

# Emissions Test Report: Source Sampling for Transportable Gasifier for Animal Carcasses and Contaminated Plant Material

## FINAL REPORT





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# Abstract

The U.S. Department of Defense (DoD) operates the Technical Support Working Group (TSWG) under a multi-agency program that provides information and technology development to support the needs of various U.S. government agencies to address counterterrorism and emergency response issues. TSWG, in collaboration with the U.S. Environmental Protection Agency's National Homeland Security Research Center (EPA/NHSRC) and the U.S. Department of Agriculture's Animal and Plant Health Inspection Service (USDA/APHIS) has funded the construction of a transportable gasifier with the goal of processing large quantities of animal carcasses and plant materials resulting from agricultural emergency events. This unit may be useful for other homeland security-related events as an on-site treatment/disposal process. This gasifier converts the biomass material into an inert ash and a combustible synthesis gas that is burned in a secondary combustion chamber. Temperatures within the unit nominally ranged from 1200 to 1800 °F (649 to 982 °C).

This report describes an emissions test to characterize gasifier operation for the following reasons:

- To provide a basis for comparison with other combustion devices;
- To address public concerns about environmental impacts from carcass disposal operations;
- To give state and local environmental agencies information to support their responsibilities in siting and operating combustion equipment; and
- To allow the permanent siting of such devices at industrial settings in the agricultural industry (e.g., at rendering plants) for use with routine mortalities and for energy production.

Testing occurred during the period from March 3 to 6, 2008, at the Valley Protein rendering facility located in Rose Hill, NC. During these tests, the gasifier was operated on two different biomass feedstocks:

- A mixture of poultry and swine; and
- Bales of wheat straw.

Samples were taken and analyzed for several targets, including:

- Fixed combustion gases, including oxygen, carbon dioxide, carbon monoxide, total hydrocarbons, sulfur dioxide, and oxides of nitrogen;
- Particulate matter, including total filterable particulate, condensable particulates, PM<sub>10</sub>, and particle size distributions;
- Metals;
- Acid gases;

- Polychlorinated dibenzo-*p*-dioxins and polychlorinated dibenzofurans;
- Leachable metals in the ash residues; and
- Amino acids in the ash residues.

The unit was successfully deployed in the field in a rapid manner and was operational to perform the necessary emissions testing described in the Quality Assurance Project Plan in spite of having less than a week for initial startup and shakedown. This truncated shakedown schedule resulted in several operational issues that should be addressed through minor design modifications. The operational issues of concern that impacted the emissions testing included:

- Failure of the ash removal auger contributed to a limitation on feed rate;
- Inefficient distribution of macerated animal matter on the hearths in the primary chamber limited the unit's maximum throughput to approximately 32% of the design capacity; and
- The plant material selected as a surrogate for contaminated plant matter could not be fed through the unit's macerator; operations involving plant matter were therefore cut to only a few hours and extractive sampling was not performed on the plant matter test emissions.

Air was infiltrating the primary chambers through some unknown mechanism, and the synthesis gas as analyzed did not bear a resemblance to synthesis gas from other gasification processes – this difference could result from air migrating from the secondary chambers through gaps in the hearth to the primary chamber in the vicinity of the sampling port, turbulent mixing from the burner zones, or an overabundance of air pulled into the combustion unit through the ports in the doors.

Emissions of the measured pollutants were at very low levels, and the ash passed the Toxicity Characteristic Leaching Procedure (TCLP) test. The particle size distribution suggested that the vast majority of the emitted particulate matter was smaller than 0.5 microns.

A very important observation was that the emissions of carbon monoxide and total hydrocarbons correlated very well with the average temperatures of the two primary chambers. This observation suggests that for emergency response deployment, the primary chamber temperatures could be used as a surrogate monitoring parameter to ensure minimization of emissions.

Analysis of amino acid in the ash yielded non-detects for all target analytes. This observation indicates that the gasifier unit would be capable of destroying prions that could potentially cause Transmissible Spongiform Encephalopathy (TSE).

# Disclaimer

The U.S. Environmental Protection Agency through its Office of Research and Development partially funded and collaborated in the research described herein under EP-C-04-023 with ARCADIS G&M. This report has been subject

to an administrative review but does not necessarily reflect the views of the Agency. No official endorsement should be inferred. EPA does not endorse the purchase or sale of any commercial products or services.

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# Acronyms and Abbreviations

APHIS	Animal and Plant Health Inspection Service
CAA	Clean Air Act
CCB(s)	continuing calibration blank(s)
CCV(s)	continuing calibration verification(s)
CEM(s)	continuous emission monitor(s)
COTS	commercial off-the-shelf
$C_{DI}$	ambient O <sub>2</sub> concentration
$C_i$	concentration of pollutant i in ppm
$C_{SC}$	secondary chamber concentration
$C_{ST}$	stack concentration
CVAA	cold vapor atomic absorption spectrophotometry
DoD	U.S. Department of Defense
DQA	data quality assessment
DR	dilution ratio
DSCF	dry standard cubic foot (feet)
DSCM	dry standard cubic meter(s)
EMSL	Environmental Monitoring Systems Laboratory
EPA	U.S. Environmental Protection Agency
g	gram(s)
gal	gallon(s)
GFAA	graphite furnace atomic absorption spectrophotometry
µg	microgram(s)
HPLC	high performance liquid chromatography
hr	hour(s)
HpCDD	heptachlorodibenzo- <i>p</i> -dioxin
HpCDF	heptachlorodibenzofuran
HxCDD	hexachlorodibenzo- <i>p</i> -dioxin
HxCDF	hexachlorodibenzofuran
ICP	inductively coupled plasma optical emission spectrometry
ICV(s)	initial calibration verification(s)
lb	pound(s)
LED	light emitting diode
m	meter(s)
µm	micrometer(s)
mg	milligram(s)
$M_i$	molecular mass of pollutant i
min	minute(s)
MQO(s)	Measurement Quality Objective(s)
Nm <sup>3</sup>	normal cubic meter(s)
NO <sub>x</sub>	oxides of nitrogen
NPT	nominal pipe thread
NSPS	New Source Performance Standard(s)
OCDD	octachlorodibenzo- <i>p</i> -dioxin
OTM-DIM	Other Test Method – Dry Impinger Method

PC	primary chamber
PCDD	polychlorinated dibenzo- <i>p</i> -dioxin
PCDF	polychlorinated dibenzofuran
PeCDF	pentachlorodibenzofuran
pg	picogram(s)
ppm	parts per million
$Q_{DI}$	dilution flow
$Q_S$	stack flow rate
$Q_{SC}$	secondary chamber flow
$Q_{ST}$	stack flow
NA	not available
ND	not detected
NHSRC	National Homeland Security Research Center
OCDF	octachlorodibenzofuran
$PM_{10}$	Particle(s) with an aerodynamic diameter of 10 micrometers or less
PeCDD	pentachlorodibenzo- <i>p</i> -dioxin
QAPP	Quality Assurance Project Plan
R	correlation coefficient
R	ideal gas constant
RCRA	Resource Conservation and Recovery Act
SC	secondary chamber
SETA	Systems Engineering and Technical Assistance
t	time
T	temperature
TCDD	tetrachlorodibenzo- <i>p</i> -dioxin
TCDF	tetrachlorodibenzofuran
TCLP	Toxicity Characteristic Leaching Procedure
TEF	Toxicity Equivalency Factor
TEQ	Toxic Equivalency
THC	total hydrocarbon(s)
TSE	Transmissible Spongiform Encephalopathy
TSWG	Technical Support Working Group
USDA	U.S. Department of Agriculture
WHO	World Health Organization

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# 1.0 Introduction

The U.S. Department of Defense (DoD) operates the Technical Support Working Group (TSWG) under a multi-agency program that provides information and technology development to support the needs of various U.S. government agencies to address counterterrorism and emergency response issues. TSWG, in collaboration with the U.S. Environmental Protection Agency's National Homeland Security Research Center (EPA/NHSRC) and the U.S. Department of Agriculture's Animal and Plant Health Inspection Service (USDA/APHIS) has funded the construction of a transportable gasifier with the goal of processing large quantities of animal carcasses and plant materials resulting from agricultural emergency events. This unit may be useful for other homeland security-related events as an on-site treatment/disposal process. This gasifier converts the biomass material into an inert ash and a combustible synthesis gas that is burned in a secondary combustion chamber. Temperatures within the unit nominally ranged from 1200 to 1800 °F (649 to 982 °C).

This report describes an emissions test to characterize gasifier operation for the following reasons:

- To provide a basis for comparison with other combustion devices;
- To address public concerns about environmental impacts from carcass disposal operations;
- To give state and local environmental agencies information to support their responsibilities in siting and operating combustion equipment; and
- To allow the permanent siting of such devices at industrial settings in the agricultural industry (e.g., at rendering plants) for use with routine mortalities and for energy production.

Testing occurred during the period from March 3 to 6, 2008, at the Valley Protein rendering facility located in Rose Hill, NC. During these tests, the gasifier was operated by the manufacturer (BGP, Inc.) on two different biomass feedstocks:

- A mixture of poultry and swine; and
- Bales of wheat straw.

The initial plan was for poultry and swine to be tested separately. However, feed for the gasifier was acquired by diverting some of the trucks delivering dead stock to the test site to supply material for the gasifier, and the feed stock material dropped onto the concrete receiving pad could remain there no longer than 24 hours. It was therefore not feasible to have a single species of animal for the feed. In addition, due to the highly compressed shakedown schedule, the unit was not operating at full design capacity throughout the tests.

The complete effort involved:

- (1) delivery and setup of the prototype gasifier at the test site for evaluation;
- (2) delivery and installation of advanced shredding/grinding equipment (macerator) at the site;
- (3) acquisition of feed materials for performance testing;
- (4) startup and shakedown of the system, using a variety of feeds and operating conditions;
- (5) establishment of operating parameters required for near-steady-state operation; and
- (6) source sampling during gasifier operation according to an EPA-approved Quality Assurance Project Plan (QAPP) (ARCADIS, 2007). This emissions test report addresses the testing covered by the QAPP.

Samples were taken and analyzed for several targets including:

- Fixed combustion gases, including oxygen, carbon dioxide, carbon monoxide, total hydrocarbons, sulfur dioxide, and oxides of nitrogen;
- Particulate matter, including total filterable particulate, condensable particulates, PM<sub>10</sub>, and particle size distributions;
- Metals;
- Acid gases;
- Polychlorinated dibenzo-*p*-dioxins and polychlorinated dibenzofurans (PCDDs/Fs);
- Leachable metals in the ash residues; and
- Amino acids in the ash residues.

The overall program objective was to deliver a prototype gasifier capable of being transported over all primary and secondary roads, for this prototype gasifier to be capable of being operational in less than 24 hours after arrival at the site, and for this prototype gasifier to have the capability to process 25 tons per day of contaminated animal carcasses or plants.

The objective of these tests was to determine the emission rates and concentrations of the target constituents by sampling the exhaust from the combustion of the synthesis gas produced in the primary chambers of the prototype gasifier.

The resulting data will be utilized by the collaborating entities to determine the operational and environmental impacts of utilizing this gasifier to process different types of agricultural residues. Although there were additional variables of interest (e.g., impact of weather conditions, other feeds), available time and resources precluded including these additional variables as test parameters.





# 2.0 Experimental

## 2.1 Gasifier Description

The BGP-D1000 gasifier is designed to process 25 tons per day of feed material, using a series of chambers, each with different fuel/air stoichiometry. Two independent primary chambers (PCs) operating sub-stoichiometrically feed into two independent secondary chambers (SCs), thus achieving a quasi-steady-state operating mode. Heat from the SCs provides the hearth with heat. The thermal inertia of the hearth prevents significant PC temperature loss when high water content materials are charged onto the hearth. The unit operates on natural draft without requiring an induced draft fan. Up to eight units can be manifolded together to achieve larger capacities, up to approximately 200 tons per day, comparable to other large capacity fixed-site technologies. Figure 2-1 shows a concept schematic diagram of the gasifier. Additional information can be found elsewhere (BGP, 2008).

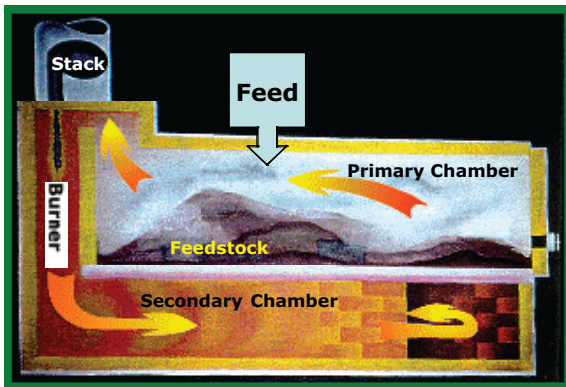


Figure 2-1. Gasifier Concept Schematic (Courtesy BGP, Inc.)

