirements.

Detailed results are presented in Appendix Table 1. A discussion of the results is presented in Section 5.0. Sample calculations, field data sheets, and laboratory data sheets are presented in Appendices A, B, and C. Engine operating data and supporting documentation are provided in Appendices D and E.

Table 2-1
Summary of Test Results

Engine/ Parameter	NOx		CO			VOC		
	ppmvd at 15% O_2	g/hp-hr	ppmvd at 15% O_2	g/hp-hr	% Reduction	ppmvd at 15% O_2[1]	g/hp-hr[1]	g/hp-hr[2]
EUENGINE3-1	39.9	0.44	7.7	0.05	96.6	46.0	0.49	0.15
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[1] Non-methane organic compounds (NMOC), as propane
[2] Non-methane, non-ethane organic compounds (NMNEOC), as propane
[3] Requirements for non-emergency engines greater than 500 brake HP, commencing construction after June 12, 2006 and manufactured on or after July 1, 2010

Table 2-2
Summary of Operating Results

Parameter	Catalyst Inlet Temp.[1] (°F)	Catalyst Press. Drop (inches)	Initial Catalyst Press. Drop (inches)
EUENGINE3-1	776	2	1.3
EUENGINE3-2	795	2	1.8
EUENGINE3-3	774	2	2.1
EUENGINE3-4	790	2	2.0
EUENGINE3-5	791	2	2.0
ZZZZ Limits	**450-1350**	**±2 (from initial)**	
ROP Limits	**450-1350**	**±2 (from initial)**	

[1] Compliance with the catalyst inlet temperature operating range is based on a 4-hour rolling average

3.0 SOURCE DESCRIPTION

FGENGINES-P3 provide mechanical shaft power to compressors to maintain natural gas pipeline pressure for movement along the pipeline system. Significant maintenance has not been performed on the engines. A summary of the engine specifications is provided in Table 3-1.

Table 3-1
Summary of Engine Specifications

Parameter[1]	FGENGINES-P3
Make	Waukesha
Model	12V275GL
Output (brake-horsepower)	3,750
Heat Input, LHV (mmBtu/hr)	28.96
Exhaust Flow Rate (ACFM, wet)	23,373
Exhaust Gas Temp.	828

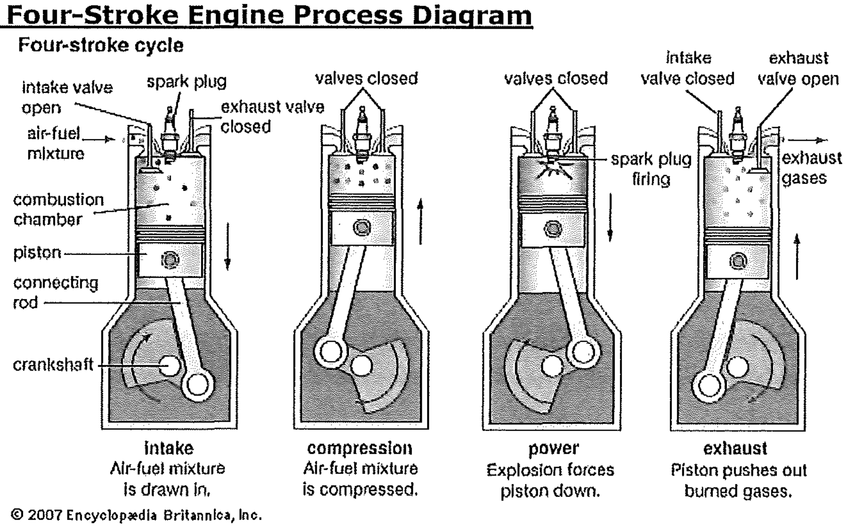
1 Engine specifications are based upon vendor data for operation at 100% of rated engine capacity

3.1 Process

In the four-stroke engine, air is aspirated into the cylinder during the downward travel of the piston on the intake stroke. The fuel charge is injected with the piston near the bottom of the intake stroke and the intake valves close as the piston moves to the top of the cylinder, compressing the air/fuel mixture. A spark plug at the top of the cylinder ignites the air/fuel charge causing the charge to expand and initiate the downward movement of the piston, called the power stroke. As the piston reaches the bottom of the power stroke, valves open to exhaust combustion products from the cylinder as the piston travels upward. A new air-to-fuel charge is injected as the piston moves downward in a new intake stroke.

The engine provides mechanical shaft power for a gas compressor. The compressor is used to maintain pressure within the natural gas pipeline transmission and distribution system to consumers. Refer to Figure 3-1 for a four-stroke engine process diagram.

Figure 3-1. Four-Stroke Engine Process Diagram



Natural gas combustion by-products are controlled through parametric controls (i.e., timing and operating at a lean air-to-fuel ratio) and by post-combustion oxidizing catalysts installed on the engine exhaust system. The RICE oxidation catalysts are manufactured by Advanced Catalyst Systems, Inc. Four catalyst modules are installed on each engine exhaust stack use proprietary materials to lower the oxidation temperature of CO and other organic compounds to engine exhaust gas temperatures, thus maximizing the catalyst efficiency specific to the exhaust gas temperatures of engines. As carbon monoxide passes through the catalytic oxidation system, CO and volatile organic compounds are oxidized to CO_2 and water, while suppressing the conversion of NO to NO_2.

