

Guidance on CAM Plan for Compressor Engines

I. Introduction

Major facilities are required to renew Part 70 permits within 5 years of the initial issuance date. For many of these facilities, permit renewal will bring into force the Compliance Assurance Monitoring (CAM) rule (40 CFR Part 64), which was issued in October 1997. The rule, an important component of the Title V permitting program, specifically requires facilities to monitor the performance of their emission control equipment. CAM plans should build on monitoring approaches that are already in place. They should discuss what parameters will be monitored, and include a monitoring frequency and operating range for each parameter that will provide reasonable assurance of compliance with requirements of the permit and any standards that apply. CAM affects only major sources with relatively large emissions.

The oil & gas industry represents a large portion of facilities that are subject to the Air Quality Division (AQD) Title V Program. The AQD has estimated / identified a number of existing oil and gas facilities that are or will be subject to the CAM rule. This fact sheet discusses issues and emission sources common to these facilities. Its focus is on compressor engines equipped with either Non-Selective Catalytic Reduction (NSCR) or catalytic oxidation. Example CAM plans for these two systems are include in the appendices.

II. CAM Applicability

The CAM rule applies to each pollutant specific emission unit (PSEU) that meets a three-part test. The PSEU must:

- a. be subject to an emission limitation or standard, and
- b. use a control device to achieve compliance, and
- c. have pre-control emissions that exceed or are equivalent to the major source threshold.

Note that pre-control emission takes into account all federally-enforceable emissions reductions except for those resulting from control devices. For example, emission reductions that occur as a result of operating hour or throughput restrictions would be taken into account in determining potential pre-control device emissions. The rule defines “control devices” on a narrow interpretation that focuses on control equipment that removes or destroys air pollutants. This definition does not encompass all conceivable control approaches, but rather those types of control devices that may be prone to upset and malfunction, and that are most likely to benefit from monitoring of critical parameters to assure that they continue to function properly.

It is specifically worth mentioning for compressor engines that EPA agreed with a comment¹ that low NO_x burners on gas-fired turbines and controllers for the adjustment of air-to-fuel ratio should be included on the list of equipment that is not considered a “control device” under CAM because this equipment neither destroys nor removes air pollutants¹. Therefore, for compressor engines required by a permit to be equipped with air-to-fuel ratio (AFR) controllers, the agency accepts emissions after the controller as pre-control emissions for CAM applicability purposes.

Note that this does not change the definition of potential to emit for Title V permits, since it is related only to CAM applicability.

III. Required Elements of a CAM Plan

Monitoring plans are based on an assumption that there is a reasonable assurance of compliance with emissions limits so long as the emission unit is operated under the conditions anticipated, and the control equipment, which has been shown to be capable of complying, continues to be operated and maintained properly. Thus, Part 64 requires the monitoring of one or more indicators of the performance of the applicable control device and establishing appropriate ranges or designated conditions for the selected indicators. The operating ranges are established to provide a reasonable assurance of compliance for the anticipated range of operating conditions. The requirement to establish an indicator range provides the objective screening measure to indicate proper operation and maintenance of the emissions unit and the control technology. Failure to stay within the indicator range does not automatically indicate a failure to satisfy applicable requirements. However, it does indicate the need for the owner or operator to evaluate and determine whether corrective action is necessary to return operations within design parameters, and to act upon that determination as appropriate.

In summary, a CAM plan must:

- a. Describe the indicators to be monitored;
- b. Describe the ranges of the process to set indicator ranges;
- c. Describe the performance criteria for the monitoring, including:
 1. Specifications for obtaining representative data
 2. Verification procedures to confirm the monitoring device's operational status
 3. Monitoring frequency
 4. Data averaging period;
- d. Provide a justification for the use of parameters, ranges, and monitoring approach;
- e. Provide emissions test data; and, if necessary,
- f. Provide an implementation plan for installing, testing, and operating the monitoring device.

IV. Control Technologies for Reciprocating Internal Combustion Engines (RICE)

Reciprocating internal combustion engines (RICE) are classified according to operating conditions as stoichiometric, rich-burn, or lean-burn, based on their inlet air-to-fuel ratio and exhaust oxygen content. Stoichiometric engine operation is defined as having the chemically correct amount of air in the combustion chamber during combustion. A rich-burn engine is characterized by excess fuel in the combustion chamber during combustion and lower exhaust oxygen concentrations. A lean-burn engine, on the other hand, is characterized by excess air in the combustion chamber during combustion, which results in higher exhaust oxygen concentration³. In practice, a rich-burn engine is an engine operated with an exhaust oxygen content less than 4 percent by volume (any naturally aspirated engine), and a lean-burn engine is an engine operated with an exhaust oxygen content of 4 percent by volume or greater (any turbocharged engine).

Emissions characteristics of these different engine types vary according to their air-to-fuel ratio, and therefore require different emission control technologies. The following table outlines the emission control technologies available for the different engine types⁴.

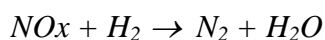
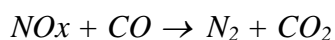
Engine Operation	Control Technology	Target Pollutants
Rich-burn	NSCR Catalyst (Three-way)	NO _x , CO, VOC
Stoichiometric	NSCR Catalyst (Three-way)	NO _x , CO, VOC
Lean-burn	Oxidation Catalyst (Two-way)	CO, VOC
	Lean-NO _x Catalyst	NO _x , CO, VOC
	SCR Catalyst	NO _x
	Ceramic Coating	NO _x , CO, VOC

This guidance will deal specifically with NSCR and oxidation catalysts, because they are the technologies most commonly used for compressor engines in the oil and gas industry.