### 2.1.1 Gasifier Construction Details

The BGP-D1000 is prototyped to be compatible with a production model Commercial Off-The-Shelf (COTS) trailer. The prototype length is 27 feet, and the prototype height is 11 feet 5 inches, designed to create a total vehicle height of less than the 162-inch legal limit so that the unit can be transported on all primary and secondary roads in the United States. The width of the prototype is approximately 11 feet 2 inches. The materials selected for the prototype unit shell have been selected to accommodate a standard 35-ton capacity low-boy trailer, capable of transporting a total payload weight of approximately 60,000 pounds. Additionally, the two-chamber design allows for increased flexibility: the gasifier can also handle smaller loads; one PC/SC combination can be left dormant without significantly affecting the operating conditions in the other chambers or one chamber can dispose of one type of waste while the other chamber handles another type. Reducing or partially eliminating any cool-down of the gasifier will increase throughput. Alternate loading of the chambers can be utilized to minimize cool-down.

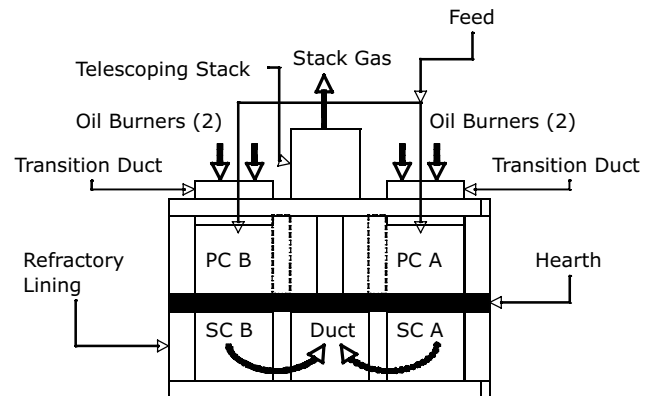


Figure 2-2. Cross-sectional View of Gasifier from the Front

### 2.1.2 Refractory Materials and Trailer Mounting

The refractory materials have been selected based on an assessment of the required transporting and operating conditions of the transportable unit. Ceramic fiber has been incorporated into this highly specialized refractory design, while maintaining refractory strength where required. Figure 2-3 shows a schematic of the gasifier as mounted on a trailer. The burners fire into each SC and the exhaust from the SCs enters the stack from a common breeching. Air is introduced into the PCs through small ports in the doors. No burners fire into the PCs, and all fumes from the PCs must pass through their respective SCs en route to the stack.

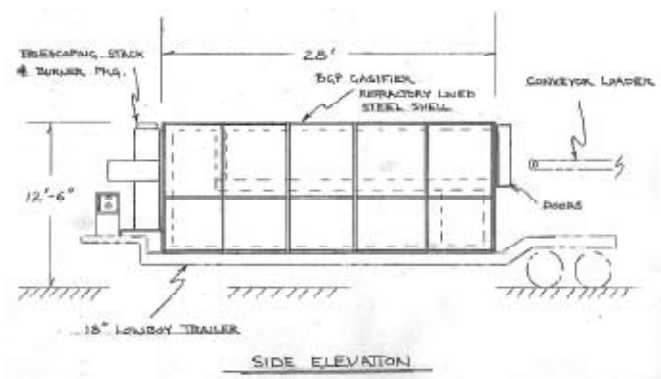


Figure 2-3. Trailer Mounted Transportable Gasifier Schematic (Courtesy BGP, Inc.)

### 2.1.3 Macerator

The COTS macerator that was purchased has a throughput ranging from 60,000 to 100,000 lb/hr of the carcass of any domestic animal species up to approximately the size of pigs. Larger carcasses (e.g., cattle) require a pre-breaker prior to the macerator. The pre-breaker was not included in the purchase of the macerator for the prototype. Figure 2-4 shows the macerator, which is mounted on a second COTS

trailer. Material leaves the macerator as approximately 1-inch chunks, in a slurry similar to that leaving a meat grinder.

The macerator is sized so that several gasifier units can be manifolded into a single macerator, resulting in a technology that is scalable for different-sized events.



**Figure 2-4.** Macerator

### 2.1.4 Feed System

Ground material leaves the macerator and is pumped into a feed distribution system that drops the material through a straight pipe onto the hearth in the PCs through manually actuated high temperature gate valves (see Figure 2-5). The material drops onto the hearth via gravity and is intended to spread out over the entire surface area of the hearth. During the tests, the material did not spread very effectively. Instead, macerated material tended to make piles underneath the feed ports, and hearth coverage was estimated to be only on the order of 40%. The only way to achieve effective distribution of the material on the hearth was to open the front doors of the PCs and manually spread the material using a metal rake. This action disrupted the sub-stoichiometric operation of the gasifier, resulting in the below-design-capacity feed rates observed during the tests. The intermittent nature of these disruptions apparently did not significantly alter the overall stack gas flow rates and thus likely did not affect sample quality.



**Figure 2-5.** Feed Distribution System

The unit was fed using a “bobcat” type front end loader with a nominal bucket capacity between 500 and 600 lb (based on operator experience). Materials were scooped off the ground and loaded into the macerator as shown in Figure 2-6.



**Figure 2-6.** Feeding Animal Carcasses into Macerator

### 2.1.5 Stack

The gasifier unit is equipped with a 34-inch diameter and approximately 12-foot high telescoping stack (Figure 2-7) projecting above the gasifier, with a 34-inch diameter dilution air inlet at the base of the stack (Figure 2-8), which allows control of the natural draft that draws the air through the primary chambers and draws the combustion gases through the secondary combustion chambers. Sampling ports



**Figure 2-7.** Telescoping Stack

(and consequently stack measurements) would normally be located at least 8 stack diameters downstream of the dilution air inlet. However, the stack’s height is only 12 feet, which will not allow such sampling port placement. In this case, measurements were made at least 2 stack diameters downstream of the damper (visible inside the dilution duct on Figure 2-7). Since any particulate matter measurements at the stack must be corrected for background PM in the dilution air, it was necessary to characterize the flow rate and PM loading in the dilution air. A duct extension was therefore mounted on the dilution air inlet so that the dilution air flow rate could be measured at an appropriate distance from the air

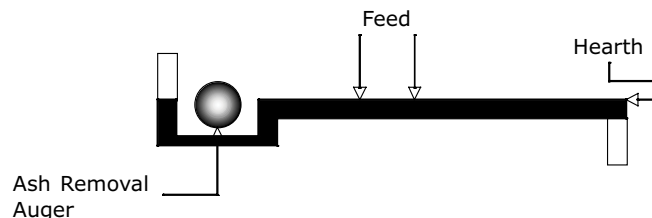
entrance of the duct extension without entrance disturbance. NOTE: The flow rate through the dilution air inlet was too low to be measured using any of the gas flow measurement devices that were available to the sampling crew, so dilution air was estimated using the dilution ratio based on the stack and SC concentrations of oxygen and carbon dioxide. The PM concentration in the dilution air was quantified by a traditional ambient PM<sub>10</sub> particulate sampler positioned near the dilution air duct inlet.



**Figure 2-8.** Stack Dilution Inlet

### 2.1.6 Auxiliary Fuel System

Four burners (two were redundant) capable of each firing 8 gal/hr of No. 2 fuel oil were mounted in the duct between the primary and secondary chambers (i.e., two burners on each side). These burners provided initial heat to make the hearth hot enough to initiate gasification in the primary chambers. The burners also provided process control to maintain predetermined temperatures in the secondary chambers. Each burner was fed from a fuel tank mounted on the trailer. The burner fuel tanks were refilled from a 500-gallon fuel tank positioned at the rear end of the trailer. It was advantageous that each burner had a redundant duplicate, since two of the burners failed during shakedown due to overheating after a generator failure. This failure led to an important lesson about the need to be able to swap out and/or repair the burners while the unit was operating. The fuel in the tanks was analyzed by Standard Laboratories, Inc., and was found to be low in sulfur (0.02%) and nitrogen (0.01%) with < 0.001 % ash content.



**Figure 2-9.** Cross-sectional View of Hearth and Ash Removal Auger

### 2.1.7 Ash Removal System

The gasifier unit was designed with a reservoir at the back end of the primary chamber to collect ash from the hearths (see Figure 2-9). An ash removal auger was supposed to periodically remove the ash to be collected in metal bins outside the gasifier. However, the ash removal auger was damaged during startup and did not work throughout the tests. There was no way to quantify the amount of ash produced in the process.

## 2.2 Sampling and Analytical Methods

Sampling was performed over four test days during which the gasifier was operating under representative conditions as determined during a very brief period of shakedown testing. Extractive samples were taken for periods as specified in Table 2-1. Much of the monitoring instrumentation that was supposed to be installed by BGP was not available in the manner prescribed in the QAPP due to financial constraints and the compressed schedule. In particular, the following measurements that were specified in the QAPP were not available on the prototype:

- Feedstock feed rate and macerator pump indicator;
- Fuel oil flow rate;
- Burner and secondary air flow rate;
- Air flow rate to primary chamber; and
- Ash mass.

Wherever possible, alternate means for estimating these parameters were used and the methods are documented in this report. The most significant deficiency was the uncertainty in the feed weights. This uncertainty is likely to affect the overall estimated emissions calculations in Section 3.10. However, given that most emission factors published in the EPA's AP-42 emission factor database [EPA, 1995] are typically order-of-magnitude estimates, these uncertainties are not likely to significantly change the interpretation of the test results.

### 2.2.1 Measurement of Process Parameters

The prototype unit was equipped with minimal process measurement instrumentation. Only the temperatures in the PCs and SCs were monitored, and the temperatures were only available via an LED readout (shown in Figure 2-10) on the control panel for each PC/SC combination. The temperatures from these readouts were manually recorded onto data sheets every 15 minutes, except when the vegetative matter was being fed, in which case the temperatures were manually recorded every 2 minutes.



**Table 2-1.** Table of Sampling Activities

Parameter	Location	Sampling/ Analytical Method	Frequency of Sampling	Sampling Day
Feedstock feed rate	Field	Visual estimation based on 550 lb/bucket on bobcat and bobcat operator experience	Each feed event	All
Fuel oil flow rate	500-gal fuel tank	Dipstick	Each time fuel added or taken from tank	All
Oil fuel elemental composition (C, H, O, N, and S) and heating value	Fuel tank	Supplied by vendor or grab sampling	One sample	Grab
Dilution air flow rate and temperature	Damper air duct	EPA Methods 1 & 2	NO DATA – FLOW TOO LOW TO MEASURE	All
Stack flue gas flow rate and temperature	Stack	EPA Methods 1 & 2	Traverse during all extractive tests	All
Temperatures	Primary chamber	Single point in each PC	15 min (2 during vegetable matter)	All
Temperature	Secondary chamber	Single point in each SC	15 min (2 during vegetable matter)	All
Ash composition	Front door	Periodic grab samples	One per day from each PC	Grab
Diluted flue gas composition (O <sub>2</sub> , CO <sub>2</sub> , CO, NO <sub>x</sub> -, SO <sub>2</sub> , and THC)	Stack	CEM (EPA M3A, 10, 7E, 6C, 25A)	Continuous	All
Flue gas prior to dilution (O <sub>2</sub> and CO <sub>2</sub> )	Exit of SC	CEM (EPA M3A)	Continuous	All
PM <sub>10</sub> and condensable particulate	Stack	EPA Methods 201A & 202	One sample per day	1, 2, 3
Total PM, HCl, and Cl <sub>2</sub>	Stack	EPA Methods 5 & 26	Two samples per day	1, 2, 3
Dioxins/furans in flue gas	Stack	EPA Method 23	Two samples per day	1, 2, 3
Metals in flue gas	Stack	EPA Method 29	Two samples per day	1, 2, 3
PM <sub>10</sub> in dilution air	Ambient	EPA HiVol	One sample per day	1, 2, 3
PC Syngas composition (CO, CO <sub>2</sub> , H <sub>2</sub> , O <sub>2</sub> , H <sub>2</sub> O, CH <sub>4</sub> , and non-methane HC)	Primary chamber	EPA M3C, 25C	At least one sample per day	1, 2, 3
Visible Emissions (Opacity)	Stack	EPA Method 9	Intermittently during carcass burns, continuously during vegetative burns	1,2,3,4



Figure 2-10. Temperature Readouts

Feed rates were measured by estimation of the degree of fullness of the bucket in the front end loader shown in Figure 2-6. Based on operator experience, a full bucket contained between 500 and 600 lb of material, while a half bucket contained between 250 and 300 lb of material. Neither the large 500-gallon fuel tank that was used as a reservoir for the burner fuel tanks nor the burner fuel tanks had any sort of level indicator, sight glass, or flow measurement device. In order to measure fuel consumption rates, a broomstick was used as a dipstick in the large fuel tank. The measurements of the tank are shown in Figure 2-11. A discussion of procedures used to measure the fuel consumption rate follows.