The catalyst vendor has guaranteed a CO destruction efficiency of 93%. Although Consumers Energy has chosen to comply with the CO reduction emission limit requirement, the catalyst also provides control of formaldehyde and non-methane and non-ethane hydrocarbons (NMNEHC). The estimated destruction efficiency for formaldehyde and NMNEHC is 80%. Optimization of the engine programing and synchronization with the compressor was recently completed.

NO_x emissions from the engine is minimized using lean-burn combustion technology. Lean-burn combustion refers to a high level of excess air (generally 50% to 100% relative to the stoichiometric amount) in the combustion chamber. The excess air absorbs heat during the combustion process, thereby reducing the combustion temperature and pressure resulting in lower NO_x emissions.

A continuous parameter monitoring system (CPMS) is installed to continuously monitor catalyst inlet temperature in accordance with the requirements specified in Table 5 (1) of 40 CFR 63, Subpart ZZZZ. This parameter is monitored in accordance with the site-specific preventative maintenance / malfunction and abatement plan to evaluate an efficient catalytic reaction and the performance of the pollution control equipment. Detailed operating data are provided in Appendix D.

3.2 Process Flow

Located in southwest Washtenaw County, the Freedom Compressor Station helps maintain natural gas pressures in the natural gas pipeline system. The main function of the station is to transport natural gas primarily from the Panhandle Eastern Pipeline Company's supply lines to Consumers Energy's pipeline system. The Panhandle Eastern Pipeline is an approximate 6,000-mile system that extends from natural gas producing areas in the Anadarko Basin of Texas, Oklahoma and Kansas through Missouri, Illinois, Indiana, Ohio and into Michigan.

FGENGINES-P3 are natural gas reciprocating engines used to drive two-stage compressors to maintain pressure and move natural gas through the pipeline system. The exhaust stacks are of non-typical design. Specifically, the bottom portion of the stack incorporates an annulus, where an outer stack surrounds an inner circular stack (the shape is like a doughnut as viewed looking down from the top of the stack). The exhaust gases from the engine enter the annulus via two horizontal ducts exhausting the engine. Once the gases enter the outer stack, they flow downwards through the oxidation catalysts placed in the bottom of the annulus. After passing through the catalysts, the exhaust gases enter the inner stack through an opening located near the base of the freestanding stack. The exhaust gases then travel upwards, through the freestanding stack, (via the inner stack) until they are discharged unobstructed vertically upwards through the 65-feet high stack to atmosphere.

3.3 Materials Processed

The engine fuel is exclusively natural gas, as defined in 40 CFR §72.2. Recent natural gas sample analyses indicate a fuel composition of approximately 92% methane, 7% ethane, 0.4% nitrogen, and 0.2% carbon dioxide.

3.4 Rated Capacity

FGENGINES-P3 have a maximum output of approximately 3,750 horsepower each, with a rated heat input of approximately 28.96 mmBtu/hr. However, the maximum achievable operating condition of the engine is constrained by site and pipeline specific conditions.

3.5 Process Instrumentation

During testing, the following engine operating parameters were monitored and collected:

- Engine brake horsepower (HP)
- Engine speed (RPM)
- Engine Load as Compressor Torque (% max)
- Fuel gas flow (scfm)
- Suction pressure (psi)
- Discharge pressure (psi)
- Catalyst temperature (°F)
- Pressure difference across oxidation catalyst (in. H_2O)

During testing of FGENGINES-P3 the process data was recorded in 15-minute increments using a combination of engine parametric data loggers and manual readings of field instrumentation. Refer to Appendix D for this operating data.

4.0 SAMPLING AND ANALYTICAL PROCEDURES

Triplicate one-hour test runs for NO_x, CO, VOC, and O_2 concentrations were conducted using the USEPA test methods in Table 4-1. The sampling and analytical procedures associated with each parameter are described further in the following sections.

Table 4-1
Test Methods

Parameter	Method	USEPA Title
Sample traverses	1	Sample and Velocity Traverses for Stationary Sources
Oxygen	3A	Determination of Oxygen and Carbon Dioxide Concentrations in Emissions from Stationary Sources (Instrumental Analyzer Procedure)
Moisture content	4/Alt-008	Determination of Moisture Content in Stack Gases
Nitrogen oxides	7E	Determination of Nitrogen Oxides Emissions from Stationary Sources (Instrumental Analyzer Procedure)
Carbon monoxide	10	Determination of Carbon Monoxide Emissions from Stationary Sources (Instrumental Analyzer Procedure)
Methane (CH_4) & Ethane (C_2H_6)	18	Measurement of Gaseous Organic Compound Emissions by Gas Chromatography
Emission rates	19	Sulfur Dioxide Removal and Particulate, Sulfur Dioxide and Nitrogen Oxides from Electric Utility Steam Generators
Volatile organic compounds	25A	Determination of Total Gaseous Organic Concentration Using a Flame Ionization Analyzer

4.1 Description of Sampling Train and Field Procedures

The test matrix in Table 4-2 summarizes the sampling and analytical methods performed during this test program.

