Development and Implementation of an Alternative Emissions Monitoring Program for Carbon Monoxide Compliance for Fluidized Catalytic Cracking Unit CO Boilers

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ABSTRACT

This paper presents the results of an alternative emissions monitoring test program for the Fluidized Catalytic Cracking Unit (FCCU) CO boilers at major oil refinery. Alternative emissions monitoring systems can be used in lieu of other compliance monitoring techniques (e.g., periodic emissions testing, continuous emissions monitoring) to relate monitored operating conditions which might indicate potential problems in emission control performance. Alternative emissions monitoring can enable a source to obtain information in a timely manner to avoid, or reduce, operational problems that could result in excess emissions.

The flue gas from the FCCU regenerator contains approximately 10% carbon monoxide (CO) by volume, which is commonly referred to as "CO gas." To control the emissions of CO, the CO gas stream is passed through two boilers (East and West) designed with sufficient residence time, turbulence, and temperature to fully combust the CO contained in the FCCU Regenerator flue gas. The FCCU is also equipped with piping which enables the FCCU regenerator CO gas to bypass the boilers and be directed to the common stack shared by the East and West boilers. This bypass piping is equipped with a butterfly valve that is normally operated in the fully closed position. To ensure against leakage, the valve is routinely packed with ceramic fiber insulation.

One of the main objectives of the alternative monitoring test program was to determine what effect the operating load of the CO boilers had on CO emissions at the boiler outlets leading to the common stack. This evaluation was performed to ascertain if variation of operating loads for the CO boilers would cause changes in CO emissions. The other main objective was to determine what effect leakage of the bypass valve had on temperatures downstream of the valve and CO emissions in the common stack. To perform this evaluation, emissions and operating data were collected during baseline and test (bypass leakage) conditions. Some of the test conditions evaluated resulted in CO emission levels in the common stack above the 200 ppm (corrected to 50% excess air) emission limit.

The test results demonstrated that the operating load of the East and West boilers had no measurable effect on CO levels in the common stack. However, by forcing leakage of the bypass valve, there were measurable temperature increases downstream of the valve that were directly related to the magnitude of leakage of CO gas across the bypass valve. As valve leakage increased, so did the CO levels in the common stack.

As a result of this test program, the facility has implemented an alternative emissions monitoring system by installing a permanent temperature sensor downstream of the bypass valve, and connecting the temperature signal to the plant process computer. The process computer has been programmed to

alert the operators of temperature increases downstream of the bypass valve. As a corrective action for significant temperature increases above normal baseline levels, the bypass valve is repacked in accordance with facility maintenance procedures. By monitoring these temperatures and taking the appropriate corrective action, the facility has a very high degree of compliance assurance that CO emissions in the common stack remain below the applicable limit.

INTRODUCTION

Alternative emissions monitoring systems can be used in lieu of other compliance monitoring techniques (e.g., periodic emissions testing, continuous emissions monitoring (CEM)) to relate monitored operating conditions which might indicate potential problems in emission control performance. Alternative emissions monitoring can enable a source to obtain information in a timely manner to avoid, or reduce, operational problems that could result in excess emissions.[1]

This paper presents the results and methodology for implementation of an alternative emissions monitoring program developed for a major oil refinery. This program evaluated the operating conditions of two CO boilers (East and West CO Boilers) which are used as control devices, and temperatures downstream of a large bypass valve, in order to provide assurance that the carbon monoxide (CO) levels in the common stack remain in compliance with the applicable state of Illinois CO emission limit. This continuous compliance determination method was developed to comply with the intent of EPA's Compliance Assurance Monitoring (CAM) requirements, thereby allowing the facility to demonstrate continuous emissions compliance without the use of a CEM system.

APPLICABILITY OF THE REGULATIONS

State of Illinois

In 35 IAC 216.361(a) of the Illinois air regulations for Petroleum and Petrochemical Processes, the applicable regulation for carbon monoxide states:

No person shall cause or allow the emission of a carbon monoxide waste gas stream into the atmosphere from a petroleum or petrochemical process unless such waste gas stream is burned in a direct flame afterburner or carbon monoxide boiler so that the resulting concentration of carbon monoxide in such waste gas stream is less than or equal to 200 ppm corrected to 50 percent excess air....