V. CAM Plan Guidance for Non Selective Catalytic Reduction (NSCR)

A. General Description of NSCR

An NSCR system reduces NO_x, CO, and hydrocarbon (VOC) emissions from a rich-burn engine when the air-to-fuel ratio is near stoichiometric (14.7 to 1). When a rich-burn engine is tuned strictly for performance, oxygen is in the 1% to 3% range. At this AFR, CO and hydrocarbon emissions are low and NO_x is high, because the engine is running hot for maximum efficiency. When using an NSCR system, the engine must be operated richer so that an increase in reducing agents (CO and hydrocarbons) occurs. In addition, the NSCR must be operated at a temperature adequate to accomplish NO_x reduction, typically at least 750°F. The catalyst is designed to produce the following reactions:



If there is too much oxygen in the exhaust, the preferential reaction in the catalytic converter is the oxidation of CO or hydrocarbon rather than the reduction of NO_x. Thus, with NSCR, the oxygen concentration should always be less than 1%, and preferably under 0.5%. The air-to-fuel ratio controller uses an oxygen sensor placed in the exhaust stream near the catalyst inlet as a feedback signal to keep the AFR at the optimum set point. The sensor is particularly sensitive to oxygen concentrations below 1%.

Some conditions that can reduce catalytic activity over time are thermal degradation, poisoning, or masking. Thermal degradation is caused by sintering of the wash coat, which closes the pores, thereby reducing catalyst surface area. Sintering can occur slowly over time, or quickly if the catalyst is operated at a temperature that is too high. Too much sulfur or phosphate in the engine oil or fuel can cause poisoning of the catalyst. Masking occurs when soot is deposited on

the catalyst because the engine is burning oil. Part 70 permits typically include requirements to control sulfur content of fuel.

B. Performance Indicators and Ranges

40 CFR §64.3(a)(1) states that the owner or operator shall design the monitoring to obtain data for one or more indicators of emission control performance for the control device, any associated capture system, and processes at a pollutant-specific emissions unit. Indicators of performance may include, but are not limited to, direct or predicted emissions, process and control device parameters that affect control device (and capture system) efficiency or emission rates, or recorded findings of inspection and maintenance activities conducted by the owner or operator.

As a minimum requirement, the following parameters that directly affect the performance of an NSCR are chosen as performance indicators: oxygen content of the exhaust gas, exhaust gas temperature, and pressure drop across the catalyst.

a. Oxygen Content of Gas into the Catalyst

As previously discussed, the oxygen content of the engine exhaust gas indicates if the engine is running as rich as is required for proper performance of the NSCR (typically exhaust gas oxygen less than 0.5%). Therefore, oxygen content of gas into the catalyst should be selected as a performance indicator.

Oxygen content is typically measured using an oxygen sensor that creates an output voltage inversely proportionally to the oxygen content⁵. The output voltage range (typically 0.1 to 0.9 volts in conditions above 650 °F) is site-specific and must be set by using an exhaust gas analyzer to determine the set-point voltage that results in the best emission performance.⁵

In normal operation, the output voltage will vacillate around the set-point and the AFRC will adjust the step motor to bring the voltage back toward the set-point. When the voltage is above the set-point, the system is richer than desired, and the stepper position is increased to further restrict fuel flow to the carburetor. Conversely, when the sensor voltage is below the set-point, the system is leaner than desired, and the stepper position is decreased to increase fuel flow. In most cases, an alarm will be triggered if the position of a stepper valve is at the minimum travel limit (indicating the engine is too rich and the controller cannot close the valve any further) or maximum travel limit (indicating that the engine is too lean and the controller cannot open the valve any further to enrich the mixture)⁵.

The minimum requirement is to monitor oxygen content of gas into the catalyst with a range of less than 0.5%. Since oxygen content is not displayed directly, each of the following three options are considered to satisfy minimum requirement:

1. Use a portable analyzer to determine the voltage range that results in compliance with permit emission limits and oxygen content of less than 0.5%. The determination should be repeated whenever the oxygen sensor is replaced. Utilize an alarm system that can notify a field office when the AFRC is unable to

bring the voltage back to the set-point, as indicated by the alarm sounding for a significant period of time (such as 30 minutes). Such excursions should trigger a site visit, corrective action, logging, and reporting in the semiannual reports.

2. Use a portable analyzer to determine the output voltage range that results in compliance with permit emission limits and oxygen content of less than 0.5%. The determination should be repeated whenever the oxygen sensor is replaced. Manually record the voltage daily during workdays to show that it remains within the predetermined range. Excursions should trigger corrective action, logging, and reporting in the semiannual reports.

3. Use a portable analyzer to determine oxygen content range that results in compliance with permit emission limits and oxygen content of less than 0.5%. The determination should be repeated whenever the oxygen sensor is replaced. Between replacements, use a portable analyzer to measure oxygen content monthly to show that it remains within the predetermined range. Excursions should trigger corrective action, logging, and reporting in the semiannual reports.

b. Exhaust Gas Temperature

As mentioned in the overview of NSCR, sintering can occur quickly if the catalyst is operated at a temperature that is too high, and the damage to the catalyst unit would lower or eliminate its effectiveness. On the other hand, a temperature that is too low will interfere with the desired chemical reactions. 40 CFR Part 63, Subpart ZZZZ requires that NSCR-equipped four-stroke rich-burn stationary RICE subject to the formaldehyde emissions standard demonstrate compliance by monitoring the catalyst inlet temperature, and maintaining it within a range of 750°F to 1,250°F. In an example CAM Plan⁶ for engines equipped with NSCR, EPA also selected inlet temperature as a performance indicator with the same range. Based on this information, inlet temperature should be included as a performance indicator, with a range of 750°F to 1,250°F.