Table 4-2 Test Matrix

Date (2023)	Run	Sample Type	Start Time (EDT)	Stop Time (EDT)	Test Duration (min)	EPA Test Method	Comment
EUENGINE3-1							
May 23	1	O_2 CO	12:30	13:29	60	1, 3A,10 19	Three-point traverse during Run 1; Single-point sample during Runs 2 and 3.
	2		14:17	15:16	60		
	3		15:52	16:51	60		
EUENGINE3-2							
May 24	1	O_2 CO	08:15	09:14	60	1, 3A,10 19	Three-point traverse during Run 1; Single-point sample during Runs 2 and 3.
	2		09:38	10:37	60		
	3		11:00	11:59	60		
EUENGINE3-3							
May 24	1	O_2 CO	13:30	14:29	60	1, 3A,10 19	Three-point traverse during Run 1; Single-point sample during Runs 2 and 3.
	2		15:00	15:59	60		
	3		16:15	17:14	60		
EUENGINE3-4							
May 25	1	O_2 NO_x CO VOC	09:00	09:59	60	1, 4/ALT-008 3A/7E/10 19 25A/18 Alt-096	Three-point traverse during Run 1; Single-point sample during Runs 2 and 3.
	2		10:15	11:14	60		
	3		11:40	12:39	60		
EUENGINE3-5							
May 25	1	O_2 NO_x CO VOC	13:10	14:09	60	1, 4/ALT-008 3A/7E/10 19 25A/18 Alt-096	Three-point traverse during Run 1; Single-point sample during Runs 2 and 3.
	2		14:30	15:29	60		
	3		16:00	16:59	60		

4.2 Sample Location and Traverse Points (USEPA Method 1)

The number and location of traverse points for each engine was evaluated according to the requirements in Table 4 of 40 CFR Part 63, Subpart ZZZZ, Table 2 of 40 CFR Part 60, Subpart JJJJ, and USEPA Method 1, *Sample and Velocity Traverses for Stationary Sources.*

The engine is equipped with sample ports located upstream and downstream (Pre and Post) of the oxidation catalyst.

Pre-catalyst Sampling Ports

Two test ports are in each of two 16-inch diameter horizontal exhaust ducts exiting the engine. The pre-catalyst sampling ports are situated:

- Approximately 347-inches or 21.7 duct diameters downstream of a duct bend disturbance in the engine exhaust duct, and

- Approximately 63-inches or 3.9 duct diameters upstream of flow disturbance caused by a change in duct diameter and flow direction as it enters exhaust stack and oxidation catalyst.

The pre-catalyst sample ports are 4-inches in diameter and sealed by a bolted blank flange approximately 4-inches outside the duct wall.

Post-catalyst Sampling Ports

Two test ports are in a 30-inch vertical exhaust stack exiting the engine and oxidation catalyst. The post-catalyst sampling ports are situated:

- Approximately 240-inches or 8.0 duct diameters downstream of a duct diameter change flow disturbance, and

- Approximately 118-inches or 3.9 duct diameters upstream of the stack exit to atmosphere.

The post-catalyst sample ports are 4-inches in diameter and sealed by a bolted blank flange approximately 4-inches outside the stack wall.

Because the ducts are >12 inches in diameter and the sampling port locations meet the two and half-diameter criterion of Section 11.1.1 of Method 1 of 40 CFR Part 60, Appendix A-1, the duct was sampled at 3 traverse points located at 16.7, 50.0, and 83.3% of the measurement line ('3-point long line'). The flue gas was sampled from the three traverse points at approximately equal intervals during the tests. Pre-catalyst and post-catalyst sampling port location images are presented as Figures 4-1 and 4-2.

