MALFUNCTION ABATEMENT PLAN

Western Michigan University

Two (2) Natural Gas-Fired RICE

Robert M. Bean Power Plant
Stadium Drive
Kalamazoo, Michigan

NTH Project No. 74-200421
January 8, 2021

NTH Consultants, Ltd.
3001 N. Coolidge, Suite 101
East Lansing, MI 48823

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1.0 INTRODUCTION

Western Michigan University (WMU) received Permit to Install (PTI) No. 23-19 on May 16, 2019 for the installation and operation of two (2) natural gas-fired reciprocating internal combustion engines (RICE), identified as EU-ENGINE1 and EU-ENGINE2, located adjacent to the Robert M. Beam Power Plant on Stadium Drive at WMU's Campus in Kalamazoo, MI.

The two (2) RICE were commissioned (initial startup on July 15, 2020) to provide electricity during on-peak hours to the WMU Kalamazoo campus. Each RICE is rated at 3,448 horsepower (HP) (2.5 megawatts (MW)) and equipped with an oxidation catalyst for control of carbon monoxide (CO) and volatile organic compound (VOC) emissions. PTI No. 23-19 contains emission limits on nitrogen oxide (NO_x), CO, and VOC at the RICE that are demonstrated through periodic stack testing, proper operation of the oxidation catalysts, and recordkeeping.

Michigan Air Pollution Control Rule R 336.1911 ("Rule 911") requires a source of an air contaminant to prepare a Malfunction Abatement Plan (MAP) that identifies means to prevent, detect, and correct malfunctions or equipment failures that may result in emissions exceeding an applicable emission limitation. PTI No. 23-19 includes a requirement that WMU submit, implement, and maintain a MAP for EU-ENGINE1 and EU-ENGINE2 and respective control devices, pursuant to Rule 911 and as listed in Special Condition III.2 of flexible group FGENGINES.

This document serves as WMU's MAP and has been prepared in accordance with WMU's PTI No. 23-19 and the requirements of Michigan Air Pollution Control Rule 911.

1.1 Structure of Malfunction Abatement Plan

This MAP contains the following information as it pertains to EU-ENGINE1 and EU-ENGINE2:

- Preventative Maintenance Program (Section 2.1), including:
    - Identification of supervisory personnel responsible for overseeing the inspection, maintenance, and repair of air cleaning devices
    - Description of the items or conditions that shall be inspected
    - Frequency of inspections or repairs

- Identification of the major replacement parts that shall be maintained in inventory for quick replacement

- Operating variables of the engines and air-cleaning devices that are monitored to detect a malfunction or failure, normal operating range of the variables, and monitoring or surveillance procedures (Section 2.2)
- Corrective procedures or operational changes that are taken in the event of a malfunction or failure to achieve compliance with the applicable emission limits (Section 2.3)

Sections 3.0 and 4.0 contain recordkeeping and reporting requirements associated with the MAP and malfunction events. Sections 5.0 and 6.0 contain a summary of plan revisions and referenced documents. Appendices A - C contain pertinent information related to this MAP, as obtained from the Michigan Caterpillar® (CAT) Operation and Maintenance Manual and MIRATECH® Catalytic Converter Installation & Operation Manual.

2.0 MALFUNCTION ABATEMENT PLAN

During a malfunction of EU-ENGINE1 and/or EU-ENGINE2, WMU will follow the procedures in this plan for proper operation in order to minimize excess emissions. A malfunction is defined in R 336.1113(a) of the Michigan Air Pollution Control Rules:

> *Malfunction means any sudden, infrequent and not reasonably preventable failure of a source, process, process equipment, or air pollution control equipment to operate in a normal or usual manner. Failures that are caused in part by poor maintenance or careless operation are not malfunctions.*

This MAP is intended to provide a roadmap to plant operations and outline procedures for operation of EU-ENGINE1 and EU-ENGINE2 during malfunction events. This plan will help ensure that:

- During malfunction events, WMU operates and maintains EU-ENGINE1 and EU-ENGINE2 in a manner consistent with good air pollution control practices;
- WMU is prepared to correct malfunctions as soon as it is safe and practicable to do so, in order to minimize excess emissions of air pollutants; and

- WMU meets the recordkeeping and reporting requirements associated with periods of malfunction events (including documenting corrective action taken to restore malfunctioning process and air pollution control equipment to its usual manner of operation).

2.1 Preventative Maintenance Program

Table 2-1 provides a list of WMU Supervisory Personnel responsible for overseeing the inspection, maintenance, and repair of EU-ENGINE1 and EU-ENGINE2, the oxidation catalysts, and associated monitoring equipment. WMU has contracted personnel from Michigan CAT to perform the preventative maintenance program as specified below.