Compliance Assurance Monitoring

Operating permit provisions of the Clean Air Act describe the requirements of permit programs, permit requirements, special conditions, compliance, enforcement, submission of applications, and approval of permits. Operating permits contain information about how a facility will comply with established emissions standards and guidelines. Operating permits also provide facility owners, regulators, and the public with information about the air pollution regulations that apply to each facility.

The Clean Air Act Amendments (Title VII) of 1990 authorized EPA to develop regulations requiring facilities to monitor the performance of their emission control equipment. In September 1993, EPA proposed an "enhanced monitoring" rule that established general monitoring criteria that facilities should follow to demonstrate continuous compliance, but the proposed rule was highly criticized for being overly prescriptive. The enhanced monitoring rules would also have imposed excessive burdens on industry to install and operate continuous emission monitoring equipment.[2]

While EPA's September 1993 proposed enhanced monitoring rule focused on direct compliance monitoring which in many cases might have required affected facilities to install expensive CEM systems, the compliance assurance monitoring approach builds on regulatory monitoring approaches already in place at the facilities in question. Its purpose is to provide “reasonable assurance” that facilities comply with emission limitations by monitoring the operation and maintenance of their control. The CAM rule defines minimum applicable monitoring, operation, and maintenance requirements to ensure that the equipment does not deteriorate to the point of failing to comply with emission limits.

CAM establishes criteria that define what monitoring of existing control devices a source should conduct to provide reasonable assurance of compliance with emission limits and standards. For emission units with control equipment, the rule requires the owner or operator to develop and conduct monitoring. The monitoring requires the source to determine an acceptable range within which to operate the control device (known as an "indicator range"). Operating control devices within acceptable ranges, as they were designed to operate, will minimize emissions and provide reasonable assurance that the facility is complying with permit terms and conditions.[3]

If control equipment is found to be operating outside acceptable ranges, facility owners and operators are required to take prompt corrective actions to make necessary adjustments to the control equipment as well as notify State and local authorities that potential compliance problems may exist.

Definitions[3]

Continuous compliance determination method means a method, specified by the applicable standard or an applicable permit condition, which

1. Is used to determine compliance with an emission limitation or standard on a continuous basis, consistent with the averaging period established for the emission limitation or standard
2. Provides data either in units of the standard or correlated directly with the compliance limit.

Control device means equipment, other than inherent process equipment, that is used to destroy or remove air pollutant(s) prior to discharge to the atmosphere. The types of equipment that may commonly be used as control devices include, but are not limited to, fabric filters, mechanical collectors, electrostatic precipitators, inertial separators, afterburners, thermal or catalytic incinerators, adsorption devices (such as carbon beds), condensers, scrubbers (such as wet collection and gas absorption devices), selective catalytic or non-catalytic reduction systems, flue gas recirculation systems, spray dryers, spray towers, mist eliminators, acid plants, sulfur recovery plants, injection systems (such as water, steam, ammonia, sorbent or limestone injection), and ***combustion devices*** independent of the particular process being conducted at an emissions unit (e.g., the destruction of emissions achieved by venting process emission streams to flares, boilers or process heaters).

Excursion means a departure from an indicator range established for monitoring under this part, consistent with any averaging period specified for averaging the results of the monitoring.

Monitoring means any form of collecting data on a routine basis to determine or otherwise assess compliance with emission limitations or standards. Record-keeping may be considered monitoring where such records are used to determine or assess compliance with an emission limitation or standard (such as records of raw material content and usage, or records documenting compliance with work practice requirements). The conduct of compliance method tests, such as the procedures in appendix A to part 60 of this chapter, on a routine periodic basis may be considered monitoring (or as a supplement to other monitoring), provided that requirements to conduct such tests on a one-time basis or at such times as a regulatory authority may require on a non-regular basis are not considered monitoring requirements for purposes of this paragraph. Monitoring may include one or more than one of the following data collection techniques, where appropriate for a particular circumstance:

1. Continuous emission or opacity monitoring systems.
2. Continuous process, capture system, control device or other relevant parameter monitoring systems or procedures, including a predictive emission monitoring system.
3. Emission estimation and calculation procedures (e.g., mass balance or stoichiometric calculations).
4. Maintenance and analysis of records of fuel or raw materials usage.
5. Recording results of a program or protocol to conduct specific operation and maintenance procedures.
6. Verification of emissions, process parameters, capture system parameters, or control device parameters using portable or in situ measurement devices.
7. Visible emission observations.