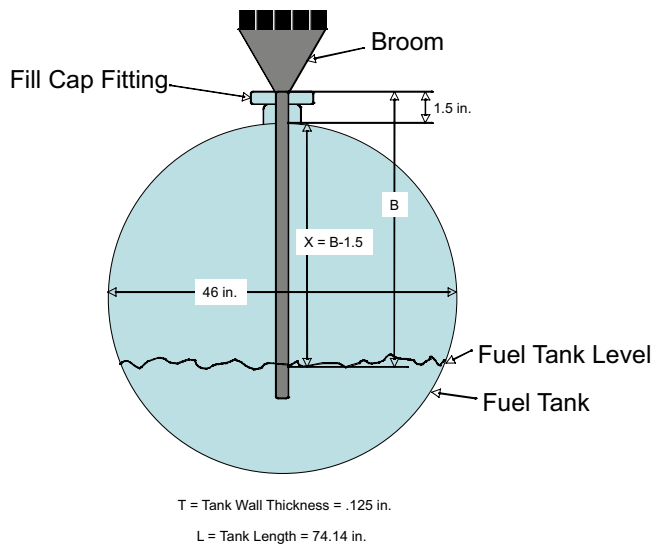


Figure 2-11. Dimensions of Broom and 500-gallon Fuel Tank

A geometric construction of the tank was created. This construction is shown in Figure 2-12.

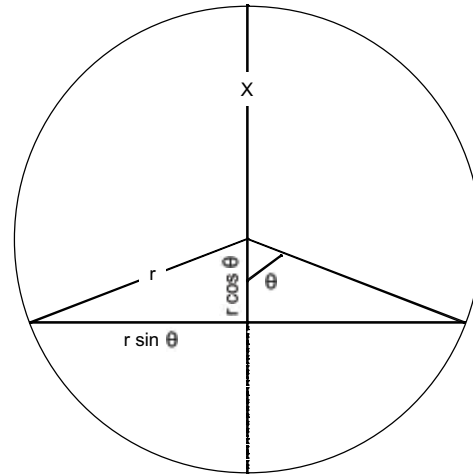


Figure 2-12. Geometric Construction of 500-gallon Fuel Tank

Using this geometric construction,

$$(1) \text{ Cross-sectional area of tank} = \pi r^2 \quad (1)$$

(2) Area of slice of tank cut by angle

$$\theta = (\pi r^2) \left( \frac{2\theta}{2\pi} \right) = r^2 \theta \quad (2)$$

The cross-sectional area of the equilateral triangle formed by two radii and the line formed by the fuel in the tank is defined as:

$$\text{Area}_{\Delta} = 2 \left( \frac{1}{2} \right) (r \sin \theta) (r \cos \theta) = r^2 \sin \theta \cos \theta \quad (3)$$

The cross-sectional area of the liquid in the tank is calculated by subtracting Eq. (3) from Eq. (2):

$$\text{Area}_{\text{liquid}} = r^2 \theta - r^2 \sin \theta \cos \theta \quad (4)$$

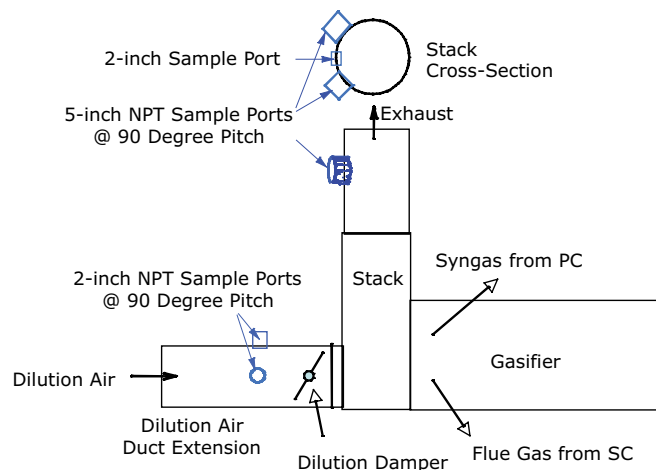
The known quantity is X, the distance from the top of the tank to the liquid level in the tank. Thus:

$$r - (2r - X) = r \cos \theta \quad (5)$$

Therefore:

$$\theta = \arccos \left( \frac{X}{r} - 1 \right) \quad (6)$$

A spreadsheet was used to calculate  $\theta$  as a function of X using Eq. (6), and the values for  $\theta$  were used in Eq. (4) to estimate the cross-sectional area. The volume of the liquid was calculated by multiplying the cross-sectional area by the length of the tank (allowing for the 1/8" wall thickness of the tank).



**Figure 2-13.** Stack Side View

### 2.2.2 Sampling

The primary sampling location was the stack of the gasifier. The stack has a 34-inch inner diameter and an extended height of 12 feet. Two 5-inch diameter sampling ports were located at 90 degrees from each other and a third 2-inch port was located between the two. The location of the two 5-inch ports was determined according to the requirements described in the EPA sampling Methods 1 and 2 to increase the accuracy of the flow measurement. The two-inch port was installed to accommodate non-isokinetic sampling, e.g., CEMs and particle sizing. Figure 2-13 shows the configuration of these sampling ports. With the isokinetic sampling trains utilizing the two 5-inch nominal pipe thread (NPT) ports (e.g., metals, dioxin/furans), the stack was traversed to measure the variation in gas velocity over its cross-section by rotating the sampling trains between the ports. With the height of the trailer included, gasifier samples were taken at approximately 26–28 feet above the ground.

The secondary sampling location was the dilution air duct extension (as provided by the manufacturer). The extension had two 2-inch ports located 90 degrees apart to accommodate non-isokinetic sampling, e.g., CEMs and air flow rate determination. Unfortunately, the flow in this duct was too low in velocity to measure with the available equipment. An ambient total particulate sampler located near its inlet quantified the contribution of the dilution air to the stack particulate loading.

The target stack gas constituents and parameters of interest in this program are:

- PM<sub>10</sub> particulate matter;
- Total particulate matter;
- Condensable particulate matter;
- RCRA/CAA metals (Sb, As, Ba, Be, Cd, Cr, Co, Pb, Mn, Hg, Ni, Se, Ag);
- HCl/Cl<sub>2</sub>;
- Dioxins/furans;
- CO<sub>2</sub>;
- O<sub>2</sub>;
- CO;
- NO<sub>x</sub>;
- SO<sub>2</sub>; and
- Total Hydrocarbons (THC).

Since the gasifier utilizes a natural draft and dilution air inlet (with potentially particle-laden ambient air) prior to the stack, corrections may need to be made to allow characterization of the emissions at the stack. Therefore, the original plan was to take simultaneous samples for PM in the ambient air near the dilution air inlet so that background PM present in the dilution air could be subtracted from the PM measured at the stack, resulting in the PM emissions due to the gasifier only. However, due to the low gas velocities in the dilution duct, the flow rates could not be quantified. Therefore, a traditional PM<sub>10</sub> particulate sampler was positioned near the dilution air duct inlet so that the ambient PM could be quantified.

In addition to the stack gas constituents, a number of opportunistic samples were taken from various points within the gasifier to aid in the further characterization of the system and to help optimize the operation. These samples included:

- Periodic grab samples of the gasification product gas in the PCs (i.e., synthesis gas) through sampling ports near the exit of primary chamber B;
- CO prior to dilution air inlet monitored through the sampling line, which connects the exit of the secondary chamber to the CEM;
- Temperatures and flow rates at all sampling locations and within the system where practical; and
- Ash after it was augered. However, the auger failed during startup. Therefore, ash was pulled out the front (through the open doors with a rake) when the manual “push back” was occurring.

# 3.0 Results

## 3.1 Process Parameter Measurements

For all the runs, Day 1 through Day 4 corresponds to March 3 to 6, 2008, respectively. Table 3-1 lists the fuel consumption results over the duration of the tests.

The  $\Delta t$  values represent the time between measurement events, which either corresponded to when the individual burner fuel tanks were topped off (both tanks were always topped off at the same time) or else times when the 500-gallon fuel tank was filled via the daily fuel delivery. The burners were operating continuously 24 hours per day throughout the entire test series.

Tables 3-2 through 3-5 list the manually recorded temperatures and SC set points for Day 1 through Day 4, respectively. Blank entries in the tables represent times when no measurements were made.

The set points on the SCs were slightly varied at times in order to provide additional heating to the PC hearths in an attempt to increase material throughput. In general, this procedure was not effective at increasing throughput, mainly because the reduction in throughput resulted from poor distribution of the macerated carcass material on the hearth and not from inadequate hearth temperatures.

**Table 3-1.** Fuel Consumption Results

Test Day	Time	Broom Length (in) ["B" in Figure 2-11]	Fuel in Tank (gal)	Elapsed t (hr)	Fuel Used (gal)	Fuel Usage Rate (gal/hr)
1	15:00	30.4	176	7.0	103.4	14.8
1	20:30	12.5	429	5.0	80.9	16.2
2	8:11	22.0	298	11.7	131.1	11.2
2	13:45	27.5	218	5.6	80.4	14.4
3	5:00	20.5	320	15.3	198.7	13.0
3	11:37	25.5	247	6.6	73.0	11.0
4	7:00	24.5	261	19.4	253.9	13.1
4	13:45	11.9	437	1.7	16.5	9.9

**Table 3-2.** Temperature and Set Point Data from Test Day 1

Time	Right Side (B) PC (°F)	Right Side (B) SC (°F)	Right Side (B) Set Point (°F)	Left Side (A) PC (°F)	Left Side (A) SC (°F)	Left Side (A) Set Point (°F)
8:15		1601	1600	NA	1582	1600
8:30		1598	1600	NA	1578	1600
8:45		1591	1600	NA	1582	1600
9:00	1540	1582	1600	NA	1579	1600
9:15	1514	1593	1600	NA	1578	1600
9:30	1497	1594	1600	NA	1578	1600
9:50	1488	1596	1600	NA	1598	1600
10:00	1467	1596	1600	NA	1574	1600
10:18	1457	1588	1600	NA	1566	1600
10:30	1450	1587	1600	NA	1560	1600
10:45	1432	1585	1600	NA	1553	1600
10:59	1426	1560	1600	NA	1548	1600
11:13	1407	1597	1600	NA	1540	1600
11:30	1445	1593	1600	NA	1535	1600
11:45	1395	1596	1600	NA	1547	1600
11:58	1236	1591	1600	NA	1542	1600
12:15	1502	1692	1600	NA	1548	1600
12:30	1592	1683	1600	NA	1543	1600
12:45	1596	1661	1600	NA	1541	1600
13:00	1568	1654	1600	NA	1535	1600
13:14	1530	1644	1600	NA	1531	1600
13:30	1485	1636	1600	NA	1526	1600
13:45	1437	1490	1600	NA	1525	1600
14:00	1428	1598	1600	NA	1530	1600
14:15	1311	1557	1600	NA	1533	1600
14:30	1429	1576	1600	NA	1544	1600
14:45	1302	1564	1600	NA	1531	1600
15:00	1321	1562	1600	NA	1541	1600
15:15	1421	1600	1600	NA	1554	1600
15:30	1262	1598	1600	NA	1552	1600
15:45	1304	1589	1600	NA	1564	1600
15:59	1011	1575	1600	NA	1550	1600
16:15	1084	1590	1600	NA	1533	1600
16:30	1221	1577	1600	NA	1528	1600
16:45	912	1576	1600	NA	1519	1600
17:03	798	1571	1600	NA	1512	1600
17:15	804	1571	1600	NA	1518	1600
17:30	897	1579	1600	NA	1518	1600
17:45	1262	1500	1600	NA	1521	1600
18:00	1286	1576	1600	NA	1523	1600
18:15	1360	1550	1600	NA	1523	1600