Table 2-1: WMU Supervisory Personnel

Name	Title
Mr. George Jarvis	Director, WMU Robert M. Beam Power Plant
Mr. Michael Walden	Chief Operating Engineer
Mr. Kevin Bridges	Assistant Chief Operating Engineer

Scheduled preventative maintenance for EU-ENGINE1 and EU-ENGINE2 will be conducted by Michigan CAT personnel in accordance with CAT's Maintenance Interval Schedule contained in Appendix A at the recommended timeframes. Records of maintenance events, including date and time of occurrence, will be completed by CAT via field service reports and will be kept onsite at the plant either electronically or in plant logbooks. Appropriate procedures for the recommended maintenance will be followed as detailed in the Michigan CAT Operation and Maintenance Manual.

Additionally, maintenance will be conducted on the oxidation catalyst by Michigan CAT personnel when necessary. Records of maintenance events, including date and time of occurrence, will be completed by CAT via field service reports and will be kept onsite at the plant either electronically or in plant logbooks. Oxidation catalyst maintenance items and an example maintenance log is contained in Appendix A, as obtained from the MIRATECH® Catalytic Converter Installation & Operation Manual. Further details on oxidation catalyst operation and maintenance are contained in the manual.

A sample list of spare/replacement parts that will be kept in inventory or will be made available by CAT or MIRATECH at the time of necessary repairs or maintenance on the RICE and/or oxidation catalysts is contained in Appendix B. These detailed lists are obtained from the CAT Operation and Maintenance Manual and the MIRATECH Catalytic Converter Installation and Operation Manual. If a spare part for the system is not available when needed, the affected engine will be shut down until the spare part can be procured and installed.

2.2 Operating Variables

The engine control module (ECM) controls the RICE's functions, including monitoring and engine operation. The ECM is connected to sensors used to monitor engine operating variables via wiring harnesses. The sensors monitor specific operating parameters, and if abnormal operation of the engine is detected, the ECM can generate an alarm, a warning, or a shutdown. Engine parameters that are monitored include inlet air temperature, oil pressure, and engine speed. Further details are contained in the CAT Operation and Maintenance Manual.

Oxidation catalyst operating variables include catalyst inlet temperature and pressure drop across the catalyst. The oxidation catalyst is equipped with a thermocouple to monitor the catalyst inlet and outlet temperature and an alarm for when the temperatures are outside the normal range. Pressure drop across the oxidation catalyst is monitored and maintained within the established range during normal operation by use of a pressure measuring device. Normal operating ranges of the catalyst inlet and outlet temperatures and pressure drop across the catalyst are listed in Table 2-2. Further details are contained in the MIRATECH Catalytic Converter Installation and Operation Manual.

Table 2-2: Oxidation Catalyst Operating Variables

Parameter	Normal Operating Range
Oxidation Catalyst Inlet Temperature	550 °F - 1,250 °F
Oxidation Catalyst Outlet Temperature	1,350 °F (maximum)
Oxidation Catalyst Pressure Drop	As established during performance testing

2.3 Corrective Procedures

If a malfunction occurs which causes, or may cause, excess emissions during engine operation, the RICE will be shut down and equipment causing the potential excess emission rate will be evaluated as soon as practicable in accordance with safe operating procedures. WMU personnel will review alarms or warnings provided by the ECM and determine the proper procedures to correct the malfunction and safely bring the RICE back into operation.

A description of troubleshooting and the corrective procedures or operational changes that shall be taken in the event of a malfunction or failure to achieve compliance with the emission limits for EU-ENGINE1 and/or EU-ENGINE2 is contained in Appendix C. In addition, WMU will identify if alarms have occurred at the engines as identified by the ECM and will follow corrective actions as specified in the manual. Refer to the Michigan CAT Operation and Maintenance Manual and MIRATECH Catalytic Converter Installation & Operation Manual for more details.

3.0 RECORDKEEPING REQUIREMENTS

WMU will keep a current copy of this MAP onsite and will maintain records of malfunction events in plant logbooks. Records of malfunction events will include the time, date, probable cause(s), duration, affected equipment, emission estimates (if known or if reasonably possible to estimate), and the corrective actions taken in response to the malfunction. WMU will maintain the records in accordance with WMU's records retention policy.

4.0 REPORTING REQUIREMENTS

This section contains an overview of the MAP reporting requirements for the RICE pursuant to Michigan Air Pollution Control Rule R 336.1912 ("Rule 912").

4.1 Michigan Air Pollution Control Rule 912 Requirements for Malfunctions

Rule 912 requires that, as it relates to malfunctions, a facility operate its source, process, or process equipment, to the extent that is reasonably possible, in a manner consistent with good air pollution control practices for minimizing emissions during periods of abnormal conditions and malfunctions. A source, process, or process equipment that complies with applicable emission standards and limitations during periods of abnormal conditions and malfunction shall be presumed to have been operated in a manner consistent with good air pollution control practices for minimizing emissions. PTI No. 23-19 contains emission limits for EU-ENGINE1 and EU-ENGINE2 for NO_x, CO, and VOC during normal operation.