Predictive emission monitoring system (PEMS) means a system that uses process and other parameters as inputs to a computer program or other data reduction system to produce values in terms of the applicable emission limitation or standard.

Monitoring design criteria. To provide a reasonable assurance of compliance with emission limitations or standards for the anticipated range of operations at a pollutant-specific emissions unit, monitoring under this part shall meet the following general criteria:

1. The owner or operator shall design the monitoring to obtain data for one or more indicators of emission control performance for the control device… processes at a pollutant-specific emissions unit. Indicators of performance may include, but are not limited to, direct or predicted emissions (including visible emissions or opacity), 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.
2. The owner or operator shall establish an appropriate range(s) or designated condition(s) for the selected indicator(s) such that operation within the ranges provides a reasonable assurance of ongoing compliance with emission limitations or standards for the anticipated range of operating conditions. Such range(s) or condition(s) shall reflect the proper operation and maintenance of the control device (and associated capture system), in accordance with applicable design properties, for minimizing emissions over the anticipated range of operating

conditions at least to the level required to achieve compliance with the applicable requirements. The reasonable assurance of compliance will be assessed by maintaining performance within the indicator range(s) or designated condition(s). The ranges shall be established in accordance with the design and performance …. If necessary to assure that the control device and associated capture system can satisfy this criterion, the owner or operator shall monitor appropriate process operational parameters (such as total throughput where necessary to stay within the rated capacity for a control device). In addition, unless specifically stated otherwise by an applicable requirement, the owner or operator shall monitor indicators to detect any bypass of the control device (or capture system) to the atmosphere, if such bypass can occur based on the design of the pollutant-specific emissions unit.

3. The design of indicator ranges or designated conditions may be: (i) Based on a single maximum or minimum value if appropriate (e.g., maintaining condenser temperatures a certain number of degrees below the condensation temperature of the applicable compound(s) being processed) or at multiple levels that are relevant to distinctly different operating conditions (e.g., high versus low load levels).

PLANT PROCESS INFORMATION

The flue gas from the Fluidized Catalytic Cracking Unit (FCCU) regenerator contains approximately 10% carbon monoxide (CO) by volume. The flue gas is commonly referred to as "CO gas." To control the emissions of CO, the CO gas stream is passed through two tangentially-fired CO Boilers (East and West) designed with sufficient residence time, turbulence, and temperature to fully combust the CO contained in the FCCU Regenerator flue gas. A process flow diagram is shown in Figure 1.

The critical operating parameters for maintaining complete CO combustion are combustion air and heat input. Combustion air is measured continuously as excess oxygen in the boiler flue gas outlets, and supplemental heat input is measured continuously as auxiliary fuel flow rate. These parameters are linked to the process computer control system. Audible alarms would sound if these measurements fell below acceptable levels. The process control system eliminates the potential for elevated CO levels entering the common stack by maintaining the combustion air and heat input above acceptable minimums. In the boilers, the FCCU Regenerator CO gas is heated well above the minimum CO ignition temperature and complete oxidation occurs. Virtually all CO is converted to carbon dioxide (CO_2). The process parameter minimums for excess oxygen and auxiliary fuel flow rates have been programmed with a sufficient safety factor to provide for audible notification to Production Technicians before there is a loss of CO ignition.

The FCCU is also equipped with piping which enables the FCCU Regenerator CO gas to bypass the boilers and be directed to the common stack. This bypass piping is equipped with a butterfly valve which is essential for the safe operation of the boilers during start-up/shutdown periods and boiler trips.

In order to ensure compliance during normal operations, the bypass valve is maintained in a fully closed position. Should the bypass valve be opened, or not seated properly, CO emissions from the FCCU Regenerator CO gas would pass through the valve and reach the common stack. The position of the bypass valve is controlled by the process computer control system.

To further ensure that the bypass valve remains adequately sealed when in the fully closed position, the facility routinely packs the valve with ceramic fiber insulation. In addition, the facility has installed temperature indicators downstream of the bypass valve in two locations. Should the bypass valve develop a significant leak, the downstream temperature indicator would respond with a measurable increase (higher than normal temperature).