Figure 4-1. Pre- and Post-Catalyst Sampling Port Locations

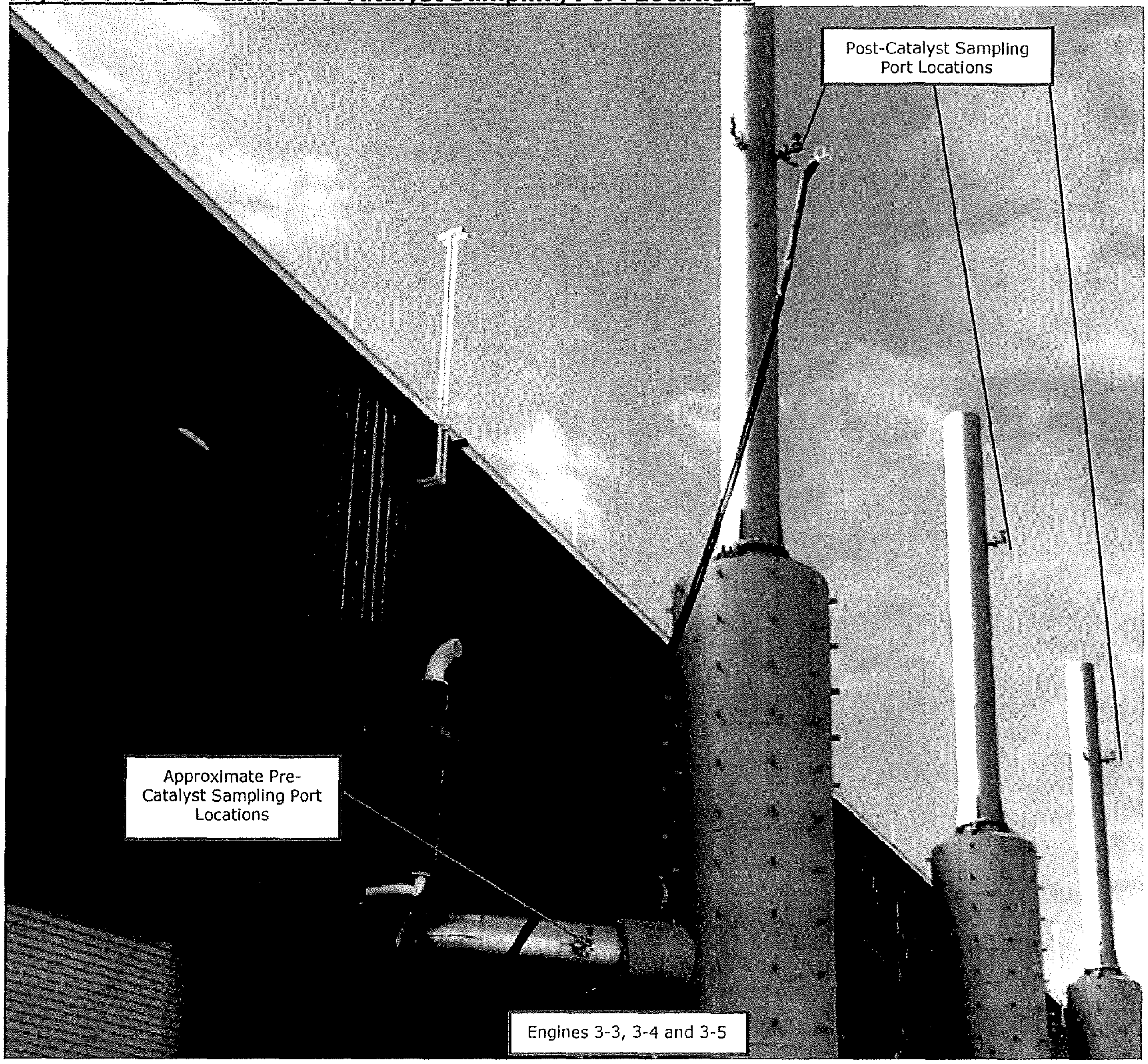
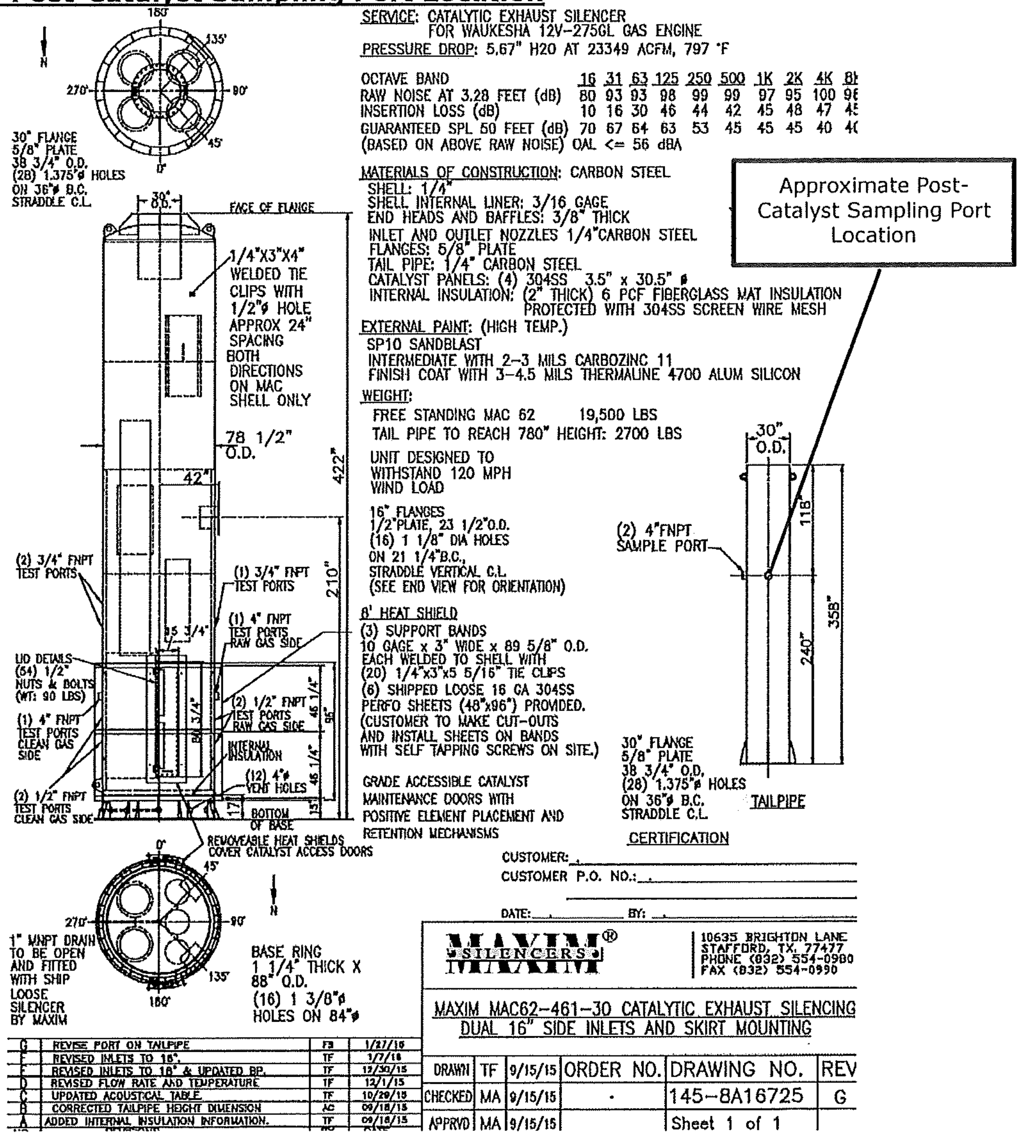