EPA's NSCR example⁶ also selected outlet temperature as a performance indicator with a range of 800°F – 1,300°F. The catalyst outlet temperature indicates not only the engine exhaust temperature, but also excessive heating of the catalyst. A requirement to monitor both the catalyst inlet and outlet temperatures is intended to ensure the preferred temperature increase across the catalyst bed.

However, temperature increase across the catalyst is highly site-specific. Some engine/catalyst combinations do not exhibit a significant temperature increase. The catalytic reactions include both exothermic oxidation of CO and hydrocarbons and endothermic NOx reduction. With lower-temperature exhaust or lower hydrocarbon concentrations, a large change in temperature may not occur across the catalyst.⁷ A smaller temperature change will also result if pollutant concentrations in the exhaust are low.

In addition, when 40 CFR Part 63, Subpart ZZZZ was proposed, it included the temperature rise across the catalyst as an indicator. EPA dropped this indicator in the final rule because they agreed with comments that this indicator most likely would not provide an accurate representation of how the catalyst is performing (69 FR 33493).⁸

Based on this information, the minimum requirement for exhaust temperature should be to monitor either the catalyst inlet temperature or the catalyst outlet temperature. The catalyst outlet temperature range should normally be set as 800°F – 1300°F. An individual facility may make a site-specific determination of the appropriate exhaust temperature range, as justified by on-site testing and/or manufacturer's recommendation. We do not discourage facilities from monitoring temperature rise across the catalyst if appropriate for the engine's operating conditions.

c. Pressure Drop Across the Catalyst

Pressure drop across the catalyst should be used as a performance indicator, because a change in pressure drop can indicate that the catalyst is becoming fouled or channeled, and therefore lowering the effectiveness of the unit. This indicator was also selected in the EPA NSCR example⁶ and 40 CFR Part 63, Subpart ZZZZ. In the preamble of the Federal Register notice for Subpart ZZZZ,⁸ EPA justified its decision to require monitoring of the pressure drop across the catalyst based on information gathered from catalyst vendors that a pressure drop that deviates by more than 2 inches of water from the pressure drop measured during the initial performance test indicates that the catalyst may be damaged or fouled (69 FR 33492).

For the purpose of CAM, a benchmark pressure drop must be established. If no benchmark was previously established, the first pressure drop reading obtained after a permit with an approved initial CAM plan is issued should be used as a benchmark for existing catalyst. For fresh catalyst or reinstalled catalyst, a pressure drop reading is required immediately after the installation, and this reading should be used as the benchmark. The CAM should set an acceptable range for the pressure drop across the catalyst as a deviation of less than 2 inches of water from the benchmark.

C. Performance Criteria

The CAM Rule includes several performance criteria in order to assure that the data generated by the monitoring present valid and sufficient information on the actual conditions being monitored. The monitoring plan must meet minimum performance specifications, quality assurance and control requirements, monitoring frequency requirements, and data availability requirements.

a. Data Representativeness

The monitoring plan must include location and installation specifications (if applicable) to ensure that the data obtained are representative of the emissions or parameters being monitored. See the example in Appendix A for details.

b. Quality Assurance and Control (QA/QC)

QA/QC is required to ensure the continuing validity of the data.

The oxygen sensor should be replaced quarterly or after 2,200 hours of operation for units not in continuous operation. The AFRC should have an oxygen sensor diagnostic. When the sensor is replaced, the voltage output set-point should be redetermined by using an exhaust analyzer to show compliance with permit emission limits and oxygen content of less than 0.5%.

Exhaust gas temperature thermocouples should be visually checked quarterly and tested for performance annually. A thermocouple should have minimum accuracy within $\pm 5^{\circ}\text{F}$ per manufacturer's specifications.

The pressure gauge(s) (if applicable) used to measure pressure drop across the catalyst should be calibrated quarterly. For facilities that measure pressure drop manually with water manometers or other devices, the device should be checked before measurement of the pressure drop. The pressure drop measurements should be accurate within ± 0.25 in. H_2O .

c. Inspection and Preventive Maintenance (IPM)

An IPM plan must be submitted with the CAM Plan. IPM should be performed on the emissions control and monitoring system, including the catalyst, thermocouples, oxygen sensor, and pressure gauge(s) (if applicable).

Engine emissions are directly influenced by a number of factors that affect combustion temperature and efficiency, including the engine timing, the type and heat-content of the fuel, the ambient air temperature and relative humidity, the fuel temperature, and changes in load. Therefore, the IPM plan should also address performance of the engine and the air-to-fuel ratio controller.

For engines utilizing NSCR, an AFRC is used to automatically adjust for changes in air and fuel conditions. However, the range of adjustment of most AFRCs is limited. In some cases, the AFRC is unable to fully compensate if the load or fuel heat-content changes significantly, which typically results in the AFRC setting off an alarm. Inability to compensate may result in the engine prematurely detonating or misfiring. Corrective action may be required, such as adjusting the engine timing to a different setting at which the AFRC can adequately adjust the air-to-fuel ratio over the expected range of fuel heat content and loading.