Pursuant to Rule 912, WMU shall provide notice and a written report of a malfunction if it results in excess emissions above the emission limitations for the RICE if the excess emissions occur for more than two (2) hours. The requirements for notices and written reports are as follows:

- An **initial notice** shall be provided to EGLE Kalamazoo District Office as soon as reasonably possible, but not later than two (2) business days after the discovery of the abnormal conditions or malfunction resulting in excess emissions for more than two (2) hours. Notice shall be by any reasonable means, including electronic, telephonic, or oral communication.
- A **written report**, containing the information listed below, shall be submitted to EGLE Kalamazoo District Office within 10 days after the abnormal conditions or malfunction has been corrected, or within 30 days of discovery of the abnormal condition or malfunction, whichever is first. The truth, accuracy, and completeness of the written report shall be certified by WMU's Responsible Official. The written report shall include all of the required information:
    - The time and date, the probable causes or reasons for, and the duration of the abnormal conditions or malfunction
    - An identification of the source, process, or process equipment that experienced abnormal conditions or which malfunctioned, and all other affected process or process equipment that have emissions in excess of an applicable requirement, including a description of the type and, where known or where it is reasonably possible to estimate, the quantity or magnitude of emissions in excess of applicable requirements
    - Information describing the measures taken and air pollution control practices followed to minimize emissions
    - For abnormal conditions and malfunctions, the report shall also include a summary of the actions taken to correct and to prevent a reoccurrence of the abnormal conditions or malfunction and the time taken to correct the malfunction

Written reports of malfunction events will also be maintained onsite in plant logbooks.

5.0 PLAN REVISIONS

The MAP will be revised within 90 days to address reasonable revision requests by EGLE or other applicable changes. Revisions may be requested if it is determined that the plan:

- Does not address a malfunction event that has occurred
- Fails to provide operation of the RICE in a manner consistent with the general duty to minimize emissions during malfunction events
- Inadequately addresses provisions for correcting malfunctioning process or emission control equipment.

Table 5-1: Revision History

Date Issued	Revision No.	Revised by	Summary of Changes
1/8/2021	0	Not Applicable	Original Version

6.0 REFERENCED DOCUMENTS

Table 6-1 contains a listing of referenced documents in this MAP and their locations. Copies of the documents can be provided to EGLE upon request.

Table 6-1: Referenced Documents

Referenced Document	Location
Michigan CAT Operation and Maintenance Manual	Power Plant Control Room or Electronic
MIRATECH Catalytic Converter Installation & Operation Manual	Power Plant Control Room or Electronic
Plant logbooks (for maintenance records)	Power Plant Control Room or Electronic

APPENDIX A

// RICE & OXIDATION CATALYST MAINTENANCE

Operation and Maintenance Manual
G3500H 60Hz Generator Sets

Media Number -SEBU9173-16 **Publication Date -01/04/2015** **Date Updated -03/12/2019**

i07945156

Maintenance Interval Schedule

SMCS - 1000; 4450; 7500

Ensure that all safety information, warnings, and instructions are read and understood before any operation or any maintenance procedures are performed. The user is responsible for the performance of maintenance, including all adjustments, the use of proper lubricants, fluids, and filters. The user is also responsible for the replacement of components due to normal wear and aging. Failure to adhere to proper maintenance intervals and procedures may result in diminished performance of the product and/or accelerated wear of components. Use fuel consumption, service hours, or calendar time, WHICH EVER OCCURS FIRST, to determine the maintenance intervals. Products that operate in severe operating conditions may require more frequent maintenance. Before each consecutive interval is performed, all maintenance from the previous interval must be performed.

When Required

Battery - Recycle
Battery - Replace
Battery or Battery Cable - Disconnect
Coolant Sample (Level 2) - Obtain
Engine Air Cleaner Element - Replace
Generator - Dry
Generator Set - Test
Generator Set Alignment - Check
Generator Winding - Test
Overhaul Considerations
Stator Winding Temperature - Test
Throttle Control Valve - Check
Varistor - Inspect

Daily

Coolant Level - Check
Drive Gearbox Oil Level - Check
Engine Air Cleaner Differential Pressure - Check
Engine Oil Filter Differential Pressure - Check
Engine Oil Level - Check
Fuel Filter Differential Pressure - Check
Fumes Disposal Filter Differential Pressure - Check
Generator Bearing Temperature - Test/Record
Generator Load - Check
Jacket Water Heater - Check
Power Factor - Check
Voltage and Frequency - Check
Walk-Around Inspection

Initial 250 Service Hours

Valve Stem Projection - Measure/Record

Every 250 Service Hours

Coolant Sample (Level 1) - Obtain
Cooling System Supplemental Coolant Additive (SCA) - Test/Add
Drive Gearbox Oil Heater - Test
Drive Gearbox Oil Sample - Obtain
Engine Oil Sample - Obtain
Fumes Disposal Filter - Drain
Space Heater - Test