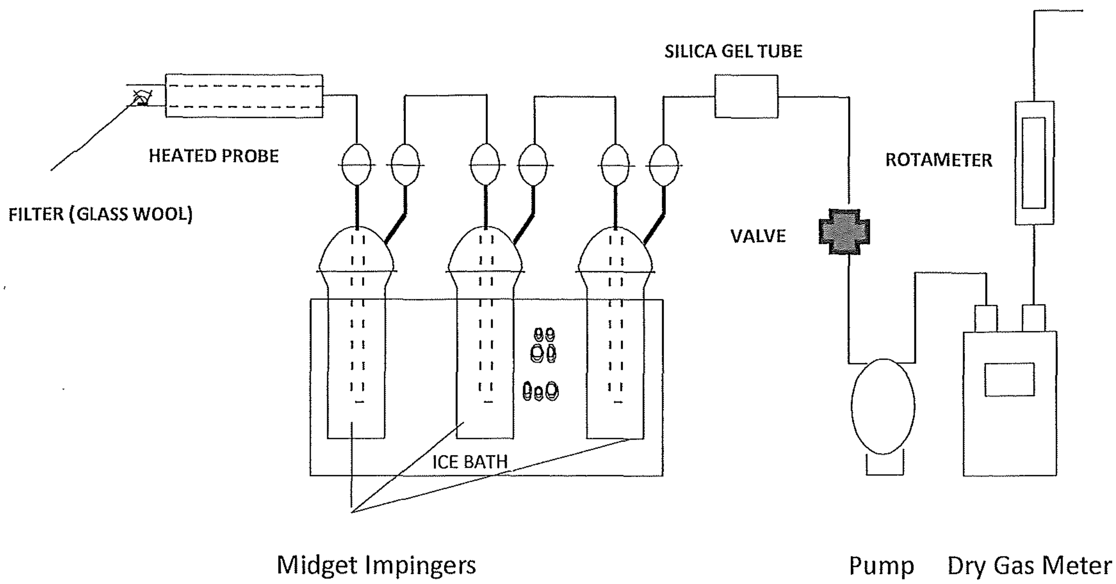
Figure 4-2. Post-Catalyst Sampling Port Location



4.3 Moisture Content (USEPA ALT-008)

Exhaust gas moisture content was determined in accordance with USEPA ALT-008, *Alternative Moisture Measurement Method Midget Impingers*, an alternative method for correcting pollutant concentration data to appropriate moisture conditions (e.g., pollutant and/or air flow data on a dry or wet basis) validated May 19, 1993, by the USEPA Emission Measurement Branch. The procedure is incorporated into Method 6A of 40 CFR Part 60 and is based on field validation tests described in *An Alternative Method for Stack Gas Moisture Determination* (Jon Stanley, Peter Westlin, 1978, USEPA Emissions Measurement Branch). The sample apparatus configuration follows the general guidelines contained in Figure 4-2 and §.8.2 of USEPA Method 4, *Determination of Moisture Content in Stack Gases,* and ALT-008 Figure 1 or 2. The flue gas is withdrawn from the stack at a constant rate through a heated sample probe, umbilical, four midget impingers, and a metering console with pump. The moisture is removed from the gas stream in the ice-bath chilled impingers and determined gravimetrically. Refer to Figure 4-3 for a figure of the Alternative Method 008 Moisture Sample Apparatus.

Figure 4-3. Alternative Method 008 Moisture Sample Apparatus



The silica gel tube depicted in this figure was replaced with a midget impinger (bubbler) with a straight tube insert, as allowed in ALT-008, §1

4.4 O_2, NO_X, and CO (USEPA Methods 3A, 7E, and 10)

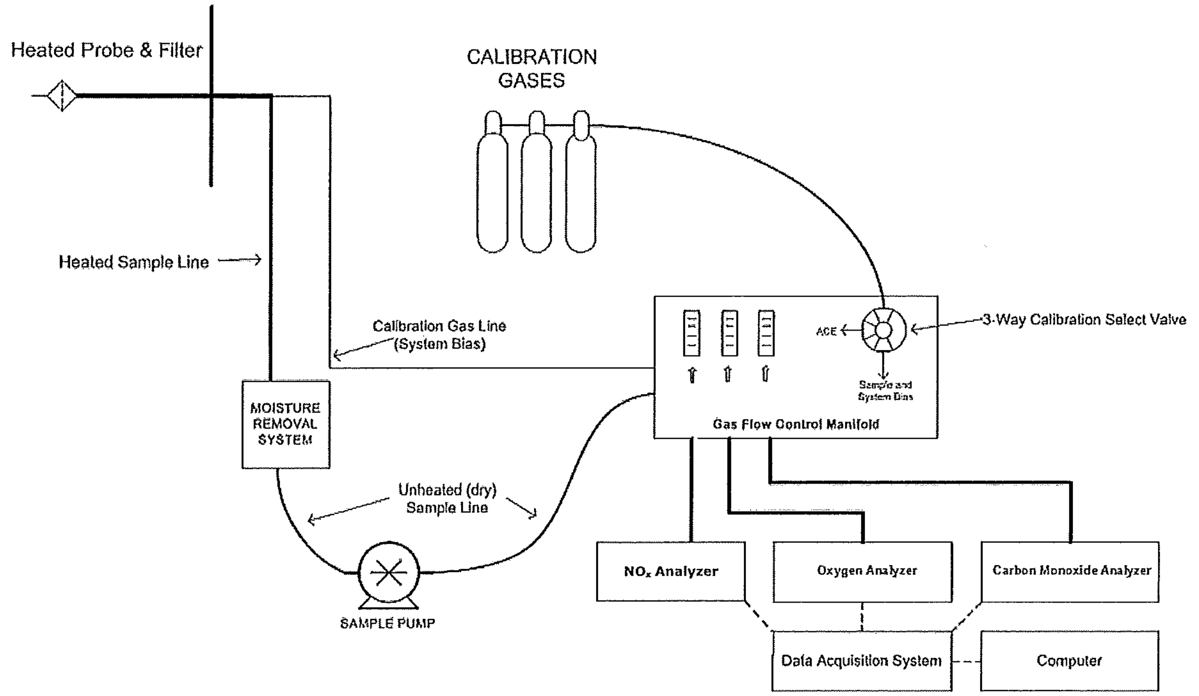
Oxygen, nitrogen oxides, and/or carbon monoxide concentrations were measured using the following sampling and analytical procedures:

