ALTERNATIVE MONITORING PROTOCOL

PREDICTIVE EMISSION MONITORING SYSTEM
TO DETERMINE NO_x AND CO EMISSIONS
FROM AN INDUSTRIAL FURNACE

The following is an alternative monitoring protocol to determine NO_x and CO emissions from an industrial furnace utilizing a predictive emission monitoring system (PEMS). This protocol is provided as an example for industry, regulators and the public. To date, no Federal requirements to install PEMSs exist; however, at some facilities, these systems may be proposed as alternatives to continuous emission monitoring systems. An electronic version of this protocol in addition to a recommended application to request the use of this protocol can be obtained via modem from EPA's Technology Transfer Network bulletin board system in the EMTIC subsystem.

For ease of reference, the elements of a protocol for a PEMS are provided and then followed in **bold** with example information to satisfy this protocol.

1. Applicability

a. Identify source name, location, and emission unit number(s)

Any Plant, Any State, USA, Furnace 1

b. Identify the type of industry;

Chemical Plant, SIC Code 28

c. Identify the process of interest;

Steam cracking furnace

d. Identify the regulations that apply (e.g.; NSPS, NESHAP, SIP);

State Air Pollution Control Agency, State RACT specifying NO_x and CO limits

e. Identify the pollutant(s) subject to monitoring (information on major/area source determination).

Major source for NO_x and CO.

f. Provide expected dates of monitor compliance demonstration testing

Testing will be performed within 120 days of approval of this alternate monitoring protocol.

2. Source Description

a. Provide a simplified block flow diagram with parameter monitoring points and emission sampling points identified (e.g.; sampling ports in the stack);

See the attached block flow diagram. Alternatively, a simplified block flow diagram with parameter monitoring points and emission sampling points will be provided in the initial verfication test report.

b. Provide a discussion of process or equipment operations that are known to significantly affect emissions or monitoring procedures (e.g., batch operations, plant schedules, product changes).

None.

3. Control Equipment Description

a. Provide a simplified block flow diagram with parameter monitoring points and emission sampling points identified (e.g.; sampling ports in the stack);

Not applicable to Furnace 1.

b. List monitored operating parameters and normal operating ranges;

Not applicable to Furnace 1.

c. Provide a discussion of operating procedures that are known to significantly affect emissions (e.g., catalytic bed replacement schedules, ESP rapping cycles, fabric filter cleaning cycles).

Not applicable to Furnace 1.

4. Monitoring System Design

a. Install, calibrate, operate, and maintain a continuous PEMS;

A PEMS has been installed and is being maintained for Furnace 1 as per State regulations.

b. Provide a general description of the software and hardware components of the PEMS including manufacturer, type of computer, name(s) of software product(s), monitoring technique (e.g., method of emission correlation). Manufacturer literature and other similar information shall also be submitted, as appropriate;

The PEMS model for Furnace 1 runs on a Digital Equipment Corporation (DEC) process computer. The DEC computer runs the VMS operations system provided by DEC. The furnace model was developed using *Process Insights*® provided by Pavilion Technologies, Inc. The model that was created by Process Insights is executed on Pavilion's *Software CEM*®. Process Insights uses a high-order, non-linear regression routine to develop a relationship between calculated and measured operating data. Plant personnel developed a Fortran program to supply the PEMS model with plant data and send calculated results to the process control computer. The process control computer is manufactured by Honeywell Corporation and runs Honeywell's process control software PMX. The PMX saves the raw plant data and calculation results. This PMX software calculates hourly averages from 1 minute snapshots. The hourly averages of raw plant data and calculation results are sent to a data base for storage.

c. List all elements used in the PEMS to be measured (e.g., pollutant(s), other exhaust constituent(s) such as O_2 for correction purposes, process parameter(s), and/or emission control device parameter(s));

- **Feed type**
- **Firing rate**
- **Fuel gas density**
- **Furnace 1 air preheat temperature**
- **Percent excess oxygen**
- **Stack temperature**
- **Inlet air humidity**
- **Inlet air temperature**

d. List all measurement or sampling locations (e.g., vent or stack location, process parameter measurement location, fuel sampling location, work stations);