Every 1000 Service Hours

Alternator - Inspect
Battery Electrolyte Level - Check
Belts - Inspect/Adjust/Replace
Crankcase Pressure - Measure
Crankshaft Vibration Damper - Inspect
Engine Crankcase Breather - Clean
Fumes Disposal Filter Element - Inspect
Hoses and Clamps - Inspect/Replace
Inlet Air System - Check
Water Pump - Inspect

Every 2000 Service Hours

Engine Oil and Filter - Change
Flexible Coupling (Rubber) - Inspect
Gas Filter Condensation - Drain

Generator Bearing - Lubricate
Generator Set Vibration - Inspect
Spark Plugs - Inspect/Adjust/Replace
Stator Lead - Check

Every 4000 Service Hours

Crankcase Blowby - Test/Record
Cylinder Pressure - Test/Record
Drive Gearbox Oil - Change
Drive Gearbox Oil Filter - Clean/Inspect
Engine Mounts - Inspect
Engine Protective Devices - Check
Engine Valve Lash and Bridge - Check
Flexible Coupling (Silicone Compression) - Inspect
Ignition System Timing - Check/Adjust
Nitrogen Oxide Sensor - Calibrate
Starting Motor - Inspect
Valve Stem Projection - Measure/Record

Every 8000 Service Hours

Coolant Temperature Regulator - Replace
Drive Gearbox Oil Filter - Replace
Drive Gearbox Sump Oil Screen - Inspect/Clean
Engine Speed/Timing Sensor - Clean/Inspect
Generator Bearing - Inspect
Generator Winding Insulation - Test
Rotating Rectifier - Check

Every 10 000 Service Hours

Nitrogen Oxide Sensor - Replace

Between 12 000 and 16 000 Service Hours

Engine Coolant Diverter Valve - Inspect

Between 18 000 and 22 000 Service Hours

Ignition Transformer - Replace
Overhaul (Top End)
Turbocharger - Inspect

Every 24 000 Service Hours or 3 Years

Coolant (NGEC) - Change

Between 35 000 and 45 000 Service Hours

Overhaul (In-Frame)

Between 70 000 and 90 000 Service Hours

Overhaul (Major)

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VI. MAINTENANCE

The MIRATECH® catalytic converter is designed for years of trouble free operation. A comprehensive maintenance and inspection program for both the catalyst and engine is of utmost importance. Using an exhaust gas analyzer that measures NOx, CO, O_2 and combustibles to check engine and catalyst performance is highly recommended.

There are several ways to ensure the optimal performance of your MIRATECH® catalyst. Depending on operating conditions and fuel gas composition, maintenance programs should include all of the following:

A. Recording Data

When the catalyst is first installed, it is important to gather data for future reference. This should include performance data at rated conditions (i.e. at set speed, load, ignition timing, and AFR set point) such as:

1. ΔT and ΔP Across the Catalyst
2. Emission Reductions of NOx and CO
3. Pre and Post Catalyst Oxygen Content

A Catalyst Maintenance Log has been provided in the Appendix H to track engine and catalyst performance.

Emission reductions are expressed as conversion efficiency. Simply put, conversion efficiency relates the amount of NOx, CO or HC reduced relative to catalyst inlet levels. This is determined with exhaust gas analyzers measuring pollutants before and after the catalyst. Other recorded data should include monitoring pressure drop or differential pressure (ΔP) across the catalyst and the temperature before and after the catalyst. Monitoring differential temperature (ΔT) across the catalyst can be a useful indicator of catalyst activity in many applications. In general, but not in every case, the temperature rise across the catalyst should be in the 25° to 100°F (14°C to 56°C) range for rich burn engines, and 5°F for lean burn engines. However, depending upon ambient conditions and where in the housing or piping the temperature is measured, lower values may be found. The absence of a temperature rise is not necessarily an indicator of non-performance, since heat transfer by convection and radiation may disperse this heat of reaction from the converter to the surroundings. Any other information, such as lube oil consumption rate, fuel gas composition, and ambient conditions, should also be recorded if available. Detailed records of catalyst maintenance and operating conditions can save time and money when diagnosing problems.

B. Physical Inspection

The catalyst should be inspected periodically for physical damage and fouling. If conversion efficiency or differential temperature (ΔT) decreases, or differential pressure (ΔP) increases, physical inspection should be performed. After removing the catalyst element, inspect for cell blockage or other obstruction. Excessive cell blockage must be cleaned before catalyst is re-installed.

A close visual inspection of the foil structures and outer frame of the element may indicate thermal deactivation. Typical signs of thermal deactivation are pinholes in the foil substrate, blue discoloration of the stainless steel frame, or in severe cases, a meltdown of the metal substrate.

C. Catalyst Analytical Testing

Laboratory analysis of the deactivated catalyst is a destructive test that includes x-ray diffraction (XRD), scanning electron microscopy (SEM) and spectrographic analysis. The analysis will provide data on the chemical composition of the catalyst including any potential poison agents and indicate any crystalline phase change in the washcoat due to thermal deactivation.