- USEPA Method 3A, *Determination of Oxygen and Carbon Dioxide Concentrations in Emissions from Stationary Sources (Instrumental Analyzer Procedure),*
- USEPA Method 7E, *Determination of Nitrogen Oxides Emissions from Stationary Sources (Instrumental Analyzer Procedure)*, and
- USEPA Method 10, *Determination of Carbon Monoxide Emissions from Stationary Sources (Instrumental Analyzer Procedure).*

Each cited method sampling is procedurally similar except for the analyzer and analytical technique used. Engine exhaust gas was extracted from the stacks or ducts through a stainless-steel probe, heated Teflon® sample line, and through a gas conditioning system to remove water and dry the sample before entering a sample pump, flow control manifold, and gas analyzers.

Figure 4-4 depicts a drawing of the Methods 3A, 7E, and 10 sampling system.

Figure 4-4. USEPA Methods 3A, 7E, and 10 Sampling System



Prior to sampling engine exhaust gas, the analyzers are calibrated by performing a calibration error test where zero-, mid-, and high-level calibration gases are introduced directly to the back of the analyzers. The calibration error check is performed to evaluate if the analyzers response was within ±2.0% of the calibration gas span or high calibration gas concentration. An initial system-bias test is then performed where the zero- and mid- or high- calibration gases are introduced at the sample probe to measure the ability of the system to respond accurately to within ±5.0% of span.

A NO_2 to NO conversion efficiency test is performed on the NO_x analyzer prior to beginning the test program to evaluate the ability of the instrument to convert NO_2 to NO before analyzing for NO_x.

Upon successful completion of the calibration error and initial system bias tests, sample flow rate and component temperatures are verified, and the probes inserted into the ducts at the appropriate traverse point. After confirming the engine is operating at established conditions, the test run is initiated. Gas concentrations are recorded at 1-minute intervals throughout each 60-minute test run. Oxygen concentrations are measured to adjust the pollutant concentrations to 15% O_2 and calculate pollutant emission rates.

At the conclusion of each test run, a post-test system bias check is performed to compare analyzer bias and drift relative to pre-test system bias checks, ensuring analyzer bias is within ±5.0% of span and drift is within ±3.0%. The analyzer response is also used to correct measured gas concentrations for analyzer drift.

For the analyzer calibration error tests, bias tests and drift checks, these evaluations are also passed if the standard criteria are not achieved, but the absolute difference between the analyzer responses and calibration gas is less than or equal to 0.5 ppmv for NO_x and CO or 0.5% for O_2.

4.5 Emission Rates (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 a fuel specific F factor and exhaust gas flowrate.

A fuel sample was collected during testing and analyzed by gas chromatography, ultraviolet fluorescence, and electronic sensing cells to obtain hydrocarbons, non-hydrocarbons, heating value, and other parameters of the natural gas samples. The results were used to calculate F_w and F_d factors (ratios of combustion gas volumes to heat inputs) using USEPA Method 19 Equations 19-13, 19-14, and 19-15. This F_d factor was then used to calculate the emission flow rate with the corresponding equation presented in Figure 4-5. The flow rate was used in calculations to present emissions in units of g/HP-hr.

Figure 4-5. USEPA Method 19 Emission Flow Rate Equation

$$Q_s = F_d H \frac{20.9}{20.9 - O_2}$$

Where:

Q_s = stack flow rate (dscf/min)
F_d = fuel-specific oxygen-based F factor, dry basis, from Method 19 (dscf/mmBtu)
H = fuel heat input rate, (mmBtu/min), at the higher heating value (HHV) measured at engine fuel feed line, calculated as (fuel feed rate in ft^3/min) x (fuel heat content in mmBtu/ft^3)
O_2 = stack oxygen concentration, dry basis (%)

4.6 Volatile Organic Compounds (USEPA Methods 18 and 25A)

VOC concentrations were measured from each engine using a Thermo Model 55i Direct Methane and Non-methane Analyzer following the guidelines of USEPA Method 25A, *Determination of Total Gaseous Organic Concentration Using a Flame Ionization Analyzer (FIA)*. The instrument uses a flame ionization detector (FID) to measure the exhaust gas total hydrocarbon concentration in conjunction with a gas chromatography column that separates methane from other organic compounds.