See the attached list of locations. Alternatively, a list of all measurement or sampling locations will be provided in the initial verfication test report.

e. Provide a simplified block flow diagram of the monitoring system overlaying process or control device diagram (could be included in Source Description and Control Equipment Description);

See the attached simplified block flow diagram. Alternatively, a simplified diagram of the monitoring system will be provided in the initial verfication test report.

f. Provide a description of sensors and analytical devices (e.g., thermocouple for temperature, pressure diaphragm for flow rate);

See the attached description of sensors and analytical devices. Alternatively, a description of sensors and analytical devices will be provided in the initial verfication test report.

g. Provide a description of the data acquisition and handling system operation including sample calculations (e.g., parameters to be recorded, frequency of measurement, data averaging time, reporting units, recording process);

The data acquisition and handling system operation is described in 4.b. The PEMS furnace model uses the sensors listed in 4.c. to calculate the NO_x and CO furnace emissions. The sensors are measured once per minute. The PEMS model performs calculations once per minute. The calculation results are averaged over a 1 hour time period for long term storage. The results from the PEMS furnace model have units of ppm for NO_x and CO. The CO results are reported in ppm. The NO_x is converted to units of pounds of NO_x per million BTU's fired based on the higher heating value (HHV) of the fuel using the calculation below.

$$NO_x,\ lb/mmBTU = NO_x \times 1.194 \times 10^{-7} \times F_d \times \left(\frac{20.9}{(20.9 - \%O_2)} \right)$$

$$CO,\ lb/mmBTU = CO \times 7.268 \times 10^{-8} x F_d \times \left(\frac{20.9}{(20.9 - \%O_2)} \right)$$

$$NO_x,\ lb/hr = NO_x,\ lb/mmBTU \times NGF \times HHV$$

$$CO,\ lb/hr = CO,\ lb/mmBTU \times NGF \times HHV$$

where

> **NO_x = ppm in exhaust stack**
> **CO = ppm in exhaust stack**
> **Fd = 8710, EPA Method 19, Table 19-1**
> **O_2 = percent oxygen in exhaust stack**
> **NGF= Natural gas feedrate, SCFH**
> **HHV = Higher Heating Value of natural gas, Btu/SCF**

h. Provide checklists, data sheets, and report format as necessary for compliance determination (e.g., forms for record keeping).

Records to be kept include hourly emission rates of NO_x and CO, results of initial verification and subsequent verification tests, PEMS downtime, and QA/QC data.

A summary report will be submitted as required on a quarterly basis.

5. Support Testing and Data for Protocol Design

a. Provide a description of field and/or laboratory testing conducted in developing the correlation (e.g., measurement interference check, parameter/emission correlation test plan, instrument range calibrations):

The NO_x, CO and O_2 CEMS operated in accordance with EPA test Methods 20 and 10 will be utilized to provide the emissions data set. Emissions during normal operations, startups, shutdowns, and various loads will be collected.

b. Provide graphs showing the correlation, and supporting data (e.g., correlation test results, predicted versus measured plots, sensitivity plots, computer modeling development data).

The graphs showing the correlation and supporting data will be provided with the initial verification test report.

6. Initial Verification Test Procedures

a. Perform an initial relative accuracy test (RA test) to verify the performance of the PEMS over the permitted operating range. The PEMS must meet the relative accuracy requirement of the applicable Performance Specification in 40 CFR Part 60, Appendix B. The test shall utilize the test methods of 40 CFR Part 60, Appendix A.

As per Performance Specification 2, the relative accuracy of the NO_x PEMS in terms of the applicable emission standard must be demonstrated to be less than 20% of the average test method value or 10% of the applicable standard, whichever is greater.