D. Catalyst Cleaning

Fouling and masking agents can often be removed by cleaning the catalyst. Monitoring conversion efficiencies and pressure drop across the catalyst will determine when a catalyst is in need of cleaning. Typical wash intervals are every 12 – 18 months of operation or 8,000 – 12,000 hrs of operation for a continuously running engine. There are several safe methods for catalyst cleaning. Two methods are vacuuming and/or washing the catalyst.

1. Vacuuming the catalyst face can sometimes clear fouling and ash buildup. This is a simple and direct procedure to restore catalyst activity.

2. Washing the catalyst can restore catalyst activity by reducing poisons, masking, fouling or inhibiting agents on the catalyst. If the catalyst does not respond to other treatments, washing the catalyst may be an effective method. A rinse in **de-ionized** water may be sufficient to remove some agents. A high pH wash is extremely effective in removing most organic resins, residues and deposits resulting from lube oil contamination. For inorganic compounds, a low pH wash will be effective. **DO NOT USE SOAP OR DETERGENTS WHEN WASHING!** Phosphates and other known poisons are present in many soaps and detergents. If you choose to wash your own catalysts, please contact your local authorities as there may be local and state regulations governing the disposal of the spent solutions. MIRATECH® provides a professional wash service for all makes of catalytic elements. This professional wash is highly recommended since it will prevent the accidental damage that frequently occurs when improper wash solutions or techniques are utilized.

E. Gasket Replacement

The gaskets around the catalyst element are critical to seal the element in the housing and prevent exhaust blow-by around the catalyst element. Gaskets should be changed when they have become brittle, friable, or otherwise degraded so that they do not seal well. This is typically done when the catalysts are washed or replaced. Instructions for proper installation of gaskets can be found in Appendix D. A blow-by rate of 5% around the catalyst perimeter can easily increase the downstream CO by 250 ppm and NOx by 150 ppm.

VII. TROUBLESHOOTING PROBLEMS WITH THE CATALYST

If a significant increase in post catalyst emissions is noticed, then the catalyst elements should be physically inspected for potential problems. Gaskets should also be inspected at this time. Missing, worn, or damaged gasket material should be replaced and the catalyst elements reinstalled according to the procedure in Appendix D. If this does not correct the problem, the following descriptions can be used to diagnose the catalyst condition.

COMPANY NAME:______________________________ ENGINE MODEL:____
LOCATION:___________________________________ RATED LOAD @ RPM:____
APPLICATION:________________________________ ENGINE ID#:____
CATALYTIC CONVERTER MAKE/MODEL:____
AIR/FUEL RATIO CONTROLLER MAKE/MODEL:____

TEST DATE	m/d/y						
ENGINE HOURS	(hrs)						
EMISSIONS PRE-CATALYST							
NO_X	(ppmvd)						
CO	(ppmvd)						
NMHC as CH_4	(ppmvd)						
O_2%	%						
EMISSIONS POST CATALYST							
NO_X	(ppmvd)						
CO	(ppmvd)						
NMHC as CH_4	(ppmvd)						
O_2%	%						
BASE EGO TARGETS							
Left Bank EGO1	(VDC)						
Right Bank EGO2	(VDC)						
EGO3	(VDC)						
OPERATING EGO VOLTAGES							
Left Bank EGO1	(VDC)						
Right Bank EGO2	(VDC)						
EGO3	(VDC)						
Control Valves Inlet Pressure	(PSIG)						
Valve Position Left Bank	% Open						
Valve Position Right Bank	% Open						
Catalyst Inlet Temperature	(°F)						
Catalyst Outlet Temperature	(°F)						
ΔP Across Converter Housing	(“ WC)						
Catalyst ΔP or Exhaust Pressure at Engine	(“ WC)						
Catalyst Washed or Replaced	(date)						
Catalyst Gasketed	(Y/N)						
Oxygen Sensors Replaced (2000 hr life)	(Y/N)						
Thermocouples Replaced (2 year life)	(Y/N)						
Catalyst Element Replaced	(Y/N)						
Spark Plugs Changed	(date)						
Ignition Timing	(°BTDC)						
Left Bank Exhaust Temperature	(°F)						
Right Bank Exhaust Temperature	(°F)						
Fuel Gas Pressure to Low Pressure Regulator	(PSIG)						
Fuel/Air Pressure to Carburetor	(“ WC)						
Manifold Pressure (vacuum/boost)	(“Hg/PSIG)						
Manifold Temperature	(°F)						
Engine Speed	(RPM)						
Engine Load	(bhp/kW)						

APPENDIX B

// RICE & OXIDATION CATALYST SPARE/REPLACEMENT PARTS LIST

Michigan CAT, Novi Engine Division
25000 Novi Road, Novi, MI 48375
Phone (248) 349-7050, Fax (248) 349-7508

Spare Parts for (2) G3520H Generators

QUANITY	Part Number	DESCRIPTION
2	105-9742	Air Filter (1)
4	393-1146	Air Filter (2)
2	350-7106	Alternator Belt (1)
8	1R-0726	Oil Filters (4)
6	7W-0482	2 Amp Fuse (3)
2	232-6314	60 Amp Fuse (1)
2	325-5216	10-Amp Fuse (1)
2	370-6128	20-Amp Fuse (1)
2	124-7716	4-Amp Fuse (1)

Note: All Caterpillar parts/components must be stored in á dry location above floor level ranging in temperatures between zero degrees to one hundred twelve degrees Fahrenheit.