The timing adjustment moves the ignition event to later or earlier in the power stroke, when the piston has begun moving downward. Because the combustion chamber volume is not at its minimum or maximum, the peak flame temperature will be either reduced or increased. This temperature change also changes the amount of thermal NO_x formed. The timing setting is site-specific, based on the fuel heat-content and the expected load on the engine. Once the timing is set, the AFRC is adjusted so that it can compensate for the range of other expected changes in air and fuel over which the engine is expected to operate. If significant changes in fuel heat-content or loading occur, the timing must be reset and the AFRC again adjusted to the new-operating conditions. These procedures should be covered in the IPM Plan and noted in the CAM Plan.

Records must be maintained to document weekly and monthly IPM. An example IPM plan has been included in Appendix A.

d. Frequency of Monitoring and Data Collection Procedures

The CAM Rule requires that the monitoring frequency be designed to obtain data at intervals that are, at a minimum, commensurate with the time period over which an excursion from an indicator range is likely to be observed. The rule states that for larger emissions units, monitoring data must be collected four or more times per hour. This applies to those units that, by themselves, are classified as a major source despite controls. For other emissions units, the monitoring must include some data collection at least once per 24-hour period. See 40 CFR §64.3(b)(4)(ii) & (iii) for details.

(1) Oxygen Content

Oxygen content should be monitored continuously by oxygen sensor voltage output. Recording frequency is based on the chosen option as listed Section V.B.a.

(2) Catalyst Inlet and/or Outlet Temperature

Catalyst inlet or outlet temperature should be monitored continuously. 40 CFR Part 63, Subpart ZZZZ also requires continuous monitoring and recording for catalyst inlet temperature. Under the CAM plan, data should be recorded continuously (with strip chart or digital data recorder, etc.) for large units (after-control emission exceeding 100 TPY) and the 4-hour rolling average of the valid data used to compare against the indicator range. For other units with controlled emissions less than 100 TPY, recording the temperature once per day during workdays is acceptable.

(3) Pressure Drop

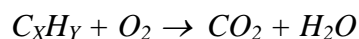
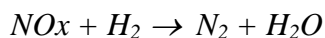
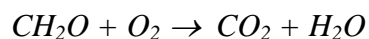
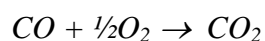
40 CFR Part 63, Subpart ZZZZ requires that pressure drop across the catalyst be measured monthly. 40 CFR §64.4(b) states that if an owner or operator relies on “presumptively acceptable monitoring,” no further justification for that monitoring is necessary, other than an explanation of how that monitoring applies to the unit in

question. Presumptively acceptable monitoring includes monitoring included for standards that are exempt from this part under §64.2(b)(1)(i): “Emission Limitations or standards proposed by the Administrator after November 15, 1990 pursuant to section 111 or 112 of the ACT.” Monitoring required by MACT Standards is presumptively acceptable monitoring for CAM, so monthly measurement for pressure drop is acceptable.

VI. CAM Plan for Oxidation Catalyst

A. General Description of Oxidation Catalyst

An Oxidation Catalyst system is used to reduce emissions of CO, formaldehyde (CH₂O), and unburned hydrocarbons. The oxidation catalyst system is designed mainly for emission reductions from a lean-burn engine, which typically has an air-to-fuel ratio greater than 14.7 to 1. Oxygen contents in the exhaust gas of the lean-burn engine are usually more than 4%, and are typically in a range of 5% to 15%. In order for an oxidation catalyst system to accomplish CO reduction, the exhaust temperature from the lean-burn engine should be at least 450°F. Generally, the following reactions take place in the oxidation catalyst:



Similar to NSCR catalysts, the performance of the oxidation catalyst is affected by catalytic deactivation, thermal degradation, poisoning, sintering, or masking.

B. Performance Indicators and Ranges

a. Exhaust Gas Temperature

As mentioned in the General Description, oxidation catalyst requires minimum inlet temperature of 450°F to reduce formaldehyde emissions. Therefore, the typical minimum inlet temperature for the oxidation catalyst should be at least 450°F. 90% of CO reduction can be achieved at 450°F and 60% to 80% of CH₂O reduction can be achieved at 550 °F according to a catalyst manufacturer’s report. EPA’s “MACT Compliance Handbook for RICE⁹” requires a catalyst inlet temperature greater than or equal to 450°F, and less than or equal to 1,350°F. 1,350°F is a typical temperature used as an upper limit to assure both proper oxidation of unburned hydrocarbons and protection of the oxidation catalyst.

Monitoring exhaust temperature at either the inlet or outlet of the catalytic unit can ensure proper performance of the catalyst. The temperature rise across oxidation catalyst could be set as an indication of catalyst performance. However, the temperature rise is significantly affected by ambient conditions and some oxidation catalysts show small temperature rise. Therefore, the minimum requirement is to monitor either the catalyst inlet, with a range of 450°F to 1,350°F, or outlet temperature, with a range of 500°F to 1,350°F. An individual facility may make a site-specific determination of the appropriate exhaust temperature range, as justified by on-site testing and/or manufacturer's recommendation.

b. Pressure Drop Across the Catalyst

As with NSCR, the pressure drop across the catalyst should be used as a performance indicator. The rationale for this performance indicator is the same as that for the NSCR catalyst. If the pressure drop across the catalyst deviates by more than 2 inches of water from the pressure drop across the catalyst measured during the initial performance test, the catalyst may be damaged, fouled, or channeled.