NA – Not available



**Table 3-3.** Temperature and Set Point Data from Test Day 2

Time	Right Side (B) PC (°F)	Right Side (B) SC (°F)	Right Side (B) Set Point (°F)	Left Side (A) PC (°F)	Left Side (A) SC (°F)	Left Side (A) Set Point (°F)
7:30	1201	1587	1600	1519	1599	1600
7:45	1083	1569	1600	1715	1462	1600
8:00	1063	1584	1600	1666	1582	1600
8:15	999	1553	1600	1649	1596	1600
8:30	949	1540	1600	1604	1590	1600
8:45	1311	1628	1600	1603	1585	1600
9:00	1144	1615	1600	1594	1552	1600
9:15	1299	1632	1600	1542	1548	1600
9:30	1094	1629	1600	1518	1577	1600
9:45	1146	1629	1700	1404	1593	1700
10:00	1249	1670	1700	1359	1668	1700
10:15	1222	1689	1700	1692	1697	1700
10:30	1253	1695	1700	1522	1663	1700
10:45	1308	1692	1700	1398	1644	1700
11:00	1344	1694	1700	1330	1621	1700
11:15	1450	1696	1700	1649	1681	1700
11:30	1471	1695	1700	1438	1710	1700
11:45	1494	1691	1700	1493	1727	1700
12:00	1441	1688	1700	1547	1724	1700
12:15	1428	1680	1700	1390	1710	1700
12:34	1500	1698	1700	1480	1692	1700
12:47	1380	1681	1700	1480	1700	1700
13:00	1419	1614	1700	1416	1702	1700
13:15	1494	1647	1700	1461	1703	1700
13:30	1530	1695	1700	1503	1695	1700
13:45	1518	1654	1700	1544	1687	1700
14:00	1526	1631	1700	1587	1688	1700
14:15	1544	1611	1700	1609	1696	1700
14:30	1586	1689	1700	1628	1700	1700
14:45	1591	1641	1700	1636	1699	1700
15:00	1592	1624	1700	1646	1687	1700
15:15	1619	1638	1700	1674	1692	1700
15:30	1628	1662	1700	1666	1694	1700

**Table 3-4.** Temperature and Set Point Data from Test Day 3

Time	Right Side (B) PC (°F)	Right Side (B) SC (°F)	Right Side (B) Set Point (°F)	Left Side (A) PC (°F)	Left Side (A) SC (°F)	Left Side (A) Set Point (°F)
7:30	1411	1653	1700	1473	1679	1700
7:45	1360	1649	1700	1461	1595	1700
8:00	1239	1692	1700	1217	1673	1700
8:17	1322	1660	1700	1325	1660	1700
8:30	1356	1666	1700	1401	1664	1700
8:45	1388	1653	1700	1420	1673	1700
9:00	1390	1695	1700	1427	1688	1700
9:15	1487	1664	1700	1535	1680	1700
9:30	1539	1772	1700	1154	1711	1700
9:47	1189	1783	1700	1105	1750	1700
10:00	1308	1772	1700	1193	1778	1700
10:15	1544	1749	1700	1333	1779	1700
10:32	1408	1776	1700	1439	1795	1700
10:45	1452	1794	1700	1434	1796	1700
11:00	1492	1800	1700	1512	1794	1700
11:15	1525	1757	1700	1478	1785	1700
11:30	1452	1758	1700	1520	1789	1700
11:47	1507	1787	1700	1566	1800	1700
12:00	1323	1753	1700	1637	1787	1700
12:15	1377	1792	1700	1647	1762	1700
12:30	1409	1781	1700	1773	1780	1700
12:45	1446	1790	1700	1687	1753	1700
13:00	1489	1752	1700	1425	1786	1700
13:15	1512	1787	1900	1645	1833	1900
13:30	1453	1802	1900	1520	1829	1900
13:45	1488	1787	1900	1574	1792	1900
14:00	1518	1756	1900	1620	1792	1900
14:15	1523	1742	1900	1688	1770	1900
14:30	1517	1795	1900	1722	1759	1900
14:45	1297	1805	1900	1590	1759	1900
15:00	1521	1870	1900	1566	1746	1900
15:15	1473	1896	1900	1539	1772	1900
15:31	1466	1853	1900	1604	1758	1900
15:45	1490	1762	1900	1429	1732	1900
16:00	1506	1799	1900	1505	1752	1900
16:15	1483	1800	1900	1574	1740	1900

**Table 3-5.** Temperature and Set Point Data from Test Day 4

Time	Right Side (B) PC (°F)	Right Side (B) SC (°F)	Right Side (B) Set Point (°F)	Left Side (A) PC (°F)	Left Side (A) SC (°F)	Left Side (A) Set Point (°F)
10:40	884	1588	1600	650	1462	1600
11:00	870	1571	1600	730	1575	1600
11:15	745	1578	1600	800	1560	1600
11:16	755	1600	1600			1600
11:17	757	1569	1600			1600
11:18	760	1597	1600			1600
11:19	960	1542	1600			1600
11:20	837	1592	1600			1600
11:21	808	1561	1600			1600
11:22	811	1592	1600			1600
11:23	810	1543	1600			1600
11:24	811	1586	1600			1600
11:25	808	1558	1600			1600
11:26	800	1586	1600			1600
11:27	796	1598	1600			1600
11:28	788	1556	1600			1600
11:29	745	1590	1600	1223	1573	1600
11:30	1046	1566	1600			1600
11:31	1023	1560	1600			1600
11:32	1118	1570	1600			1600
11:33	1147	1589	1600			1600
11:34	1198	1542	1600			1600
11:35	1245	1598	1600			1600
11:36	1320	1562	1600			1600
11:37	1335	1598	1600			1600
11:38	1333	1560	1600			1600
11:39	1326	1594	1600			1600
11:40	1316	1582	1600			1600
11:41	1311	1576	1600			1600
11:42	1305	1597	1600			1600
11:43	1310	1535	1600			1600
11:44	1307	1587	1600			1600
11:45	1306	1599	1600	1162	1569	1600
11:46	1303	1559	1600			1600
11:47	1298	1596	1600			1600
11:48	1293	1551	1600	1143	1571	1600
11:49			1600	1133	1571	1600
11:50			1600	1018	1551	1600
11:51			1600	1261	1558	1600
11:52			1600	1291	1565	1600
11:53			1600	1323	1568	1600
11:54			1600	1348	1567	1600
11:55			1600	1329	1568	1600
11:56			1600	1319	1568	1600
11:57			1600	1311	1567	1600
11:58			1600	1309	1566	1600
11:59			1600	1303	1568	1600
12:00	1261	1584	1600	1295	1564	1600

**Table 3-5.** Temperature and Set Point Data from Test Day 4 (Continued)

Time	Right Side (B) PC (°F)	Right Side (B) SC (°F)	Right Side (B) Set Point (°F)	Left Side (A) PC (°F)	Left Side (A) SC (°F)	Left Side (A) Set Point (°F)
12:02			1600	1282	1567	1600
12:04			1600	1272	1568	1600
12:06			1600	1265	1565	1600
12:15	1270	1602	1600	1224	1567	1600
12:21			1600	1373	1567	1600
12:23	1439	1570	1600	1375	1564	1600
12:25	1440	1594	1600	1366	1564	1600
12:27	1413	1590	1600	1365	1569	1600
12:29	1390	1590	1600	1358	1566	1600
12:30	1378	1545	1600			1600
12:31			1600	1353	1565	1600
12:32	1363	1598	1600			1600
12:33			1600	1347	1565	1600
12:34	1342	1594	1600			1600
12:35			1600	1346	1568	1600
12:36	1329	1584	1600			1600
12:37			1600	1343	1567	1600
12:38	1318	1578	1600			1600
12:39			1600	1350	1568	1600
12:40	1308	1537	1600			1600
12:41			1600	1342	1566	1600
12:42	1298	1537	1600			1600
12:43			1600	1474	1571	1600
12:44	1293	1560	1600			1600
12:45			1600	1460	1573	1600
12:46	1287	1578	1600			1600
12:47			1600	1426	1574	1600
12:48	1281	1597	1600			1600
12:49			1600	1412	1573	1600
12:50	1275	1599	1600			1600
12:51			1600	1402	1576	1600
12:52	1269	1591	1600			1600
12:53			1600	1392	1573	1600
12:54	1399	1579	1600			1600
12:55			1600	1383	1573	1600
12:56	1464	1599	1600			1600
12:57			1600	1378	1578	1600
12:58	1486	1600	1600			1600
13:00	1494	1600	1600	1373	1576	1600
13:02	1485	1597	1600	1370	1574	1600
13:04	1466	1592	1600	1662	1549	1600
13:06	1444	1594	1600	1698	1579	1600
13:08	1428	1598	1600	1725	1584	1600
13:10	1420	1598	1600	1675	1587	1600
13:12	1406	1585	1600	1629	1587	1600

**Table 3-5. Temperature and Set Point Data from Test Day 4 (Continued)**

Time	Right Side (B) PC (°F)	Right Side (B) SC (°F)	Right Side (B) Set Point (°F)	Left Side (A) PC (°F)	Left Side (A) SC (°F)	Left Side (A) Set Point (°F)
13:13	1687	1563	1600			1600
13:14			1600	1599	1586	1600
13:15	1687	1569	1600			1600
13:16			1600	1564	1588	1600
13:17	1691	1575	1600			1600
13:18			1600	1547	1586	1600
13:19	1670	1592	1600			1600
13:20			1600	1535	1527	1600
13:21	1623	1580	1600			1600
13:22			1600	1527	1586	1600
13:23	1607	1600	1600			1600
13:24			1600	1676	1574	1600
13:25	1582	1568	1600			1600
13:26			1600	1709	1581	1600
13:27	1650	1563	1600			1600
13:28			1600	1704	1592	1600
13:29	1599	1586	1600			1600
13:30			1600	1689	1596	1600
13:31	1658	1586	1600			1600
13:32			1600	1673	1594	1600
13:33	1682	1560	1600			1600
13:34			1600	1654	1596	1600
13:35	1692	1562	1600			1600
13:36			1600	1640	1597	1600
13:37	1687	1577	1600			1600
13:38			1600	1622	1596	1600
13:39	1655	1541	1600			1600

Table 3-6 lists the estimated feed quantities and feed times. These feed quantities are based on 550 lb per bucket (approximately  $\pm 50$  lb) load on the front end loader, and

35 lb/bale of wheat straw. Blank entries in the table represent times when no measurements were made.

**Table 3-6.** Estimated Feed Quantities and Times

Test Day	Time	Loader Buckets into PC A	Loader Buckets into PC B	Material	Quantity (lb)
1	14:07	1		Poultry and Swine	550
1	14:10		1	Poultry and Swine	550
1	14:32		1	Poultry and Swine	550
1	14:36		1	Poultry and Swine	550
1	15:23		1	Poultry and Swine	550
1	15:45		1	Poultry and Swine	550
1	15:47	1		Poultry and Swine	550
1	16:38		1	Poultry and Swine	550
1	16:41	1		Poultry and Swine	550
2	8:54		1	Poultry and Swine	550
2	9:28		1	Poultry and Swine	550
2	11:24	0.5		Poultry and Swine	275
2	11:57		0.5	Poultry and Swine	275
2	12:03	0.5		Poultry and Swine	275
2	12:43		3	Poultry and Swine	1650
2	12:47	0.5		Poultry and Swine	275
2	16:00	2	2	Poultry and Swine	2200
3	6:15	0.5	0.5	Mostly Swine	550
3	7:55		1	Mostly Swine	550
3	7:57	1		Mostly Swine	550
3	10:27		0.5	Mostly Swine	275
3	10:40	0.5		Mostly Swine	275
3	11:10	0.5		Poultry and Swine	275
3	11:17		0.5	Poultry and Swine	275
3	11:54		1	Poultry and Swine	550
3	13:16		0.5	Poultry and Swine	275
3	13:23	0.5		Poultry and Swine	275
3	14:30	0.5		Poultry and Swine	275
3	15:00	0.5		Poultry and Swine	275
3	15:05		0.5	Poultry and Swine	275
3	15:24	0.5		Poultry and Swine	275
3	15:37	0.5		Poultry and Swine	275
Test Day	Time	Bales into PC A	Bales into PC B	Material	Quantity (lb)
4	11:29		2	Wheat Straw	70
4	11:50	1		Wheat Straw	35
4	12:23		1	Wheat Straw	35
4	12:41	1		Wheat Straw	35
4	12:54		1	Wheat Straw	35
4	13:02	1		Wheat Straw	35
4	13:13		1	Wheat Straw	35
4	13:24	1		Wheat Straw	35
4	13:27		1	Wheat Straw	35

By breaking the day up into 3-hour blocks and averaging the carcass feed quantities over those periods, Figure 3-1 was developed. This figure shows the unit was operating at approximately 30–40% of its design capacity during the tests. The average carcass feed rate over all runs was 0.32 tons/hr, which was about 1/3 of target.

### 3.2 Continuous Emissions Monitors

Plots of CEM data are based on a completed validation of the CEM data (raw CEM data can be found in Volume 2 of this report). Invalid data were removed from the data set. Invalid data resulted during periods of zero/span checks, instrument manipulation (swapping instruments and modifying sample flows, checking probes, etc.).