IQ2/RCS2/RHS2 Replacement Parts

CATALYST HOUSING		CATALYST ELEMENT	GASKET KIT	NUT, BOLT, & GASKET KIT	CATALYST ELEMENT WASH
RCS2-aa10	IQ2-10	IQ-RE-10x	GS-IQ10	NBG-IQ10	IQ-10-E-WSH
RCS2-aa12	IQ2-12	IQ-RE-12x	GS-IQ12	NBG-IQ12	IQ-12-E-WSH
RCS2-aa14	IQ2-14	IQ-RE-14x	GS-IQ14	NBG-IQ14	IQ-14-E-WSH
RCS2-aa16	IQ2-16	IQ-RE-16x	GS-IQ16	NBG-IQ16	IQ-16-E-WSH
RCS2-aa18	IQ2-18	IQ-RE-18x	GS-IQ18	NBG-IQ18	IQ-18-E-WSH
RCS2-aa20	IQ2-20	IQ-RE-20x	GS-IQ20	NBG-IQ20	IQ-20-E-WSH
RCS2-aa22	IQ2-22	IQ-RE-22x	GS-IQ22	NBG-IQ22	IQ-22-E-WSH
RCS2-aa24	IQ2-24	IQ-RE-24x	GS-IQ24	NBG-IQ24	IQ-24-E-WSH
RCS2-aa26	IQ2-26	IQ-RE-26x	GS-IQ26	NBG-IQ26	IQ-26-E-WSH
RCS2-aa28	IQ2-28	IQ-RE-28x	GS-IQ28	NBG-IQ28	IQ-28-E-WSH
RCS2-aa30	IQ2-30	IQ-RE-30x	GS-IQ30	NBG-IQ30	IQ-30-E-WSH
RCS2-aa34	IQ2-34	IQ-RE-34x	GS-IQ34	NBG-IQ34	IQ-34-E-WSH
RCS2-aa36	IQ2-36	IQ-RE-36x	GS-IQ36	NBG-IQ36	IQ-36-E-WSH
RCS2-aa38	IQ2-38	IQ-RE-38x	GS-IQ38	NBG-IQ38	IQ-38-E-WSH
The above stock codes fit both RCS and RHS products. aa – Silencer diameter x –Catalyst Type (C, H, L, or U)					

VX Replacement Parts

CATALYST HOUSING	CATALYST ELEMENT	GASKET KIT	NUT, BOLT, & GASKET KIT	CATALYST ELEMENT WASH
VXC-1005-3.5-HSG	VX-RE-05XC	GS-VXC05	NBG-VXC05	VXC-05-E-WSH
	VX-RE-HALF05XC	GS-VXC05	NBG-VXC05	VXC-HALF05-E-WSH
VXC-1408-04-HSG	VX-RE-08XC	GS-VXC08	NBG-VXC08	VXC-08-E-WSH
	VX-RE-HALF08XC	GS-VXC08	NBG-VXC08	VXC-HALF08-E-WSH
VXC-1610-05-HSG	VX-RE-10XC	GS-VXC10	NBG-VXC10	VXC-10-E-WSH
	VX-RE-HALF10XC	GS-VXC10	NBG-VXC10	VXC-HALF10-E-WSH
Above stock codes fit VXC, VXH, and VXR product lines. Use “-2” after gasket or nut, bolt, gasket kits to denote a dual-catalyst kit.				

Z-Flow Replacement Parts

CATALYST ELEMENT	GASKET KIT	NUT, BOLT, & GASKET KIT	CATALYST ELEMENT WASH
ZXS-RE-FULL35cXx	GS-ZXSy	NBG-ZXSy	ZXS-FULL-E-WSH
ZXS-RE-HALF35cXx	GS-ZXSy	NBG-ZXSy	ZXS-HALF-E-WSH
ZXS-RE-FULLBLIND	GS-ZXSy	NBG-ZXSy	NA
Above stock codes fit ZCS, ZHS, and ZES product lines and are applicable for all housing sizes. c – cells per square inch (cpsi) (2 or 4) (2 = 200 cpsi (ONLY XL & XU), 4 = 400 cpsi) x – VORTEX® Catalyst Type (C, H, L, or U) y– Number of Catalyst Tracks (2,3,4, or 6)			