For the purpose of CAM, a benchmark pressure drop must be established. If no benchmark was previously established, the first pressure drop reading obtained after a permit with an approved initial CAM plan is issued should be used as the benchmark for existing catalyst. For fresh catalyst or reinstalled catalyst, a pressure drop reading is required immediately after installation, and should be used as the benchmark. The CAM should set an acceptable range for the pressure drop across the catalyst as a deviation of less than 2 inches of water from the benchmark.

C. Performance Criteria

The general requirements for performance criteria are the same as those for NSCR. This section describes any minimum performance specification, quality assurance and control requirements, monitoring frequency requirements, and data availability requirements that are specific to oxidation catalytic reduction.

a. Data Representativeness

See the example in Appendix B for details of location and installation specifications designed to ensure that the data obtained are representative of the emissions or parameters being monitored.

b. Quality Assurance and Control (QA/QC)

QA/QC is required to ensure the continuing validity of the data.

Exhaust gas temperature thermocouples should be visually checked quarterly and tested for performance annually. A thermocouple should have minimum accuracy within $\pm 5^\circ\text{F}$.

The pressure gauge(s) (if applicable) used to measure pressure drop across the catalyst should be calibrated quarterly. For facilities that measure pressure drop manually with water manometers or other devices, the device should be checked before measurement of the pressure drop. The pressure drop measurements should be accurate within ± 0.25 in. H₂O.

c. Inspection and Preventive Maintenance (IPM)

An IPM plan must be submitted with the CAM Plan. IPM should be performed on the engine and emissions control and monitoring systems, including the catalyst, thermocouples and pressure gauge(s). Records must be maintained to document weekly and monthly IPM. An example IPM plan has been included in Appendix B.

d. Frequency of Monitoring and Data Collection Procedures

Frequency of monitoring and data collection for catalyst inlet and/or outlet temperatures and pressure drop across the oxidation catalyst are similar to NSCR (see the "Frequency of Monitoring and Data Collection Procedures" section for NSCR).

(1). Catalyst Inlet and/or Outlet Temperature

Catalyst inlet or outlet temperature should be monitored continuously. 40 CFR Part 63, Subpart ZZZZ also requires continuous monitoring and recording for catalyst inlet temperature. Under the CAM plan, data should be recorded continuously (with strip chart or digital data recorder, etc.) for large units (after-control emission exceeding 100 TPY) and the 4-hour rolling average of the valid data used to compare against the indicator range. For other units with controlled emissions less than 100 TPY, recording the temperature once per day during workdays is acceptable.

(2). Pressure Drop

Similar to the rationale for monitoring pressure drop in the NSCR section, monthly measurement for pressure drop across the oxidation catalyst is acceptable for CAM purposes.

REFERENCES

1. Compliance Assurance Monitoring Rulemaking (40 CFR Parts 64, 70, and 71), Responses to Public Comments (Part III). Clean Air Act Information Network, 10/2/1997.
2. Compliance Assurance Monitoring; Final Rule Notice (62 FR 54900, 10/22/97).
3. State of Art (SOTA) Manual for Reciprocating Internal Combustion Engines. Department of Environmental Protection, State of New Jersey, 2003.

4. Emission Control Technology for Stationary Internal Combustion Engines, Status Report. Manufacturers of Emission Controls Association, July 1997.
5. Altronic Air/Fuel Ratio Controller Operating Manuals, <http://www.altronicinc.com>.
6. Example Compliance Assurance Monitoring: Catalyst for NO_x Control – Facility G. EPA Document.
7. How to Apply Non-Selective Catalytic Reduction Systems to Rich Burn Engines Successfully. Southern California Gas Company, Presented at 2002 CMRC Gas Machinery Conference, October 7-9, 2002.
8. National Emission Standards for Hazardous Air Pollutants for Stationary Reciprocating Internal Combustion Engines; Final Rule (69 FR 33474, 6/15/2004).
9. MACT Compliance Handbook for RICE NESHAP, OAQPS, US EPA, July, 2004
10. Technical Guidance Document: Compliance Assurance Monitoring. U.S. Environmental Protection Agency, August 1998.
11. AP 42, Fifth Edition, Volume I, Chapter 3: Stationary Internal Combustion Sources.

Appendix A: Example CAM Plan for Non Selective Catalytic Reduction (NSCR)

Note: This is a sample CAM Plan. Indicators and indicator ranges were selected as minimum requirement based on our research of EPA documents and technical papers. The plan includes a Monitoring Approach Justification and a sample Inspection and Preventive Maintenance Plan. However, a facility's CAM Plan should be customized to reflect actual site conditions. Indicators and indicator ranges included in the monitoring approach should be determined during testing and refined during periodic monitoring. AQD expects CAM plans to have tighter acceptable temperature ranges, based on actual site conditions. The agency will also consider alternative monitoring methods, if solid documentation is provided that demonstrates a link between proper operation, emissions, and the proposed monitoring.

I. Background

A. Emissions Unit

Description:	Rich Burn Natural Gas Compressor Engines
AQD ID:	C1, C2
Facility:	Compressor Station Any town, OK

B. Applicable Requirement, Emission Limits, and Monitoring Requirements

Requirement:	AQD Permit No. 99-XXX-TVR
Emission limits:	
NOx:	2.0 g/hp/hr
CO	3.0 g/hp/hr
Monitoring requirements:	Oxygen percent of gas into catalyst (O ₂ %), Pressure drop across catalyst, temperature into or out of catalyst, inspection and preventive maintenance program

C. Control Technology:

Non-selective catalytic reduction (NSCR w/AFRC)

II. Monitoring Approach

The key elements of the monitoring approach for both engines are presented in Table A.