OBJECTIVES OF THE ALTERNATIVE EMISSIONS MONITORING TEST PROGRAM

The two main objectives of the alternative monitoring test program were to:

1. Determine what effect the operating load of the CO boilers has on CO emissions at the boiler outlets leading to the common stack. This evaluation was essential to ascertain if variation of operating load for the CO boilers could cause increases in CO emissions.
2. Determine what effect leakage of the bypass valve has on temperatures downstream of the bypass valve and CO emissions in the common stack. To perform this evaluation, emissions and operating data were collected during baseline and test (bypass leakage) conditions.

Emissions Monitoring Equipment

Two sets of analyzers for CO, O_2, and CO_2 were utilized in order to determine CO emissions corrected to 50% excess air. Straight extractive emissions monitoring was performed continuously in the common stack at Point E of Figure 1. Concurrently, straight extractive emissions monitoring of the boiler outlets was performed at Points C and D of Figure 1 prior to the flue gas entering the common stack. Boiler outlet emissions monitoring was time-shared.

The CO emissions were monitored with a Thermo-Environmental Instruments Model 48 gas filter correlation analyzers. The CO monitor for the boiler outlets was operated on a 0 to 100 ppmvd scale, with accuracy to ± 1 ppmvd. For the stack sampling system, the CO analyzer was operated on a 0 to 500 ppm scale.

The O_2 and CO_2 emissions were monitored with a Servomex 1400 Series Oxygen and Carbon Dioxide analyzers operating on the 0-25% scale.

Prior to the start of testing each day, and routinely throughout the test program, the analyzers were calibrated at the probe using EPA Protocol 1 calibration gases.

Emissions Monitoring Program and Data Collection

$CO/CO_2/O_2$ emissions in the common stack and the CO boiler outlets, along with temperatures upstream and downstream of the bypass valve, were concurrently monitored. Carbon dioxide and oxygen levels were necessary to calculate percent excess air in accordance with Equations 1 and 2 below.

Equation 1

$$\%\,\text{Excess Air} = \frac{\left(\%\,O_2 - \left(\frac{\%CO}{2}\right)\right)}{0.264 * \left[100 - (\%\,O_2 + \%\,CO_2)\right] - \left(\%\,O_2 - \left(\frac{\%CO}{2}\right)\right)} * 100$$

Equation 2 $$\text{CO (ppm) at 50\% Excess Air} = \text{CO (ppm)} * \left(\frac{100 + (\text{\% Excess Air})}{150}\right)$$

The facility's process computer system recorded one-minute snapshot values of the following operating parameters during the test program:

- Process fuel gas flows to each boiler
- CO gas flow to each boiler (calculated value)
- Steam production for each boiler
- Boiler outlet oxygen levels
- Feedwater flows for each boiler
- Expander inlet and outlet temperatures (outlet temperature is represented as Point A, Figure 1, which is the temperature upstream of the bypass valve)
- Vertical (Point B, Figures 1 & 2) and horizontal temperature (Point F, Figures 1 & 2) readings downstream of the bypass valve
- Burner pressures (PSIG)
- Air flow louver positions (%)
- CO level in the CO gas (% by volume)

Evaluation of Operating Load on Outlet CO Emissions from the East and West Boilers

To evaluate the effects of various operating loads on the boiler outlet CO concentrations, emissions data was collected throughout the test program. During the data collection period, a total of 400 minutes of boiler outlet emissions data were collected for the East Boiler, and 476 minutes of boiler outlet emissions data for the West boiler.

The boiler steam flow and CO levels are summarized in Table 1. During the evaluation period, the East CO Boiler was operated with steam production rates between 322,500 lb/hr and 461,700 lb/hr, which represented the normal range of operation outside of start-up and shutdown periods during the test program. The West CO Boiler was operated with steam production rates between 266,200 lb/hr and 462,900 lb/hr. Emissions results showed that both boilers emitted negligible CO levels, regardless of operating load.

Evaluation of the Effect of Bypass Valve Leakage on Temperature Readings and CO Levels in the Common Stack

According to the facility, normal (baseline) operation of the bypass valve is in the fully closed position with packing material around the valve to minimize leakage. Leakage across the bypass valve in the closed/packed condition, as measured during the test program, resulted in a CO level in the common stack of less than 50 ppmvd at 50% excess air.