Ground Access / PT Replacement Parts

CATALYST ELEMENT	GASKET KIT	NUT, BOLT, & GASKET KIT	CATALYST ELEMENT WASH
RXS-RE-30c-S2424Xx	GS-S2424-y	NBG-S2424-y	RXS-S2424-E-WSH
RXS-RE-30c-S3624Xx	GS-S3624-y	NBG-S3624-y	RXS-S3624-E-WSH
RXS-RE-S2424BLIND	GS-S2424-y	NBG-S2424-y	NA
RXS-RE-S3624BLIND	GS-S3624-y	NBG-S3624-y	NA
Above stock codes fit RXSIGA and some PT product lines and are applicable for all housing sizes. c – cells per square inch (cpsi) (2 or 4) (2 = 200 cpsi (ONLY XL & XU), 4 = 400 cpsi) x – VORTEX® Catalyst Type (H, L, or U) y– Number of Catalyst Tracks (1, 2, 3, 4, or 6)			

APPENDIX C

// CORRECTIVE PROCEDURES

chemical composition of the catalyst including any potential poison agents and indicate any crystalline phase change in the washcoat due to thermal deactivation.

D. Catalyst Cleaning

Fouling and masking agents can often be removed by cleaning the catalyst. Monitoring conversion efficiencies and pressure drop across the catalyst will determine when a catalyst is in need of cleaning. Typical wash intervals are every 12 – 18 months of operation or 8,000 – 12,000 hrs of operation for a continuously running engine. There are several safe methods for catalyst cleaning. Two methods are vacuuming and/or washing the catalyst.

1. Vacuuming the catalyst face can sometimes clear fouling and ash buildup. This is a simple and direct procedure to restore catalyst activity.

2. Washing the catalyst can restore catalyst activity by reducing poisons, masking, fouling or inhibiting agents on the catalyst. If the catalyst does not respond to other treatments, washing the catalyst may be an effective method. A rinse in **de-ionized** water may be sufficient to remove some agents. A high pH wash is extremely effective in removing most organic resins, residues and deposits resulting from lube oil contamination. For inorganic compounds, a low pH wash will be effective. **DO NOT USE SOAP OR DETERGENTS WHEN WASHING!** Phosphates and other known poisons are present in many soaps and detergents. If you choose to wash your own catalysts, please contact your local authorities as there may be local and state regulations governing the disposal of the spent solutions. MIRATECH® provides a professional wash service for all makes of catalytic elements. This professional wash is highly recommended since it will prevent the accidental damage that frequently occurs when improper wash solutions or techniques are utilized.

E. Gasket Replacement

The gaskets around the catalyst element are critical to seal the element in the housing and prevent exhaust blow-by around the catalyst element. Gaskets should be changed when they have become brittle, friable, or otherwise degraded so that they do not seal well. This is typically done when the catalysts are washed or replaced. Instructions for proper installation of gaskets can be found in Appendix D. A blow-by rate of 5% around the catalyst perimeter can easily increase the downstream CO by 250 ppm and NOx by 150 ppm.

VII. TROUBLESHOOTING PROBLEMS WITH THE CATALYST

If a significant increase in post catalyst emissions is noticed, then the catalyst elements should be physically inspected for potential problems. Gaskets should also be inspected at this time. Missing, worn, or damaged gasket material should be replaced and the catalyst elements reinstalled according to the procedure in Appendix D. If this does not correct the problem, the following descriptions can be used to diagnose the catalyst condition.

A. Normal Condition

Catalyst Appearance/ Performance:	When inspecting the catalyst, note the brown to grayish color and the minimal amount of carbon or ash that indicates the catalyst is operating within the correct heat range and at the correct air/fuel ratio. Backpressure is less than or equal to the guaranteed value. In general, but not in every case, the temperature rise across the catalyst should be in the 25° (14°C) to 100°F (56°C) range for rich burn engines, and 5°F for lean burn engines. Typically, temperature rises in these ranges indicate that the reaction conversion of CO is greater than or equal to 90%.
Cause:	A normal and "healthy" engine environment.
Action Required:	NONE.

B. Carbon Fouled/Masked

Catalyst Appearance/ Performance:	Soft, black sooty deposits are easily detected and characteristic of carbon fouling. Symptoms of carbon fouling are high backpressure, low temperature rise, and reduced conversion performance. A high backpressure can cause damage to the catalyst, reduce engine load carrying capacity and increase fuel consumption. Misfiring of the engine could also cause burning of surface deposits.
Cause:	Possible causes of carbon fouling are clogging of the air cleaner, a carburetor problem, or too rich of an air/fuel ratio. A weak ignition voltage or extremely low cylinder compression can also contribute to carbon fouling.
Action Required:	Correct air/fuel ratio of the engine. Send catalyst element to MIRATECH® for a chemical wash. Check air filter, carburetor, and ignition system.