III. Response to Excursion

Excursions outside of the indicator ranges will trigger an inspection, corrective action, and reporting. Maintenance personnel will inspect the compressors, the catalytic converters, and the air-to-fuel ratio controllers within 24 hours of receiving notification of an excursion and make

needed repairs as soon as practicable. See Table A for additional details. Operation will return to normal upon completed corrective action.

TABLE A. MONITORING APPROACH

	Indicator No. 1	Indicator No. 2	Indicator No. 3*	Indicator No 4*
I. Indicator	O ₂ from engines	Pressure drop across the catalyst.	Temperature of exhaust gas into catalyst.	Temperature of exhaust gas out of catalyst.
Measurement Approach	O ₂ concentration into the catalyst is measured continuously using an in-line O ₂ sensor.	Pressure drop across the catalyst beds is measured monthly using a differential pressure gauge.	Exhaust gas temperature is measured continuously using an in-line thermocouple.	Exhaust gas temperature is measured continuously using an in-line thermocouple.
II. Indicator Range	The indicator range is O ₂ % < 0.5% Excursion is an alarmed event lasting 30 minutes or longer. Excursions trigger corrective action, logging and reporting in semiannual report.	The indicator range is a pressure drop deviation of less than 2 in. H ₂ O from the benchmark. Excursions trigger corrective action, logging and reporting in semiannual report	The indicator range is above 750°F, but lower than 1,250°F. Excursions trigger corrective action, logging and reporting in semiannual report.	The indicator range is above 800°F, but lower than 1,300°F. Excursions trigger corrective action, logging and reporting in semiannual report.
III. Performance Criteria				
A. Data Representativeness	Observations are performed at the engine exhaust while the engine is operating.	Pressure drop across the catalyst is measured at the catalyst inlet and exhaust. The minimum accuracy of the device is ±0.25 in. H ₂ O.	Temperature is measured at the inlet to the catalyst by a thermocouple. The minimum accuracy is ±5°F.	Temperature is measured at the outlet of the catalyst by a thermocouple. The minimum accuracy is ±5°F.
B. QA/QC – Practices and Criteria	O ₂ sensor replaced quarterly.	Pressure gauge calibrated quarterly. Pressure taps checked monthly for plugging.	Thermocouple visually checked quarterly and tested annually.	Thermocouple visually checked quarterly and tested annually.
C. Monitoring Frequency	O ₂ percent monitored continuously.	Pressure drop is measured monthly.	Temperature is measured continuously.	Temperature is measured continuously.
D. Data Collection Procedures	O ₂ is measured whenever the oxygen sensor is replaced. Records are maintained to document alarmed events and any required maintenance.	Records are maintained to document monthly readings and any required maintenance.	A strip chart records the temperature continuously.	A strip chart records the temperature continuously.
E. Averaging period	None, not to exceed maximum.	None, not to exceed maximum.	4-hour rolling average.	4-hour rolling average.

*Minimum requirement is to include at least one of these two indicators.

Monitoring Approach Justification

I. Background

The monitoring approach outlined here applies to the non-selective catalysts (NSCR) on compressor engines C1 and C2 at this facility. The NSCR lowers NO_x, as well as CO, CH₂O, and hydrocarbon emissions. The catalysts are passive units and have no mechanical components.

II. Rationale for Selection of Performance Indicators

The oxygen content of the engine exhaust gas was selected as a performance indicator because the gas must have less than 0.5 percent oxygen as it enters the catalyst. Oxygen can interfere with proper reactions and oxygen content indicates if the engine is running rich as is required. Oxygen content is typically measured using an oxygen sensor that creates an output voltage inversely proportionally to the oxygen content.

The pressure drop across the catalyst is measured monthly. A significant change in pressure drop from the benchmark can indicate that the catalyst is becoming fouled, slowing gas flow through the unit, and lowering the effectiveness of the unit.

Temperature into or out of the unit is measured because temperature excursions can indicate problems with engine operation and can prevent the chemical reduction from taking place in the catalyst bed. An exhaust gas temperature that is too low reduces the activity of the intended chemical/catalyst reaction. A temperature that is too high can indicate engine problems and can damage the catalyst unit.

Implementation of an engine and catalyst inspection and preventive maintenance (IPM) program provides assurance that the engine and catalyst are in good repair and are being operated as anticipated. Once per week, proper operation of the engine is verified to ensure that the catalysts aren't being fouled or damaged. Proper operation of the engine also facilitates catalyst reactions. Other items on the daily IPM checklist include inspecting the air-to-fuel ratio controller, visual inspection of probes to ensure there is no clogging, and inspection of temperature gauges and chart recording devices. The inspection and preventive maintenance plan contains a schedule for replacing oxygen sensors quarterly or every 2,200 hours of operation.

III. Rationale for Selection of Indicator Ranges

The output voltage range (typically 0.1 to 0.9 volts above 650°F) is site-specific and must be set by using an exhaust gas analyzer to determine the set-point voltage that results in the best emission performance. An alarm will be triggered if the position of an AFRC stepper valve is at the minimum travel limit (indicating the engine is too rich and the controller cannot close the valve any further) or maximum travel limit (indicating that the engine is too lean and the controller cannot open the valve any further to enrich the mixture). The field office will receive notification when the alarm sounds for 30 minutes. Such excursions should trigger corrective action, logging, and reporting in the semiannual reports.