The dilution ratio (DR) is defined as:

$$DR = \frac{Q_{ST}}{Q_{SC}} \quad (7)$$

where  $Q_{ST}$  is stack flow and  $Q_{SC}$  is the secondary chamber flow. DR can be calculated using either  $CO_2$  measurements or  $O_2$  measurements.

Calculation of DR using  $CO_2$  measurements is done with the following equation:

$$Q_{ST}C_{ST} = Q_{SC}C_{SC} \quad (8)$$

which results in the following:

$$DR_{CO_2} = \frac{Q_{ST}}{Q_{SC}} = \frac{C_{SC}}{C_{ST}} \quad (9)$$

where  $C_{ST}$  is the stack  $CO_2$  concentration and  $C_{SC}$  is the SC  $CO_2$  concentration.

Calculation of DR using  $O_2$  measurements is done with the following equation:

$$Q_{ST}C_{ST} = Q_{DI}C_{DI} + Q_{SC}C_{SC} \quad (10)$$

where  $Q_{DI}$  is dilution flow and  $C_{DI}$  is the ambient  $O_2$  concentration (21%).

Therefore

$$DR_{O_2} = \frac{(21 - C_{SC})}{(21 - C_{ST})} \quad (11)$$

There was an approximately 10% difference between calculating the DR via the two different methods. Dilution ratios plotted in the following sections represent an average of the DR calculated via  $CO_2$  and  $O_2$ .

In all of the Figures from 3-2 to 3-26, a “feed event” is defined as a point in time when a load of material was dumped into the macerator and pumped onto one of the hearths; a “door event” is defined as a time when the front doors of the gasifier were opened and either the burning material on the hearth was spread out or ash was pushed to the back of the PC.

#### 3.2.1 Continuous Emissions Data from Test Day 1 (March 3, 2008)

The feed material for Test Day 1 was a mixture of swine and poultry carcasses. The day started with unburned animal carcass material remaining from the material that was fed to the PCs the night before. On Test Day 1, carcass feeding began around the same time as initiation of operation of the second set of sampling trains. The PC thermocouple on Side A did not operate correctly for the entire day. On this test day, the CEM sampling out of the SC had not been set up yet.