As per Performance Specification 4A, the relative accuracy of the CO PEMS in terms of the applicable emission standard must be demonstrated to be less than 10% of the average test method value or 5 ppm, whichever is greater. The initial relative accuracy tests will be performed utilizing EPA Method 20 for NO_x and O_2 and Method 10 for CO.

b. Identify the most significant independently modifiable parameter affecting the emissions. Within the limits of safe unit operation, and typical of the anticipated range of operation, test the selected parameter for three RA test data sets at the low range, three at the normal operating range and three at the high operating range of that parameter, for a total of nine RA test data sets. Each RA test data set should be between 21 and 60 minutes in duration:

The most significant independently modifiable parameter affecting NO_x emissions is the furnace firing rate. The most significant independently modifiable parameter affecting CO emissions is excess oxygen. An instrumental sample van equipped with redundant NO_x and CO analyzers will be connected to the Furnace 1 stack. The furnace will be lined out at maximum, and intermediate, and a minimum firing rate for 63 minutes (21 minutes for each data set) at each rate. Analyzer measurements of the Furnace 1 emissions of NO_x and CO will be collected throughout the total test period. Concurrent with the collection of the analyzer data, the NO_x and CO emission data predicted by the PEMS model will be collected. The PEMS model's calculated emissions will then be compared with emissions measured by the analyzers. The RATA will be repeated with excess oxygen being the independently modifiable variable instead of firing rate to test the relative accuracy of the CO model.

c. Maintain a log or sampling report for each required stack test listing the emission rate in accordance with the applicable emission limitations:

A log will be maintained during the required stack tests that will include all parameter readings and emissions measurements for each minute of the stack test.

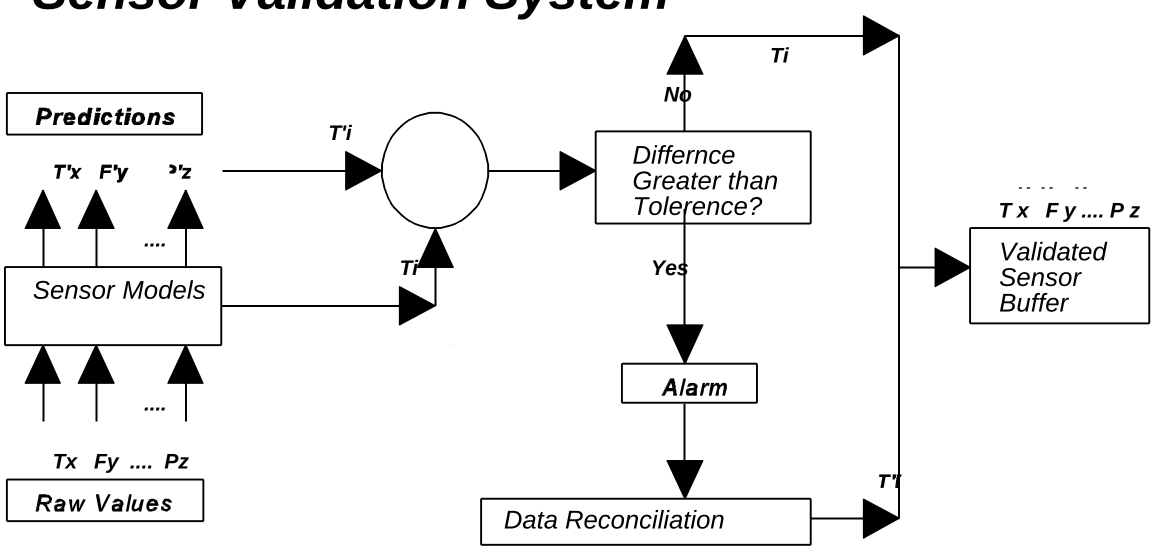
d. Demonstrate the ability of the PEMS to detect excessive sensor failure modes that would adversely affect PEMS emission determination. These failure modes include gross sensor failure or sensor drift.

i. The owner or operator shall demonstrate the ability to detect sensor failures that would cause the PEMS emissions determination to drift significantly from the original PEMS value.

ii. The owner or operator may use calculated sensor values based upon the mathematical relationships established with the other sensors used in the PEMS. The owner or operator shall establish and demonstrate the number and combination of calculated sensor values which would cause PEMS emission determination to drift significantly from the original PEMS value.

Pavilion's *Software CEM* consists of a Sensor Validation System and an Emission Model. The Sensor Validation System consists of a highly accurate model of each sensor as a function of the other incoming sensors. These sensor models are derived with the same modeling tool used to create the emission model and are highly accurate (within 2% of the normal sensor readings) over the entire operation range of the emission unit.