The indicator range for the catalyst pressure drop is a pressure drop that deviates less than 2 inches of H₂O from the benchmark. This range was selected based on the manufacturer's specifications. A change in pressure drop indicates fouling of the catalyst and requires either cleaning or replacing of the catalyst bed.

Each catalyst bed is designed to work optimally at recommended temperatures. The temperature ranges selected are based on the catalyst manufacturer's suggested operating parameters for optimal chemical reaction.

The most recent periodic monitoring, using AQD's approved portable monitoring protocol, was conducted on July 8-9, 2004. During this test, the average measured NO_x emissions were 1.6 g/hp/hr for engine C1 and 1.7 g/hp/hr for engine C2 (both were below the compliance limit of 2.0 g/hp/hr). Oxygen content from the engine exhaust averaged 0.2 percent during testing. Temperature averaged 1,000°F for the inlet and 1,100°F for the outlet temperature. Pressure drop across the unit averaged 0.8 inches of H₂O. This data point will serve as the benchmark for monitoring changes in the pressure drop. The complete test results are documented in the test report.

Inspection and Preventive Maintenance Plan

The following is an inspection and preventive maintenance plan for engines equipped with NSCR. The plan is designed to ensure optimum operation of the converters, avoid situations that could cause converter damage and identify problems in a timely manner.

I. Engine Operations

Proper engine operation is critical to the performance of catalytic converters. Emissions are directly influenced by a number of factors that affect combustion temperature and efficiency, including the engine timing, the type and heat-content of the fuel, the ambient air temperature and relative humidity, the fuel temperature, and changes in load. An Air-to-Fuel Ratio Controller (AFRC) is used to automatically adjust for changes in these factors. However, the range of adjustment of most AFRCs is limited. Each engine is equipped with an alarm system that sounds if the AFRC is unable to fully compensate for significant changes in the load or fuel heat-content that may result in the engine prematurely detonating or misfiring. If an engine misfires, it produces high catalyst temperatures because the unburned air/fuel mixture burns when it contacts the catalyst. Several misfiring cylinders can produce enough heat to cause permanent damage to the catalyst.

Preventive Maintenance: Engines will be checked weekly for proper operation and for misfiring conditions. Corrective action may include adjusting the engine timing to a different setting at which the AFRC can adequately adjust the air-to-fuel ratio over the expected range of fuel heat content and loading. The timing setting is site-specific, based on the fuel heat-content and the expected load on the engine. Once the timing is set, the AFRC is adjusted so that it can compensate for the range of other expected changes in air and fuel over which the engine is expected to operate. If significant changes in fuel heat-content or loading occur, the timing must be reset and the AFRC again adjusted to the new operating conditions.

II. Over-Temperature System

The converter is equipped with an over-temperature system that protects the catalyst from excessive temperature conditions caused by engine misfires.

Preventive Maintenance: The catalyst over-temperature system will be tested annually to ensure it is working.

III. Exhaust Temperature

For efficient converter operations, the NSCR inlet gas must be above 750°F at all times, with a maximum of 1,250°F; or the NSCR outlet gas must be above 800°F at all times, with a maximum of 1,300°F.

Preventive Maintenance: The thermocouples measuring the exhaust temperature will be tested annually. The thermocouple probes will be visually inspected quarterly.

IV. Air-to-Fuel Ratio Controller

The air-to-fuel ratio controllers are used in conjunction with catalytic converters to control the oxygen content of the exhaust. The air/fuel ratio controllers are set to control oxygen content to less than 0.5%.

Preventive Maintenance: The air-to-fuel ratio set-points will be checked and adjusted quarterly and the oxygen sensors will be replaced on an as-needed basis, but at least quarterly or every 2200 hours of operation. The controller will be checked weekly to ensure that the alarm set-points are correct.

V. Performance Monitoring

Catalyst temperature will be used to monitor catalyst performance.

Preventive Maintenance: A portable analyzer will be used quarterly (semiannually or annually) to test the NO_x and CO emission rates in the exhaust gas.

Appendix B: Example CAM Plan for Oxidation Catalyst

Note: This is a sample CAM Plan. Indicators and indicator ranges were selected as minimum requirement based on our research of EPA documents and technical papers. The plan includes a Monitoring Approach Justification and a sample Inspection and Preventive Maintenance Plan. However, a facility's CAM Plan should be customized to reflect actual site conditions. Indicators and indicator ranges included in the monitoring approach should be determined during testing and refined during periodic monitoring. AQD expects CAM plans to have tighter acceptable temperature ranges, based on actual site conditions. The agency will also consider alternative monitoring methods, if solid documentation is provided that demonstrates a link between proper operation, emissions, and the proposed monitoring.

I. Background

A. Emissions Unit

Description:	Lean Burn Natural Gas Compressor Engines
AQD ID:	CE1, CE2
Facility:	Compressor Station
	Any town, OK

B. Applicable Requirement, Emission Limits, and Monitoring Requirements

Requirement:	AQD Permit No. 99-XXX-TVR
Emission limits:	
CO	3.0 g/hp/hr
CH ₂ O	0.18 g/hp/hr
Monitoring requirements:	Pressure drop across catalyst, temperature into or out of catalyst, inspection and preventive maintenance program

C. Control Technology:

Oxidation catalyst

II. Monitoring Approach

The key elements of the monitoring approach are presented in Table B.