Figure 2 is an illustration showing the proximity of the vertical and horizontal temperature locations to the bypass valve and common stack. The temperature of the CO gas upstream of the bypass valve (which is the expander outlet temperature) was roughly 960 ºF at all times. During baseline (minimal leakage) operation when the CO level in the common stack was less than 50 ppmvd at 50% excess air, the temperature inside of the vertical section of the bypass line (19 feet downstream of the bypass valve) was roughly 410 ºF, and dropped to roughly 112 ºF in the horizontal section of the line (47 feet downstream of the bypass valve).

In order to evaluate bypass valve leakage during the test program, the following conditions were monitored:

- ***Baseline*** Normal operation, minimal leakage
- ***Open1*** Open/close bypass valve to force leakage (day 2)
- ***Leak*** Monitoring period following valve open/close
- ***Pack1*** Monitoring period after one tube of packing was injected into valve
- ***Pack2*** Monitoring period after a second tube of packing was injected
- ***Pack3*** Monitoring period after a third tube of packing was injected
- ***Pack45*** Monitoring period after a fourth and fifth tube of packing was injected
- ***Open2*** Open/close bypass valve to force leakage a second time (day 3)
- ***Leak2*** Monitoring period following valve open/close #2
- ***Pack1X*** Monitoring period after one tube of packing was injected into valve after Leak2.
- ***Pack2X*** Monitoring period after a second tube of packing was injected after Leak2.

To induce leakage of the bypass valve, the facility operating personnel opened the valve approximately 5% (Leak, day 2) and 3% (Leak2, day 3), and immediately closed the valve after each opening. The duration of each open/close was less than one-minute, during which time the valve packing material broke loose allowing an increase in the leakage of CO gas through the closed valve.

Initially upon inducing leakage, the temperatures in the vertical and horizontal sections of the bypass line increased quickly, and steadily, to levels in excess of 600 ºF in the vertical section, and 400 ºF in the horizontal section. After the initial surge in temperature following the open/close action, the temperature continued to increase while it approached a stable temperature. The estimated range from minimum to maximum (stabilized) temperature following valve leakage could be as much as 200 ºF in the vertical location, depending upon the amount of leakage.

To evaluate the effect of valve packing (which followed induced leakage periods) on downstream temperatures and CO levels in the common stack, the valve was progressively packed with ceramic fiber insulation and allowed to stabilize.

The primary objective of this portion of the alternative monitoring program development was to quantify the relationship between temperature readings downstream of the bypass valve and CO levels in the common stack. Furthermore, the comparison should be conservative in the identification of temperature readings in the vertical and horizontal sections of the bypass line that relate to CO emission levels in the common stack. Therefore, the 5th-percentile temperature readings for each test condition were compared to the concurrent 95th-percentile CO readings.

The 5th-percentile temperature readings reflect levels at the lower end of the range for each condition, which correspond to levels that can alert the boiler operator that the bypass valve leakage is increasing. Conversely, since CO levels varied during each test condition, the 95th-percentile CO levels for each test condition were selected to be conservative (on the high side). The temperature and CO level percentiles for each case can be found in the univariate analysis found in Appendix D, and are summarized in Table 2.

The test results have been plotted in Figures 3 and 4. Figure 3 illustrates the relationship of vertical temperature readings (5th-percentile values) versus CO levels in the common stack (95th-percentile) corrected to 50% excess air. Figure 4 is a similar curve displaying horizontal temperature readings (5th-percentile) versus CO levels.

The results show that there is a significant relationship between both vertical and horizontal temperature measurements downstream of the bypass valve, and CO emission levels in the common stack. As valve leakage increases, so do the downstream temperature measurements and CO levels in the stack.

IMPLEMENTATION OF THE ALTERNATIVE EMISSIONS MONITORING PROGRAM

In order to implement this alternative emissions monitoring program, the facility has installed a temperature sensor (K-type thermocouple with transmitter) in the vertical location downstream of the bypass valve to the plant process computer system.

The process computer is programmed to alert the operators of temperature increases in the vertical section downstream of the bypass valve. As a corrective action for significant temperature increases, boiler operators will respond by arranging for the bypass valve to be repacked in accordance with their maintenance procedures. By monitoring temperature and taking the appropriate corrective action, the facility has a high degree of assurance that CO emissions in the common stack remain below the applicable limit.