The components of the extractive sample interface apparatus are constructed of Type 316 stainless steel and Teflon. Flue gas was sampled from the stack via a sample probe and heated sample line and into the analyzer, which communicates with data acquisition handling systems (DAHS) via output signal cables. The analyzer uses a rotary valve and gas chromatograph column to separate methane from hydrocarbons in the sample and quantifies these components using a flame ionization detector.

Sample gas is injected into the column and due to methane's low molecular weight and high volatility, the compound moves through the column more quickly than other organic compounds that may be present and is quantified by the FID. The column is then flushed with inert carrier gas and the remaining non-methane organic compounds are analyzed in the FID. This analytical technique allows separate measurements for methane and non-methane organic compounds via the use of a single FID. Refer to Figure 4-6 for a drawing of the USEPA Method 25A sampling apparatus.

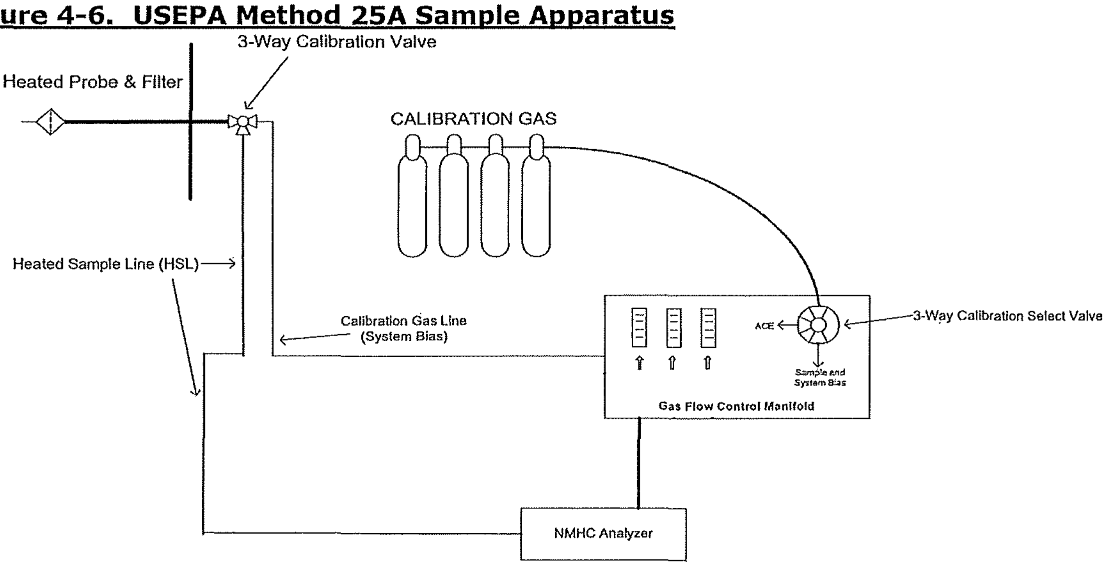
The field VOC instrument was calibrated with zero air and three propane and methane in air calibration gases following USEPA Method 25A procedures at the zero level, low (25 to 35 percent of calibration span), mid (45 to 55 percent of calibration span) and high (equivalent to 80 to 90 percent of instrument span). Note that the field VOC instrument measures on a wet basis, therefore measured exhaust gas moisture content was used to convert wet basis VOC concentrations to dry and calculate VOC mass emission rates.

Please note that 40 CFR Part 60, Subpart JJJJ refers to the definition of VOC found in 40 CFR, Part 51 and does not include methane or ethane. Specifically, §51.100(s)(1) defines VOC as "*any compound of carbon...other than the following, which have been determined to have negligible photochemical reactivity: methane, ethane...*" The Thermo 55i analyzer used measured exhaust gas ethane as part of the NMOC measurement. Therefore, Tedlar bag samples were collected to quantify the ethane fraction of the NMOC concentration using USEPA Method 18, *Measurement of Gaseous Organic Compound Emissions by Gas Chromatography*.

Bags manufactured from polyvinyl fluoride (PVF) film, also known as Tedlar film, were collected in the field from the engine exhaust. The ethane concentrations in each bag were measured by separating the major organic components using a gas chromatograph (GC) column and measuring them with a suitable detector. To identify and quantify the major components, the retention times of each separated component were compared with those of known compounds under identical conditions. The approximate concentrations were estimated before analysis and standard mixtures prepared so the GC/detector was calibrated under physical conditions identical to those used for the samples.

Method 18 requires the sample results to be corrected based on results obtained from a spike recovery study. For the bag sampling technique to be considered valid for a compound, the recovery must be between 70% <R < 130%. The recovery study performed on the Freedom Compressor engine Tedlar bag samples successfully achieved the R value requirement and that value was applied to correct the reported methane and ethane concentrations as propane. It should be noted, the laboratory report provides the concentration of analyte in sample as ppmv as well as ppmv as propane. Consumers Energy has converted the ppmv concentration to ppmv as propane using the calculation and data analysis procedures consistent with USEPA Method 25A, Section 12.0, which provides a more conservative estimate of NMNEVOC emissions. The USEPA Method 18 laboratory report is presented in Appendix E.

Figure 4-6. USEPA Method 25A Sample Apparatus



5.0 TEST RESULTS AND DISCUSSION

The test program conducted May 23 through 25, 2023, satisfies the performance testing and compliance evaluation requirements in 40 CFR Part 60, Subpart JJJJ, "Standards of Performance for Stationary Spark Ignition Internal Combustion Engines," 40 CFR Part 63, Subpart ZZZZ, "National Emission Standards for Hazardous Air Pollutants for Reciprocating Internal Combustion Engines," and MI-ROP-N3920-2022a.