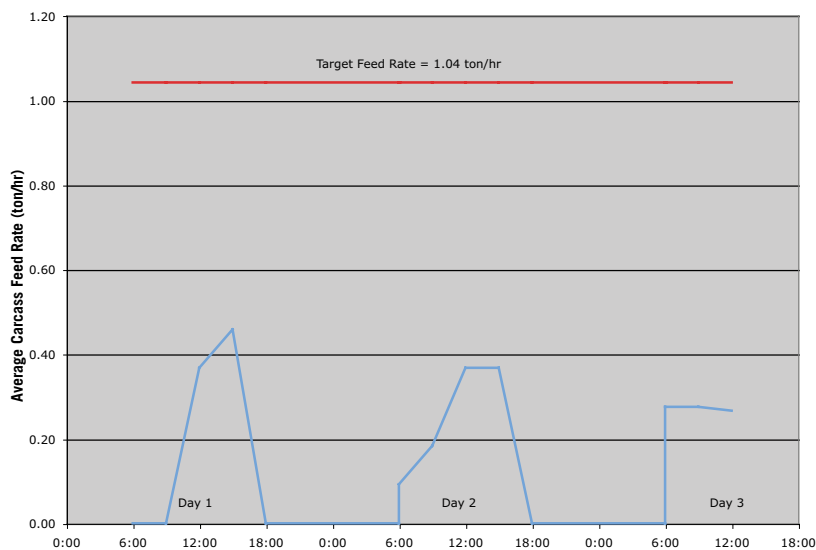


Figure 3-1. Average Carcass Feed Rate

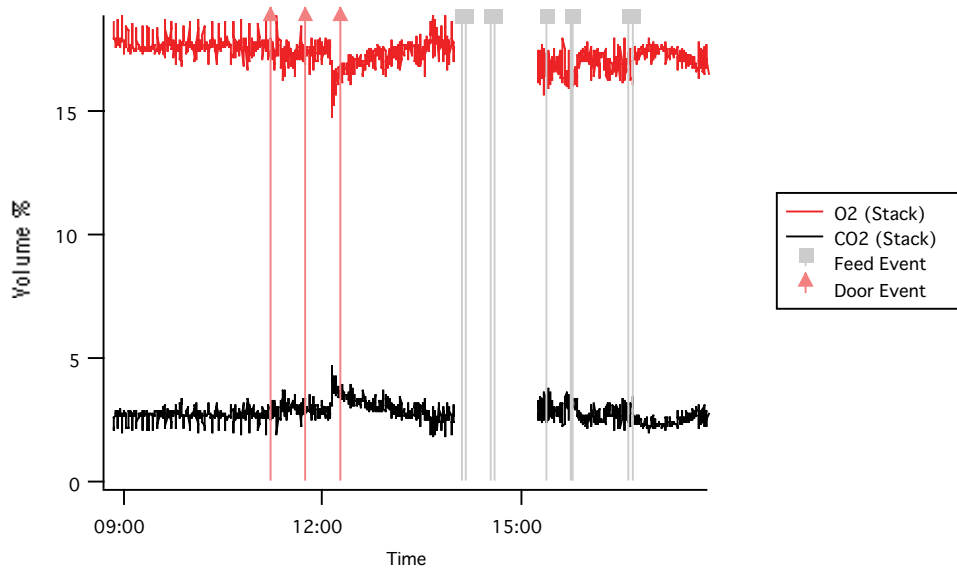


Figure 3-2. Stack O<sub>2</sub> and CO<sub>2</sub> from Test Day 1

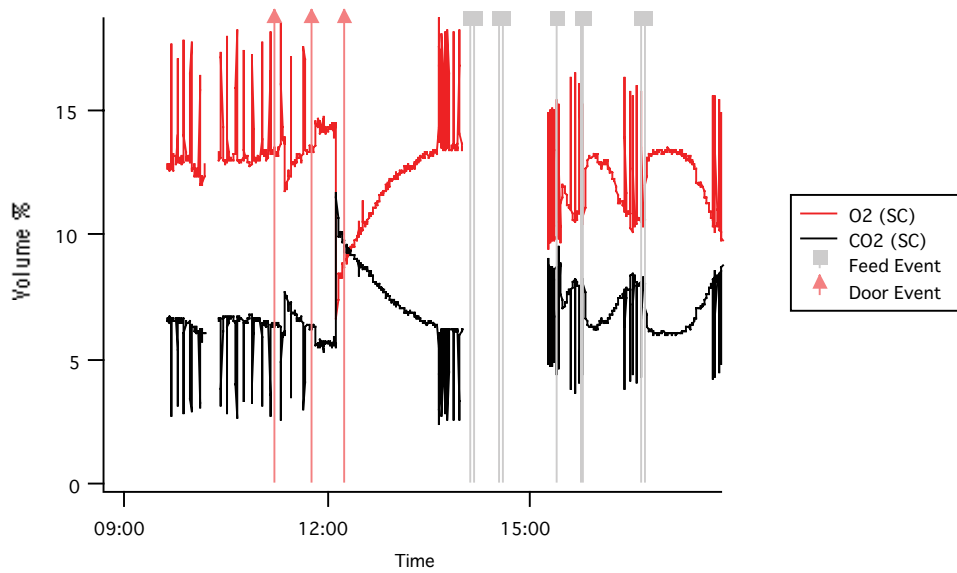


Figure 3-3. SC O<sub>2</sub> and CO<sub>2</sub> from Test Day 1

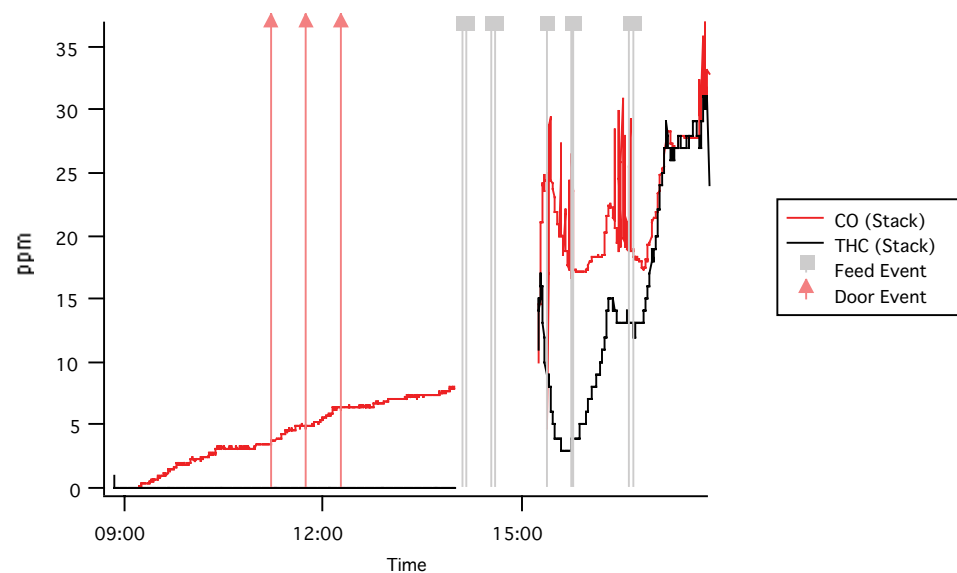


Figure 3-4. Stack CO and THC from Test Day 1



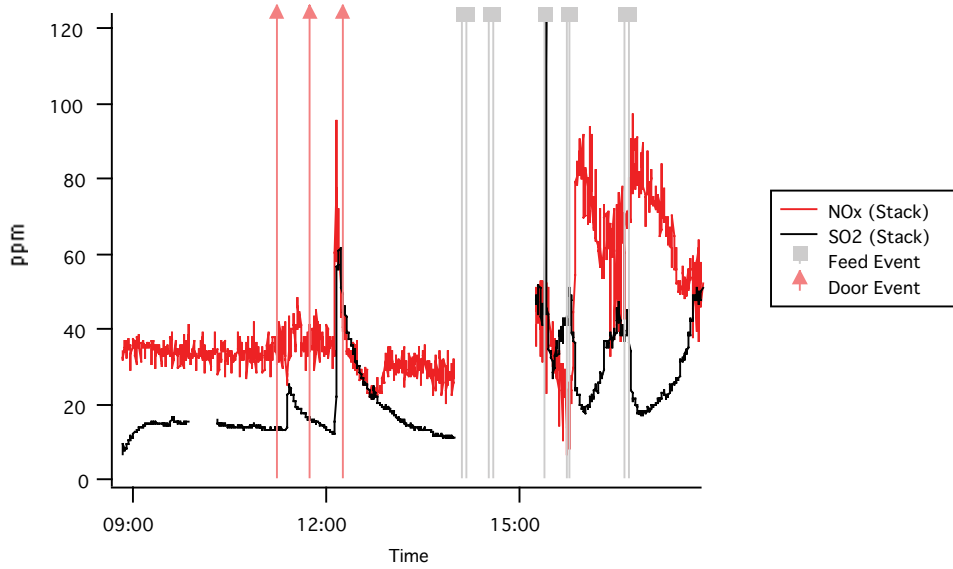


Figure 3-5. Stack NO<sub>x</sub> and SO<sub>2</sub> from Test Day 1

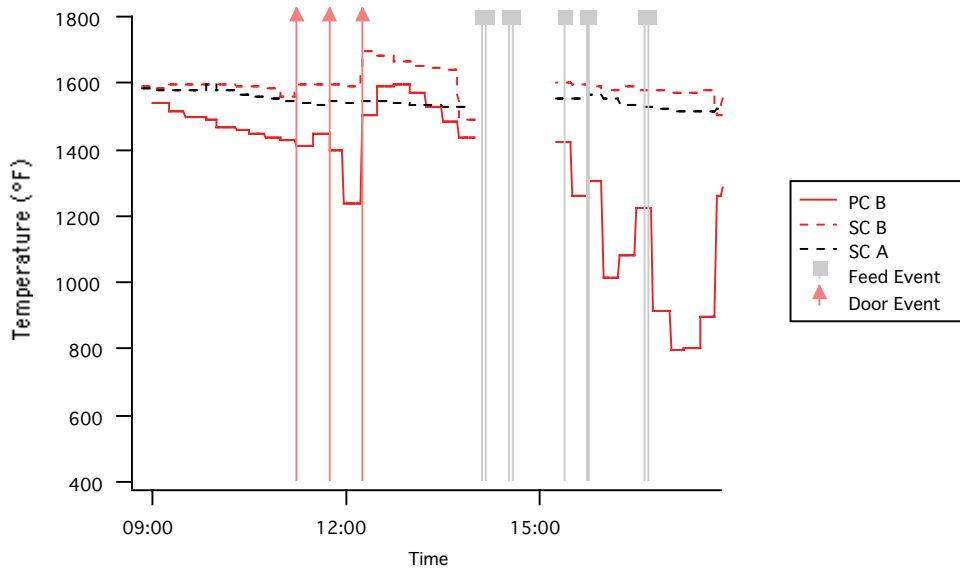


Figure 3-6. Temperatures from Test Day 1

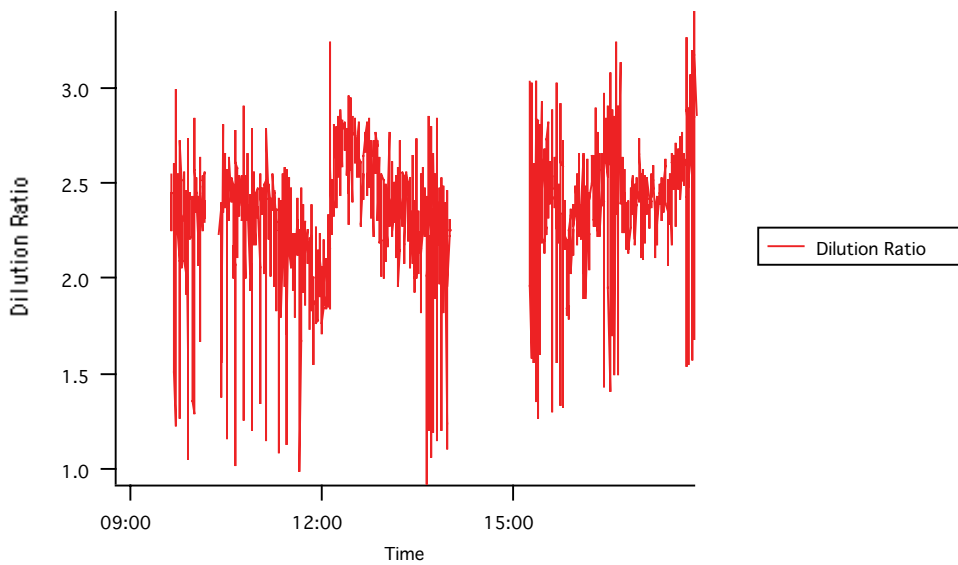


Figure 3-7. Dilution Ratio from Test Day 1 (Average = 2.36)

### 3.2.2 Continuous Emissions Data from Test Day 2 (March 4, 2008)

On Test Day 2 the animal carcass feed was initiated early in the day. Mostly poultry carcasses were fed this day. The feed

was full bobcat loads fed somewhat infrequently. The SC CEMs were operating. Temperature data were recorded from both sets of PCs and SCs.

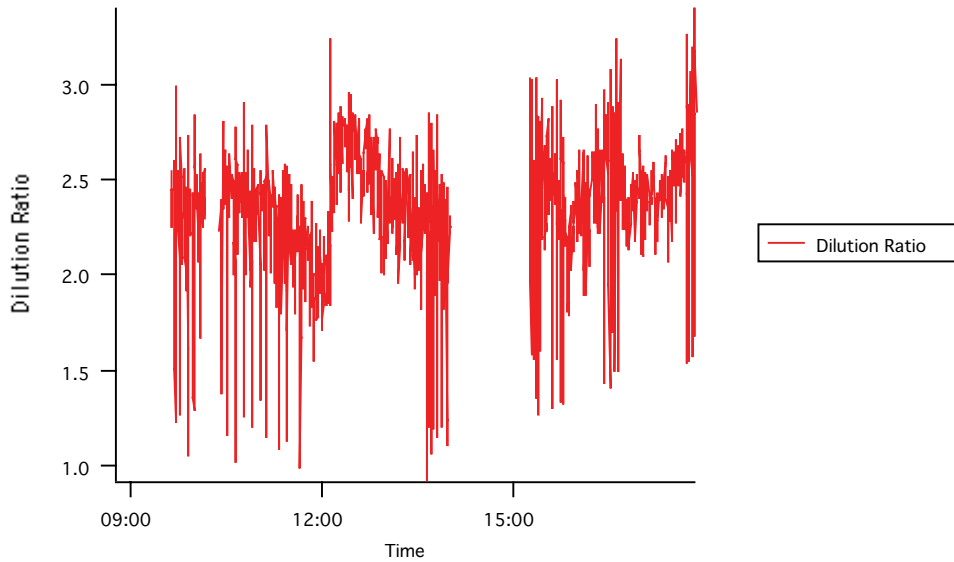


Figure 3-7. Dilution Ratio from Test Day 1 (Average = 2.36)