REFERENCES

1. Macak, Joseph J. *The Pros and Cons of Predictive, Parametric, and Alternative Emissions Monitoring Systems for Regulatory Compliance*, Air & Waste Management Association, 1996 Annual Conference and Exhibition, Paper 96-WP92.02, June 23-28, 1996.
2. EPA Fact Sheet, *Compliance Assurance Monitoring*, published October 3, 1997, Internet, http://www.epa.gov/ttnuatw1/camprfs.html.
3. EPA, *Compliance Assurance Monitoring*, 40 CFR 64, October, 1997.

Table 1. Boiler Outlet CO Emissions Summary.

Boiler Parameter	East CO Boiler (Point D)	West CO Boiler (Point C)
Minimum Steam Flow (lb/hr)	322,500	266,200
Maximum Steam Flow (lb/hr)	461,700	462,900
Average Steam Flow (lb/hr)	392,023	364,911
Minimum CO Level (ppmvd at 50% excess air)	0[a]	0[a]
Maximum CO Level (ppmvd at 50% excess air)	0[a]	0[a]
Average CO Level (ppmvd at 50% excess air)	0[a]	0[a]

[a] Note: the CO levels at the boiler outlets are all considered zero, or negligible, when taking into consideration the accuracy of the instrumentation and calibration gases. For the East boiler, CO ranged from -0.39 to 0.6 ppm, and -0.45 to 0.22 ppm for the West boiler.

Table 2. Summary of Temperature and CO Emission Levels During Test Conditions.

Condition	# Min.	Vertical Temperature Readings (ºF)		Horizontal Temperature Readings (ºF)		CO Level (ppmvd at 50% excess air)	
		Average	5th Percentile	Average	5th Percentile	Average	95th percentile
Baseline -- Normal operation, minimal leakage	222	409.8	404.9	112	109.2	39.5	44.5
Open1 -- Open/close bypass valve to force leakage (day 2)	8	*Transient Data Period*					
Leak -- Monitoring period following valve open/close	98	683.1	641.2	463.3	426.4	350.7	358
Pack1 -- Monitoring period after one tube of packing was injected into valve	10	*Transient Data Period*					
Pack2 -- Monitoring period after a second tube of packing was injected	57	675.6	670.9	452.6	449.3	222.8	229.6
Pack3 -- Monitoring period after a third tube of packing was injected	1084	634.4	629.2	341	307.4	168.9	191.3
Pack45 -- Monitoring period after a fourth and fifth tube of packing was injected	176	482.2	443.2	178.7	159.5	30	35.7
Open2 -- Open/close bypass valve to force leakage a second time (day 3)	9	*Transient Data Period*					
Leak2 -- Monitoring period following valve open/close #2	105	640.5	604	443.4	410.8	242.1	248.2
Pack1X-- Monitoring period after one tube of packing was injected into valve after Leak2	20	*Transient Data Period*					
Pack2X-- Monitoring period after a second tube of packing was injected into valve after Leak2	122	588	576.5	397.3	388.9	123.4	126.5

Figure 1. Process Flow Diagram for FCCU and CO Boilers.