Sensor Validation System



Prior to any sensor data being used in the emission model, the data is validated by the Sensor Validation System as shown above. Data from each sensor is validated every minute to ensure that the emission model is receiving data consistent with that obtained during the PEMS development. By ensuring that the sensor data is consistent with the data gathered during the development of the PEMS, the accuracy of the emission model, at all times, is ensured. The Sensor Validation System is based on solid principles that are commonly used in all measurements, essentially, checking one sensor measurement against an independent measurement. This is exactly how calibration of a sensor is done; a sensor is compared against an independent reference value and if it is off, it is

adjusted or replaced. This is the same concept behind every Sensor Validation System. It is based on independent checks of each sensor, but the reference in the case of the sensor validation system is a highly accurate sensor model based on data from the other sensors collected during the PEMS development. Each sensor model is highly accurate over the entire range of operation of the emission unit.

Consider the following: Sixteen temperature transducers located at various positions on a process. The temperature measurements of each transducer is correlated and interdependent. If, for example, these transducers are located on a pipe and one sees that transducer A reads 134 degrees , C reads 135.2 degrees, but B reads 57 degrees, then if B is located between A and C on the pipe, it is evident that B is wrong. In fact, B should be measuring around 134.6 degrees. Note that with the information provided here, it is unclear as to whether B has failed or whether A or C have failed. Since A and C agree, the assumption is that B has failed. The same is true in calibration of any instrument. If when comparing an instrument to a reference, and there is a significant deviation, it could be that the instrument is off, or the reference is off or both. To check which one is off, another instrument is used to validate the results. If two instruments agree, but one is off, then it is highly probable that the one that is off is bad. To be very sure, another instrument could be used to further validate the results. If three agree and one is off, then the one that deviates from the other three is almost assuredly in error.

The Sensor Validation System uses this same principle. It compares each sensor to the other sensors. In fact, it compares not just with one other sensor, but independently with several other sensors to ensure the accurate validation of the sensor data before the data is used in the emission model.

A sensor drift limit will be established for each sensor so that PEMS inaccuracy from excessive drift is minimized. The excessive sensor drift values will be demonstrated prior to the RA tests as not adversely effecting the PEMS accuracy and will be incorporated into the PEMS so that the operator can be alerted to any sensor malfunction.

Another benefit of the Sensor Validation System is the ability of the sensor models to accurately determine sensor values so that in the event of a sensor failure or drift, the emission model can continue to determine emissions accurately by utilizing the calculated sensor value. This validation and data reconciliation function ensures that the PEMS will continuously provide accurate monitoring values in a reliable and robust fashion.

Prior to the initial RATA, a demonstration of the ability of the PEMS to identify

failed sensors and to reconcile failed sensors while maintaining the accuracy of the PEMS to within 20% of the original PEMS value will be performed. This demonstration will be conducted over the entire operating range of the emission unit. The demonstration will consist of: artificially failing each sensor and then ascertaining the accuracy of the PEMS when utilizing the calculated sensor value; artificially failing each combination of sensors and then ascertaining the accuracy of the PEMS when utilizing the calculated sensor values; and the ability of the PEMS to alert the operator regarding the status of PEMS accuracy in the unlikely event of sensor failure or failures. The results of the demonstration will be reported in the initial verification test report.

7. Quality Assurance Plan

a. Provide a list of the input parameters to the PEMS (e.g., transducers, sensors, gas chromatograph, periodic laboratory analysis), and a description of the sensor validation procedure (e.g., manual or automatic check):

The list of PEMS furnace operating parameters will be included in the initial verification test report. The Sensor Validation System is used to automatically validate each of the sensors once each minute. An alarm will activate if the Sensor Validation System identifies a sensor input as outside the acceptable range.

b. Provide a description of routine control checks to be performed during operating periods (e.g., preventive maintenance schedule, daily manual or automatic sensor drift determinations, periodic instrument calibrations)

The sensor validation system performs automatic sensor drift determinations. Each sensor input to the PEMS is received and evaluated before it is allowed to be used in the PEMS emission model. The sensor validation system evaluates each sensor independently of the PEMS emission model using redundant data from or mathematical relationships based on other sensors inputs to the PEMS. In addition, the input sensors will be calibrated prior to the data gathering program and periodically as recommended by the manufacturer.