C. Ash Fouled/Masked

Catalyst Appearance/ Performance:	A gray/white powdery covering on the surface of the catalyst and plugging of the catalyst cells is ash fouling. High backpressure and lower than normal conversions are indicative of ash fouling.
Cause:	The ash on the catalyst originates in the engine oil. Frequent and heavy ash fouling could be indicative of excessive lube oil consumption.
Action Required:	Send catalyst element to MIRATECH® for a chemical wash. Lower the lube oil consumption rate and/or the sulfated ash and ZDP content of the engine oil.

D. Oil Fouled/Masked

Catalyst Appearance/ Performance:	The catalyst will appear from dark bronze to black in color. Symptoms of oil fouling are high backpressure, reduced conversion, plugging of cells of the catalyst, and high temperature shutdowns/alarms. In extreme cases, the catalyst may smell like engine oil.

Cause: Oil fouling is caused by too much oil entering the combustion chamber or a damaged turbocharger. Rings or cylinder walls that are badly worn often cause oil entering the combustion chamber. Oil may also be pulled into the chamber because of excessive clearance in the valve stem guides. A build up of crankcase pressure can force vapors past the rings and valve guides into the combustion chamber.

Action Required: Correct engine related problems.
Send catalyst element to MIRATECH® for a chemical wash. (This will only be effective if the catalyst is lightly fouled/masked.)

E. Overheated

Catalyst Appearance/ Performance: The catalyst has a clean, white powdery appearance. The substrate may have a blue tint. Pinholes can be observed in the substrate by holding the substrate up to the light. The catalyst's stainless steel frame has turned blue. Symptoms of overheating are high temperature shutdowns, reduced conversions, and physical changes to the integrity of the catalyst element.

Cause: This condition may be caused by excessive unburned fuel-air mixtures in the exhaust created by ignition misfire, sticking exhaust valve, or leaking intake manifold. Other fuel or ignition system related problems can also cause overheating.

Action Required: Correct engine malfunctions.
Replace the catalyst element.

VIII. TROUBLE SHOOTING PROBLEMS CAUSED BY THE ENGINE

A. Mechanical Damage

Symptoms: Low back pressure and low catalyst conversions.

Cause: Mechanical damage may be caused or accelerated by excess vibration or engine backfires, which have accidentally occurred.

Actions Required: It is recommended that a complete recalibration of all engine parameters be done to ensure correct engine operation. Inspect and possibly replace catalyst element.

B. Detonation

Symptoms: High temperature shutdown triggers and low conversion efficiencies.

Cause: Detonation applies extreme pressure on internal engine components. Major reasons for detonation include ignition timing advanced too far, lean air/fuel ratio mixture and insufficient fuel heating values. The aforementioned can lead to higher than normal temperatures, which, if not corrected, can cause permanent catalyst damage.

Actions Required:	Correct engine malfunctions. Replace catalyst element. Calibrate/inspect high temperature shut down switches.

C. Engine Related Problems

Exhaust Leaks:	Check all exhaust components for leaks including turbocharger boot, expansion joints, flanges, and sample ports. Crankcase ventilation should be routed after the catalyst or to the atmosphere or intake air with appropriate filters and drains.
Ignition Timing:	Check ignition timing with manufacturer's recommendations.
Ignition Misfire:	Check magneto, ignition coils, wiring, spark plugs, and firing order. A misfire will cause an unburned fuel-air mixture to enter the exhaust piping. CO in excess of 7,000 ppm with oxygen above 0.5% is a clear indication of a misfire.
Exhaust Valve Leaks:	Check exhaust valves with cylinder leak down test. A leaking exhaust valve will allow combustion byproducts to prematurely escape the cylinder. Leaking exhaust valves will produce higher levels of CO (7,000 to 9,000 ppm) while operating the engine at 0.5% oxygen.
Low Combustion:	Check the compression ratio. Low compression will create unstable combustion resulting in higher CO levels. Unstable combustion may also cause erratic swings in the oxygen sensor voltage output(s).
Low Load:	Low load simulates low compression, poor volumetric efficiency, and poor fuel economy based on the high vacuum in the intake manifold. Symptoms are very similar to low compression. Catalyst performance stability and conversion efficiency is tied directly to combustion stability within the engine.

D. Air/Fuel Ratio Controller Related Problems

To isolate problems relating to poor catalyst performance, it is often useful to set the engine's air/fuel ratio manually to rule out automatic air/fuel ratio controller problems. Using the engine manufacturer's suggested procedure, balance the engine on manifold absolute pressure (MAP). *On V-engines, both banks must be balanced.* Follow the Air/Fuel Ratio Controller manufacturer's guidelines to manually set the controller. Typical oxygen sensor voltage signals for rich burn engines are listed in the table found in Appendix H.

Improper Oxygen Target:	Controller must be fine tuned with an exhaust analyzer to determine the correct oxygen sensor target voltage.
Aged Oxygen Sensor(s):	The oxygen sensor(s) has an expected operating life of 2,000 hours and must be replaced at regular intervals as part of the preventive maintenance schedule. In general, voltage output declines with age, and sensor response becomes sluggish relative to changing exhaust chemistry.