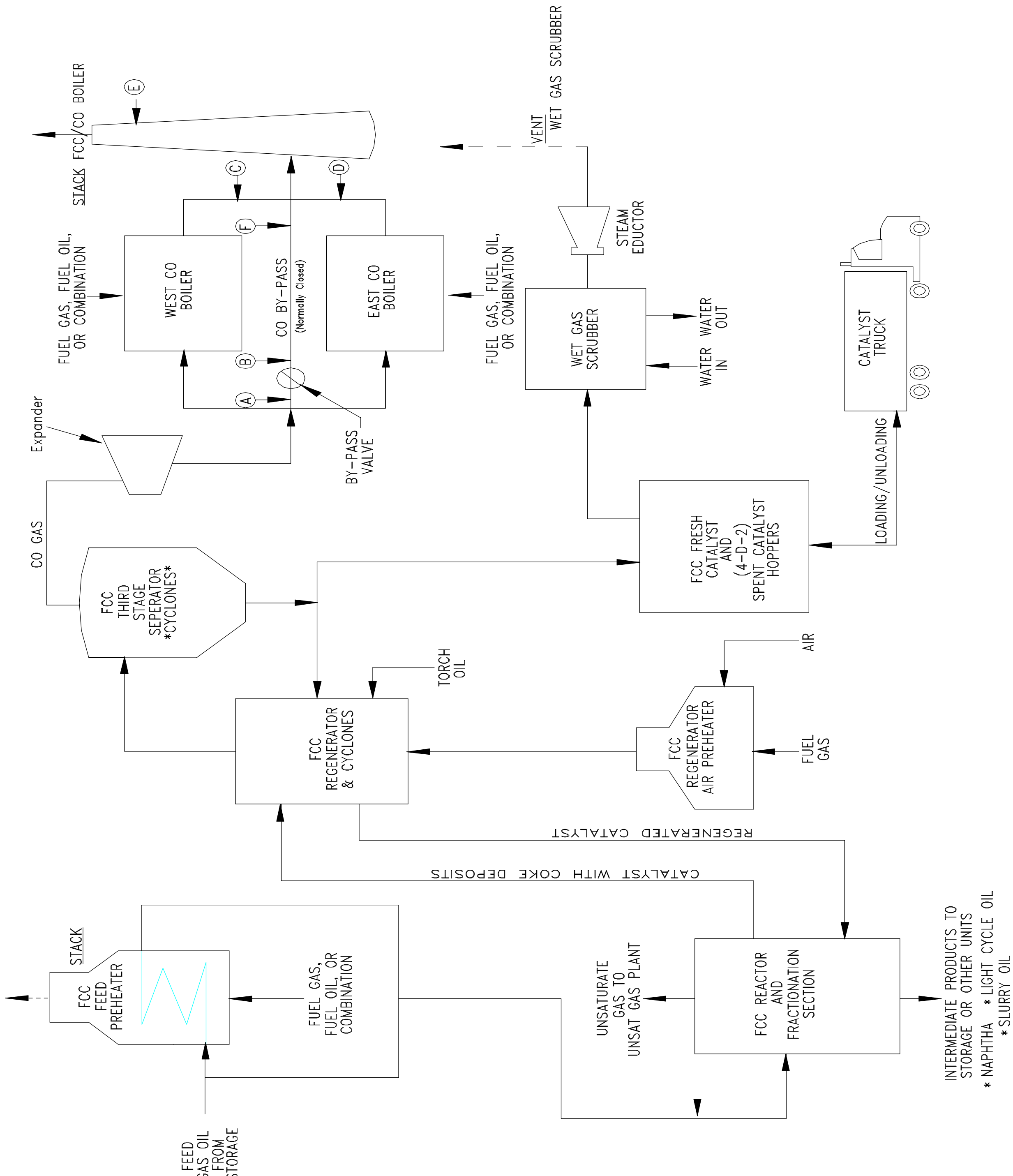

Figure 2. Location of the Vertical and Horizontal Temperature Sensors.