c. Provide minimum data availability requirements and procedures for supplying missing data (including specifications for equipment outages for QA/QC checks):

Valid data will be collected for at least 95% of the unit operating hours. Process data recorded during PEMS outages can be read directly from electronic records into the PEMS and the resulting emissions recorded normally for the purposes of missing data substitution.

d. List corrective action triggers [e.g., response time deterioration limit on pressure sensor, use of statistical process control (SPC) determinations of problems, sensor validation alarms]:

The sensor validation system will alarm whenever excessive sensor drift or failure is detected or the sensor pattern is not recognized as would be the case of the furnace being improperly operated.

e. List trouble-shooting procedures and potential corrective actions:

Sensor Validation System alarms will trigger an investigation into the cause of the alarm. The operator will investigate the cause and take corrective actions as necessary. Potential corrective actions could include furnace operating adjustments or sensor repair or replacement. If furnace operating adjustments are necessary, they will be done expeditiously. Sensor repair or replacement will occur as soon as practicable, however, sensor reconciliation will occur immediately.

f. Provide an inventory of replacement and repair supplies for the sensors:

Spare parts for all sensors will be obtained directly from the manufacturer on an as needed basis.

g. Specify, for each input parameter to the PEMS, the drift criteria for excessive error (e.g.: the drift limit of each input sensor that would cause the PEMS to exceed relative accuracy requirements):

The drift criteria for excessive error will be computed for each parameter using Pavilion software that performs a drift perturbation analysis of each parameter. The results of the perturbation analysis will be provided with the initial verification test report.

h. Conduct a quarterly electronic data accuracy assessment tests of the PEMS.

The quarterly electronic data accuracy assessment tests will consist of:

1. An emissions model integrity check that is performed by challenging the PEMS with a set of known inputs, obtaining the PEMS output, and then comparing that output to the expected output (i.e. the output that would be given by the PEMS when it passed the most recent RA test). The difference between the expected output and the actual output should be within ±5%. If the PEMS does not meet this criteria, it will be tuned or adjusted as described in section 8.a. of this protocol.

2. A sensor validation system integrity check that is performed by comparing (manually or automatically) each input parameter to an independent measurement or calculated sensor value. If this drift detection check shows that any of the input parameters have drifted by more than the criteria for excessive error as established in accordance with Section 6.d, then those parameters shall be recalibrated, or replaced and calibrated, and subjected to another sensor drift check as described in this section.

i. Conduct semiannual RA tests of the PEMS. Annual RA tests may be conducted if the most recent RA test result is less than or equal to 7.5%. Identify the most significant independently modifiable parameter affecting the emissions. Within the limits of safe unit operation and typical of the anticipated range of operation, test the selected parameter for three RA test data pairs at the low range, three at the normal operating range, and three at the high operating range of that parameter for a total of nine RA test data sets. Each RA test data set should be between 21 and 60 minutes in duration:

Three test runs at maximum, three at normal, and three at minimum firing rates will be conducted. Analyzer measurements of the furnace NO_x emissions will be collected throughout the total test period. Concurrent with the collection of the test method emissions data, the NO_x emissions data determined by the PEMS will be collected. The PEMS emissions data will then be compared with emissions measured by the test method.

8. PEMS Tuning

a. Perform tuning of the PEMS provided that the fundamental mathematical relationships in the PEMS model are not changed.

Tuning may be performed in order to enhance the accuracy of the PEMS for the following reasons provided the availability of reference emissions data: process aging, process modification, and new process operating modes. The PEMS must be tuned on an augmented set of data which includes the set of data used for developing the model in use prior to tuning and the newly collected set of data needed to tune the model. Verification that the PEMS model is acceptable after tuning must be performed utilizing a set of reference test method emissions data and PEMS emissions data from the most recent RATA or other test which was not used for model tuning. The date, reasons and details of PEMS tuning will be documented and indicated in the quarterly report.

b. Perform tuning of the PEMS in case of sensor recalibration or sensor replacement provided that the fundamental mathematical relationships in the PEMS model are not changed.

Tuning may be performed so that the recalibrated sensor or replacement sensor mimics the original sensor used in the PEMS. Tuning is based upon the mathematical relationships between the original sensor and the other sensors used in the PEMS.