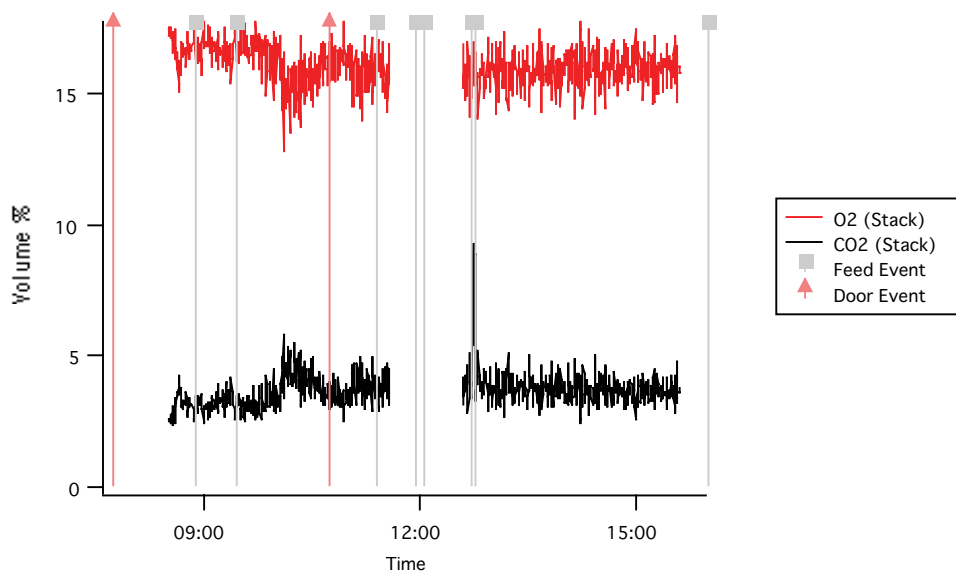


Figure 3-8. Stack O<sub>2</sub> and CO<sub>2</sub> from Test Day 2

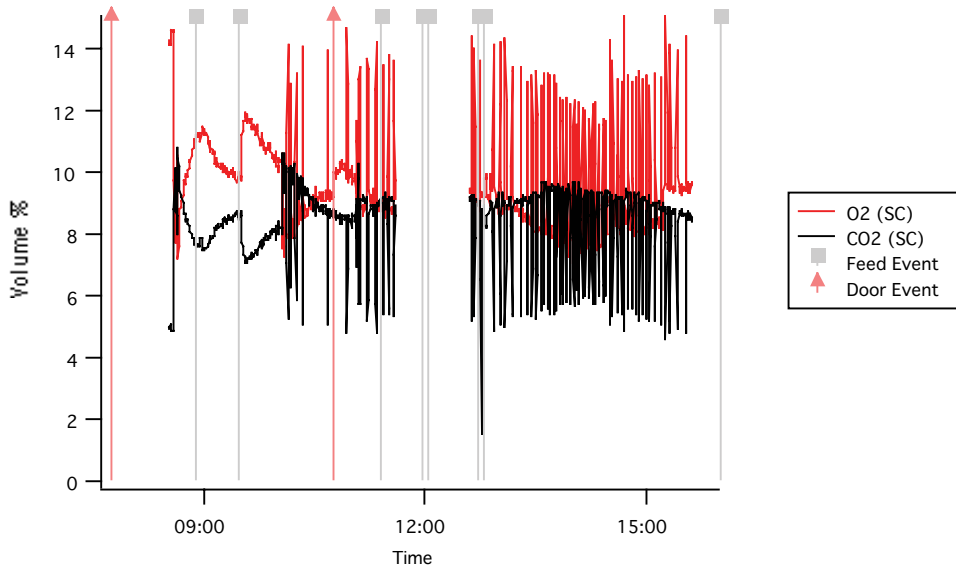


Figure 3-9. SC O<sub>2</sub> and CO<sub>2</sub> from Test Day 2

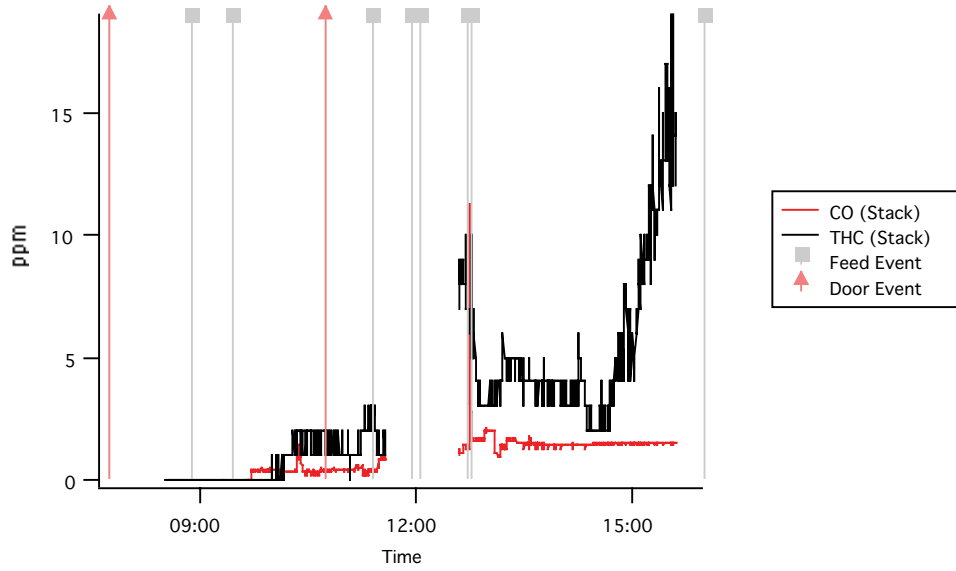


Figure 3-10. Stack CO and THC from Test Day 2

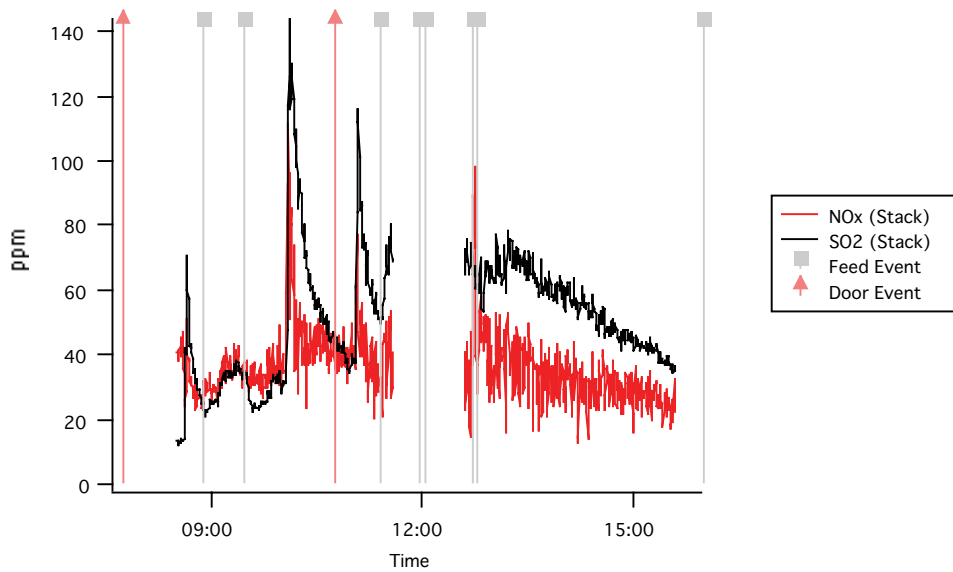


Figure 3-11. Stack NO<sub>x</sub> and SO<sub>2</sub> from Test Day 2

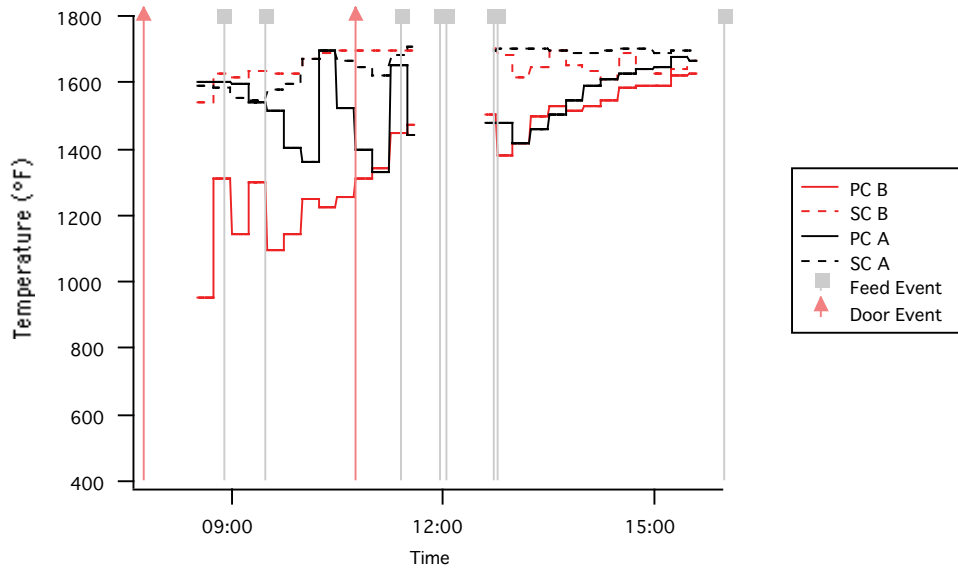


Figure 3-12. Temperatures from Test Day 2

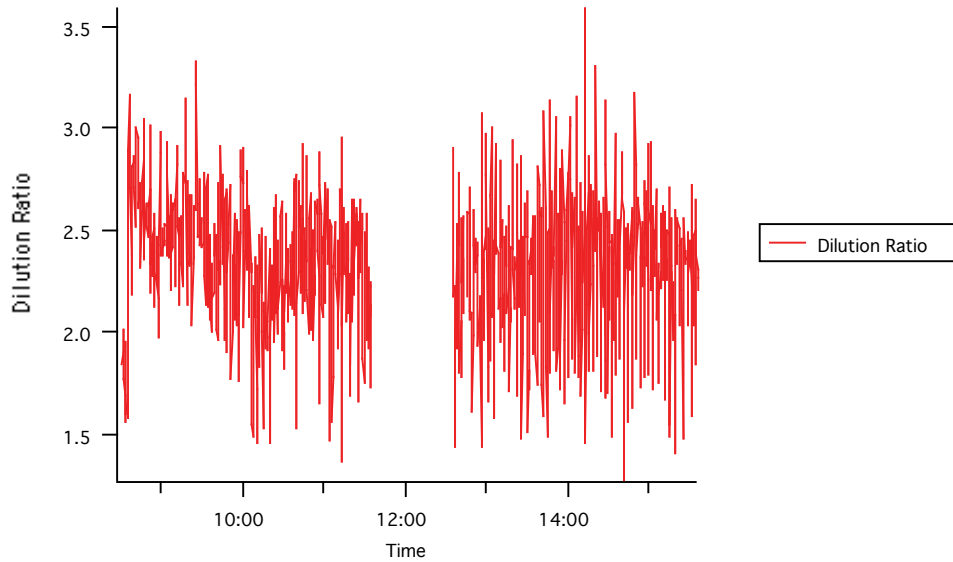


Figure 3-13. Dilution Ratio from Test Day 2 (Average = 2.34)

### 3.2.3 Continuous Emissions Data from Test Day 3 (March 5, 2008)

On Test Day 3 animal carcasses were successfully fed all day. The feed was a mix of swine and poultry carcasses, with

occasionally more swine than poultry. This day, the feeding was half bobcat loads fed at shorter intervals. Part of the day a CO sample was acquired from the SC.

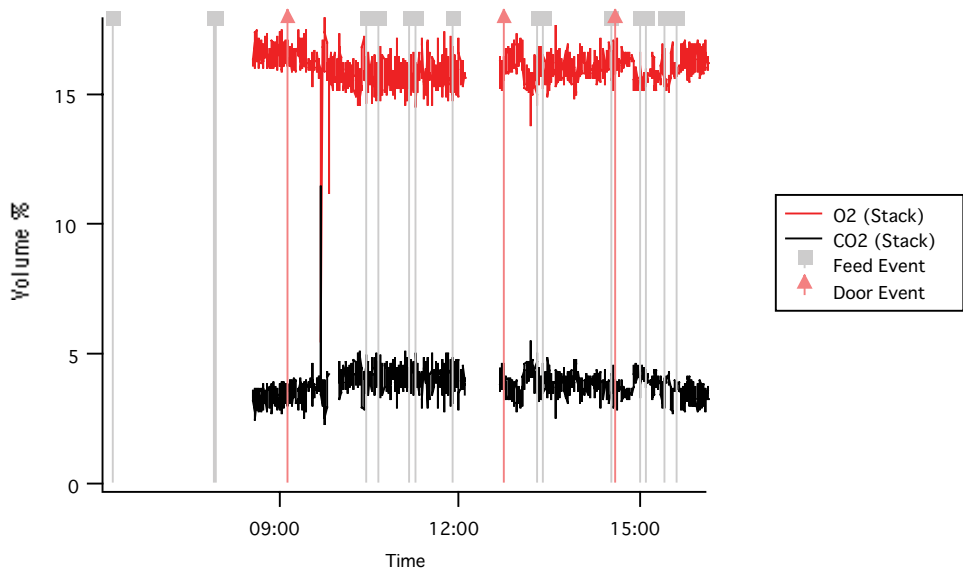


Figure 3-14. Stack O<sub>2</sub> and CO<sub>2</sub> from Test Day 3

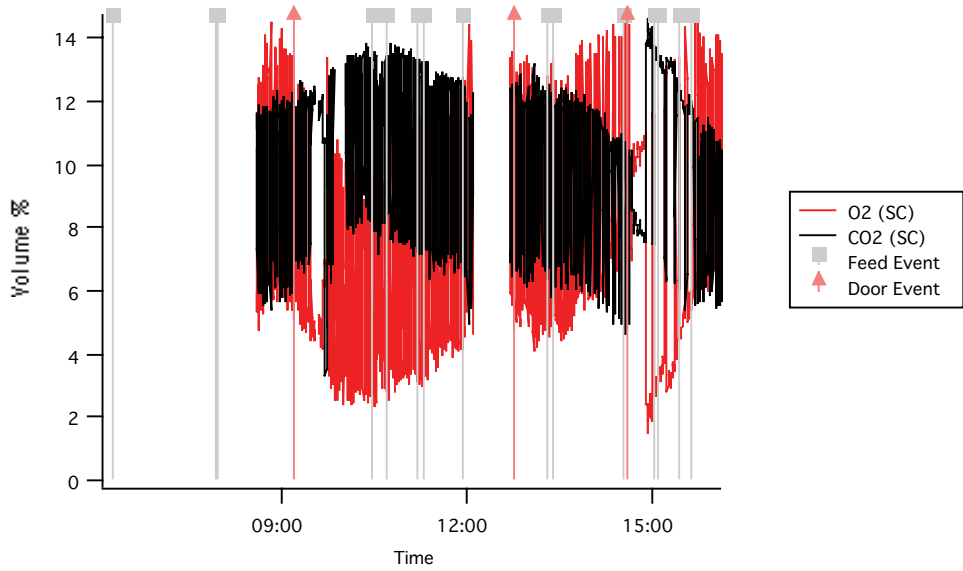


Figure 3-15. SC O<sub>2</sub> and CO<sub>2</sub> from Test Day 3

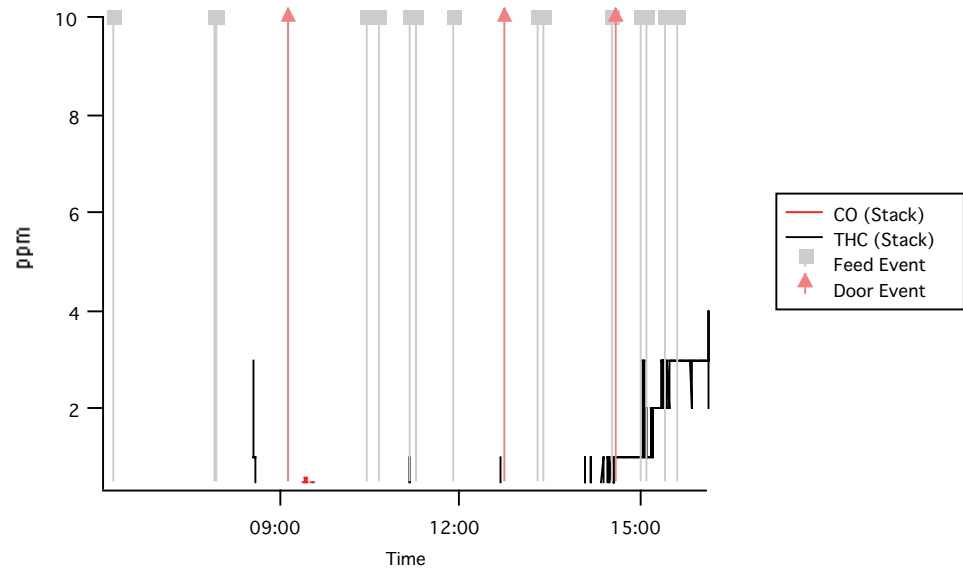
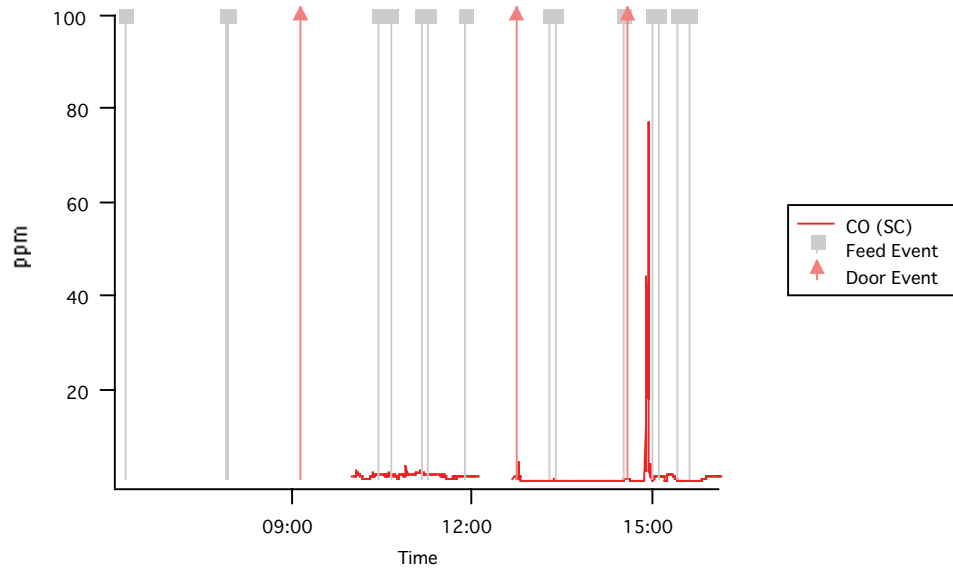
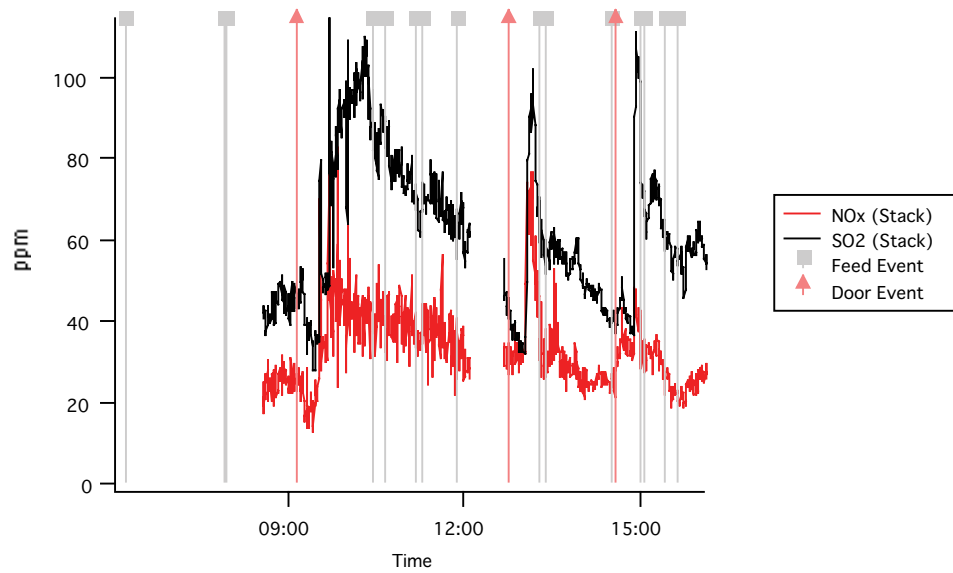