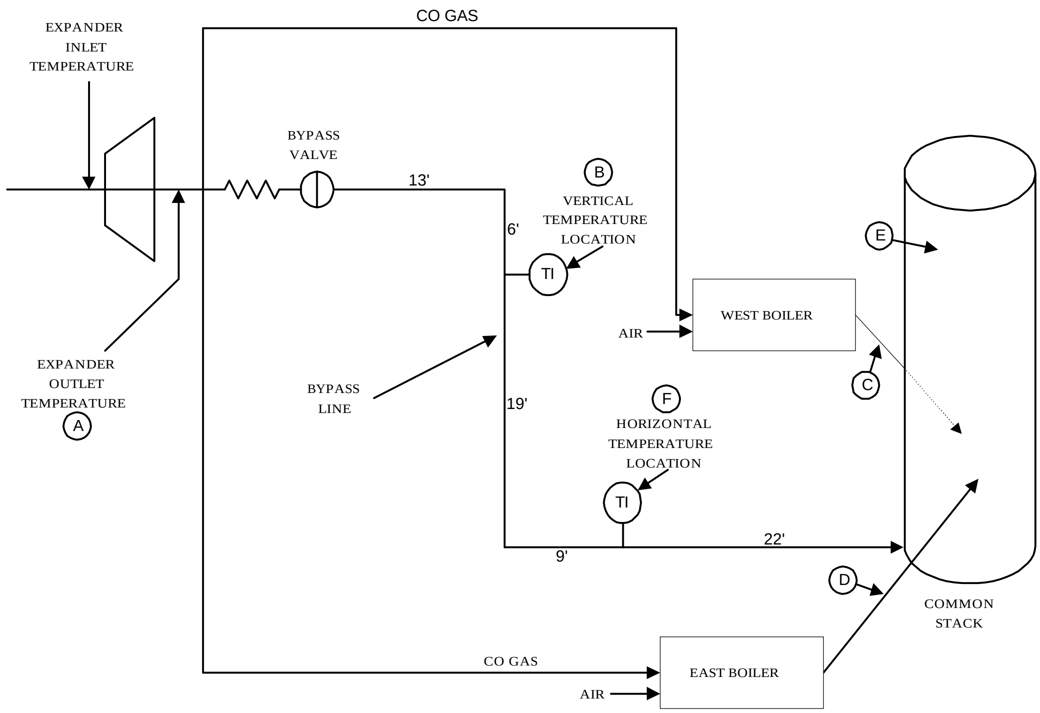

Figure 3. CO Level (95th-Percentile) in the Common Stack vs. Vertical Temperature Measurement (5th-Percentile).

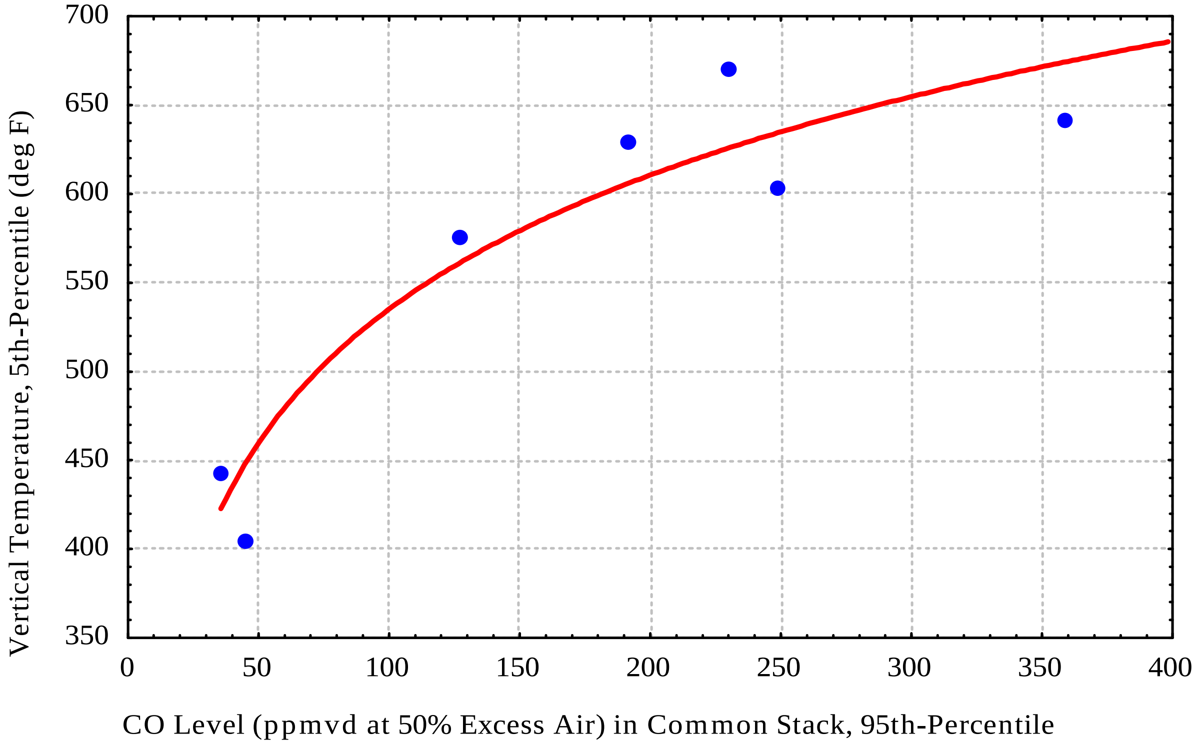

Figure 4. CO Level (95th-Percentile) in the Common Stack vs. Horizontal Temperature Measurement (5th-Percentile).