5.1 Tabulation of Results

The results of the testing indicate FGENGINES-P3 are compliant with the applicable NO_x, CO, and VOC emissions limits and associated operating requirements as summarized in Table 2-1 and Table 2-2. Appendix Table 1 contains detailed tabulation of results, process operating conditions, and exhaust gas conditions.

5.2 Significance of Results

The results of the testing indicate compliance with the applicable emission limits.

5.3 Variations from Sampling or Operating Conditions

During testing non-methane VOC concentrations were measured at concentrations ranging from approximately 25 to 64 ppmv as propane where compliance could not be determined without quantifying ethane concentrations through the collection of Tedlar bag samples and USEPA Method 18 analysis. One Tedlar bag sample of the exhaust gas was collected during each run. The measured ethane concentration was subtracted from the average non-methane VOC concentration for each test run to estimate non-methane, non-ethane VOC emissions and evaluate compliance with permit limits. This approach was outlined within the approved test protocol and discussed with EGLE representatives onsite during testing.

5.4 Air Pollution Control Device Maintenance

Other than routine maintenance, no major air pollution control device maintenance was performed during the three-month period prior to the test event. Engine optimization is continuously performed to ensure lean-burn combustion and ongoing compliance with regulatory emission limits.

5.5 Re-Test Discussion

Based on the results of this test program, a re-test is not required. Subsequent air emissions testing on the engines will be performed:

- annually to evaluate the reduction of CO emissions across the oxidation catalyst in accordance with 40 CFR Part 63 Subpart ZZZZ and the ROP
- every 8,760 engine operating hours or 3 years (2026), whichever is first, thereafter, to evaluate compliance with NO_x, CO, and VOC emission limits in 40 CFR Part 60, Subpart JJJJ and the ROP. The engine hours after the conclusion of testing were:
    - EUENGINE3-1: 6406 hours
    - EUENGINE3-2: 6992 hours
    - EUENGINE3-3: 5723 hours
    - EUENGINE3-4: 5046 hours
    - EUENGINE3-5: 5551 hours

5.6 Results of Audit Samples

Audit samples for the reference methods utilized during this test program are not available from USEPA Stationary Source Audit Sample Program providers. The USEPA reference methods performed state reliable results are obtained by persons equipped with a thorough knowledge of the techniques associated with each method. Factors with the potential to cause measurement errors are minimized by implementing quality control (QC) and assurance (QA) programs into the applicable components of field testing. QA/QC components were included in this test program. Table 5-1 summarizes the primary field quality assurance and quality control activities that were performed. Refer to Appendix E for supporting documentation.

Table 5-1
QA/QC Procedures

QA/QC Activity	Purpose	Procedure	Frequency	Acceptance Criteria
M1: Sampling Location	Evaluates suitability of sampling location	Measure distance from ports to downstream and upstream flow disturbances	Pre-test	≥2 diameters downstream; ≥0.5 diameter upstream.
M1: Duct diameter/ dimensions	Verifies area of stack is accurately measured	Review as-built drawings and field measurement	Pre-test	Field measurement agreement with as-built drawings
M3A, M7E, M10, M25A: Calibration gas standards	Ensures accurate calibration standards	Traceability protocol of calibration gases	Pre-test	Calibration gas uncertainty ≤2.0%
M3A, M7E, M10: Calibration Error	Evaluates analyzer operation	Calibration gases introduced directly into analyzers	Pre-test	±2.0% of span or ≤0.5 ppmv or ≤0.5 % abs. difference
M3A, M7E, M10: System Bias and Analyzer Drift	Evaluates analyzer/sample system integrity and accuracy over test duration	Calibration gas introduced at sample probe tip, HSL, and into analyzers	Pre-test and Post-test	Bias: ±5.0% of span Drift: ±3.0% of span or ≤ 0.5 ppmv or 0.5% abs. difference
M7E: NO_2-NO converter efficiency	Evaluates NO_2-NO converter operation	NO_2 gas introduced directly into analyzer	Pre-test or Post-test	NO_x response ≤2% drop from peak value observed
M25A: Calibration Error	Evaluates analyzer and sample system operation	Calibration gases introduced through sample system	Pre-test	±5.0% of the calibration gas value
M25A: Zero and Calibration Drift	Evaluates analyzer/sample system integrity and accuracy over test duration	Calibration gases introduced through sample system	Pre-test and Post-test	±3.0% of the analyzer calibration span

5.7 Calibration Sheets

Calibration sheets, including gas protocol sheets and analyzer quality control and assurance checks are presented in Appendix E.

5.8 Sample Calculations

Sample calculations and formulas used to compute emissions data are presented in Appendix A.

5.9 Field Data Sheets

Field data sheets are presented in Appendix B.

5.10 Laboratory Quality Assurance / Quality Control Procedures

The method specific quality assurance and quality control procedures in each method employed during this test program were followed, without deviation. Refer to Appendix C for the laboratory data sheets associated with the natural gas fuel samples collected during the test program.

5.11 QA/QC Blanks

The Method 3A, 7E, 10, and 25A calibration gases described in Table 5-1 above were the only QA/QC media employed during the test event. QA/QC data are shown in Appendix E.

Appendix Table