III. Response to Excursion

A. Excursions outside of the indicator ranges will trigger an inspection, corrective action, and reporting. Maintenance personnel will inspect the compressors and the catalytic converters within 24 hours of receiving notification of an excursion and make needed repairs as soon as practicable. See Table B for additional details. Operation will return to normal upon completed corrective action.

TABLE B MONITORING APPROACH

	Indicator No. 1	Indicator No. 2	Indicator No. 3
I. Indicator	Pressure drop across the catalyst.	Temperature of exhaust gas into catalyst.	Temperature of exhaust gas out of catalyst.
Measurement Approach	Pressure drop across the catalyst beds is measured monthly using a differential pressure gauge.	Exhaust gas temperature is measured continuously using an in-line thermocouple.	Exhaust gas temperature is measured continuously using an in-line thermocouple.
II. Indicator Range	The indicator range is a pressure drop deviation of less than 2 in. H ₂ O from the benchmark. Excursions trigger corrective action, logging and reporting in semiannual report	The indicator range is above 450°F, but lower than 1,350°F. Excursions trigger corrective action, logging and reporting in semiannual report.	The indicator range is above 500°F, but lower than 1,350°F. Excursions trigger corrective action, logging and reporting in semiannual report.
IV. <u>Performance Criteria</u>			
A. Data Representativeness	Pressure drop across the catalyst is measured at the catalyst inlet and exhaust. The minimum accuracy of the device is ±0.25 in. H ₂ O.	Temperature is measured at the inlet to the catalyst by a thermocouple. The minimum accuracy is ±5°F.	Temperature is measured at the outlet of the catalyst by a thermocouple. The minimum accuracy is ±5°F.
B. QA/QC Practices and Criteria	Pressure gauge calibrated quarterly. Pressure taps checked monthly for plugging.	Thermocouple visually checked quarterly, and tested annually.	Thermocouple visually checked quarterly, and tested annually.
C. Monitoring Frequency	Pressure drop is measured monthly.	Temperature is measured continuously.	Temperature is measured continuously.
D. Data Collection Procedures	Records are maintained to document monthly readings and any required maintenance.	A digital data recorder collects the temperature continuously.	A digital data recorder collects the temperature continuously.
E. Averaging period	None, not to exceed maximum.	4-hour rolling average.	4-hour rolling average.

Monitoring Approach Justification

I. Background

The monitoring approach outlined here applies to the oxidation catalysts on compressor engines CE1 and CE2 at this facility. The oxidation catalyst lowers CO, as well as CH₂O, NO_x, and hydrocarbon emissions. The catalysts are passive units and have no mechanical components.

II. Rationale for Selection of Performance Indicators

The pressure drop across the catalyst is measured monthly. A significant change in pressure drop from the benchmark can indicate that the catalyst is becoming fouled, slowing gas flow through the unit, and lowering the effectiveness of the unit.

Temperature into or out of the unit is measured because temperature excursions can indicate problems with engine operation and can prevent the chemical reduction from taking place in the catalyst bed. An exhaust gas temperature that is too low reduces the activity of the intended chemical/catalyst reaction. A temperature that is too high can indicate engine problems and can damage the catalyst unit.

Implementation of an engine and catalyst inspection and preventive maintenance (IPM) program provides assurance that the engine and catalyst are in good repair and are being operated as anticipated. Once per week, proper operation of the engine is verified to ensure that the catalysts aren't being fouled or damaged. Proper operation of the engine facilitates catalyst reactions. Other items on the daily IPM checklist include visual inspection of probes to ensure there is no clogging, and inspection of temperature gauges and chart recording devices.

III. Rationale for Selection of Indicator Ranges

The indicator range for the catalyst pressure drop is a pressure drop that deviates less than 2 inches of H₂O from the benchmark. This range was selected based on the manufacturer's specifications. A change in pressure drop indicates fouling of the catalyst and requires either cleaning or replacing of the catalyst bed.

Each catalyst bed is designed to work optimally at recommended temperatures. The temperature ranges selected are based on the catalyst manufacturer's suggested operating parameters for optimal chemical reaction.

Inspection and Preventive Maintenance Plan

The following is an inspection and preventive maintenance plan for engines equipped with an oxidation catalyst. The plan is designed to ensure optimum operation of the catalyst, avoid situations that could cause the catalyst damage and identify problems in a timely manner.

I. Engine Operations

Proper engine operation is critical to the performance of an oxidation catalyst. If an engine misfires, it produces high catalyst temperatures because the unburned air/fuel mixture burns when it contacts the catalyst. Several misfiring cylinders can produce enough heat to cause permanent damage to the catalyst.

Preventive Maintenance: Each engine will be checked weekly for proper operation and for misfiring conditions.

II. Over-Temperature System

The oxidation catalyst is equipped with an over-temperature system that protects the catalyst from excessive temperature conditions caused by engine misfires.

Preventive Maintenance: The catalyst over-temperature system will be tested quarterly to ensure it is working.

III. Exhaust Temperature

For efficient oxidation catalyst operations, the catalyst inlet gas must be above 450°F at all times, with a maximum of 1,350°F; or the catalyst outlet gas must be above 500°F at all times, with a maximum of 1,350°F.

Preventive Maintenance: The thermocouples measuring the exhaust temperature will be tested annually. The thermocouple probes will be visually inspected quarterly.

IV. Performance Monitoring

Catalyst temperature will be used to monitor catalyst performance.

Preventive Maintenance: A portable analyzer will be used quarterly (semiannually or annually) to test the NO_x and CO emission rates in the exhaust gas.