Figure 3-16. Stack CO and THC from Test Day 3

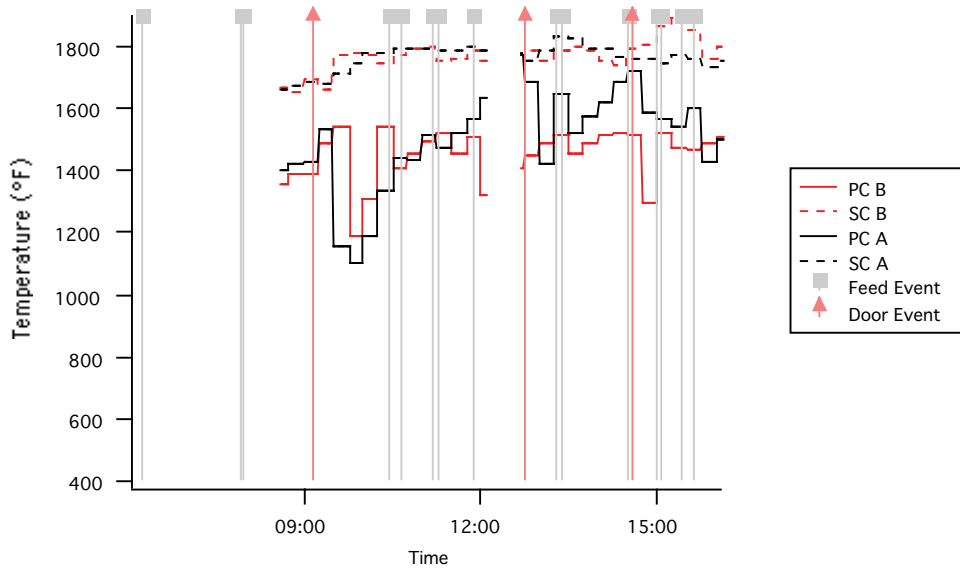
(Note that Stack CO was not being measured during the time when SC CO was being measured [see Figure 3-17].)



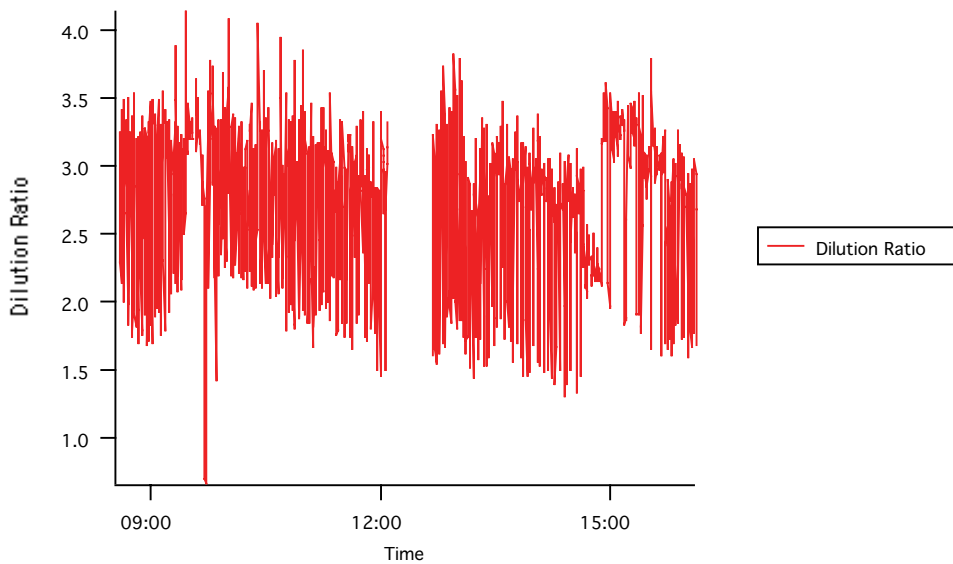
**Figure 3-17.** SC CO from Test Day 3



**Figure 3-18.** Stack NO<sub>x</sub> and SO<sub>2</sub> from Test Day 3



**Figure 3-19.** Temperatures from Test Day 3



**Figure 3-20.** Dilution Ratio from Test Day 3 (Average = 2.74)

### 3.2.4 Continuous Emissions Data from Test Day 4 (March 6, 2008)

On Test Day 4 wheat straw was burned as a surrogate for contaminated plant material. This material was not acceptable for long-term operation due to the very dry nature of the wheat straw and the inability to feed the wheat straw through the macerator (wetted wood chips were preferred). Several feed methods were used, including hand charging dry

material, hand charging wet material, and conveyor charging of wet material. Opening the doors to feed was not safe or practical for this material, since the material burst into flame nearly immediately, and gas flows through the PC were higher than in gasification mode, making a visible plume. PC chamber temperatures kept increasing over the feeding period.

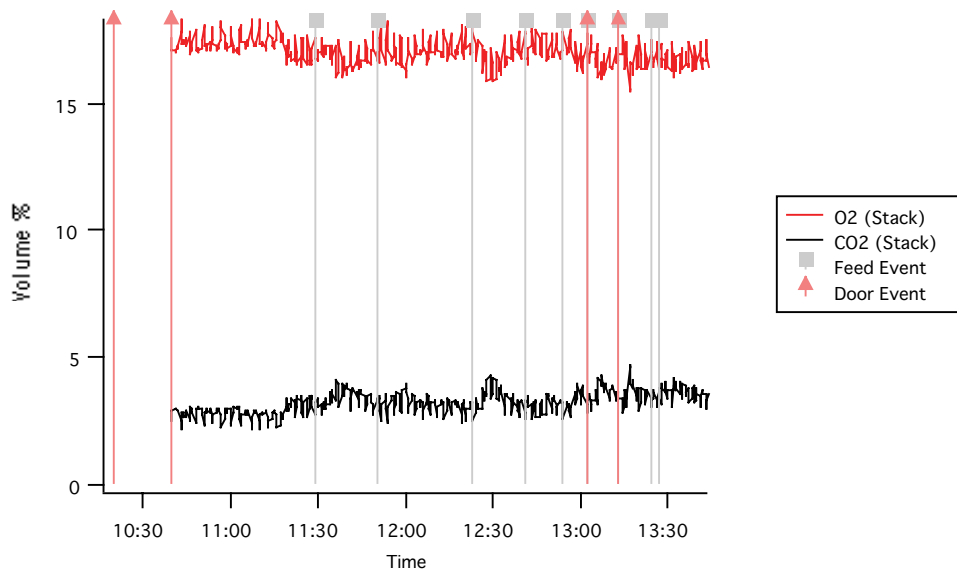


Figure 3-21. Stack O<sub>2</sub> and CO<sub>2</sub> from Test Day 4

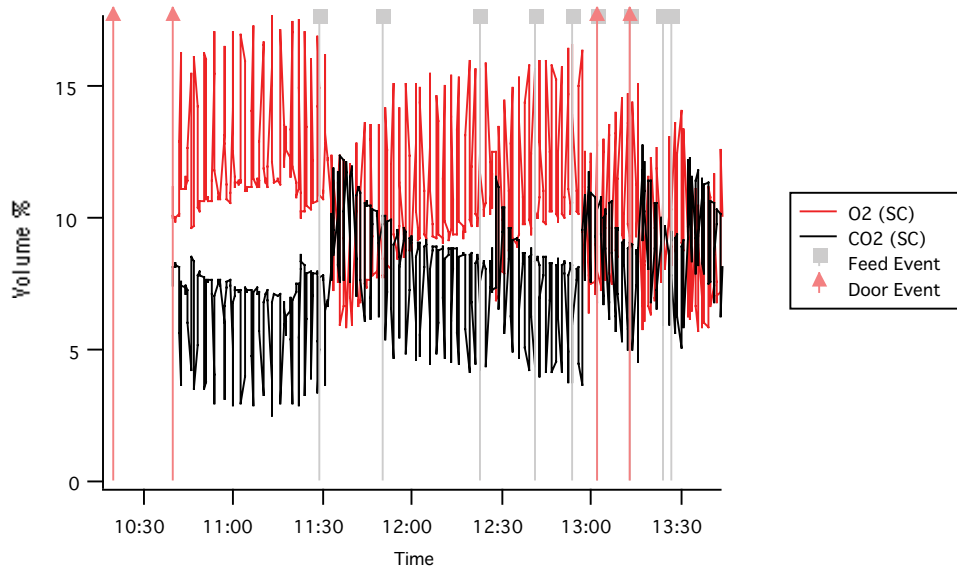


Figure 3-22. SC O<sub>2</sub> and CO<sub>2</sub> from Test Day 4

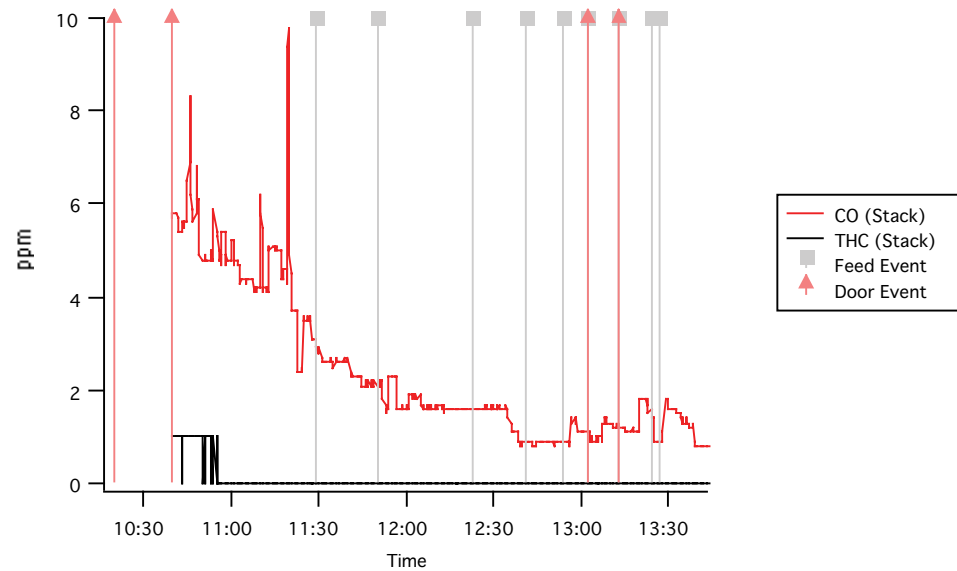


Figure 3-23. Stack CO and THC from Test Day 4



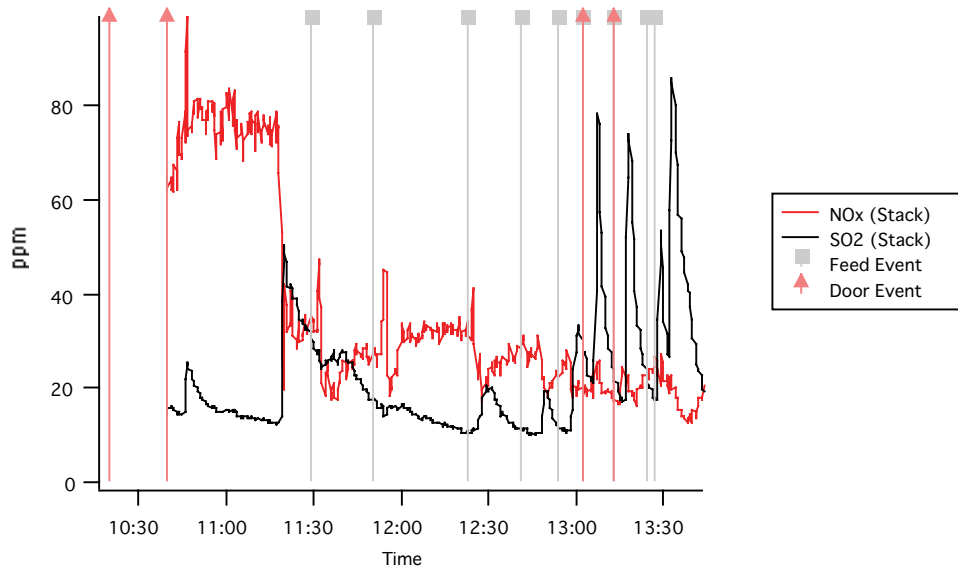


Figure 3-24. Stack NO<sub>x</sub> and SO<sub>2</sub> from Test Day 4

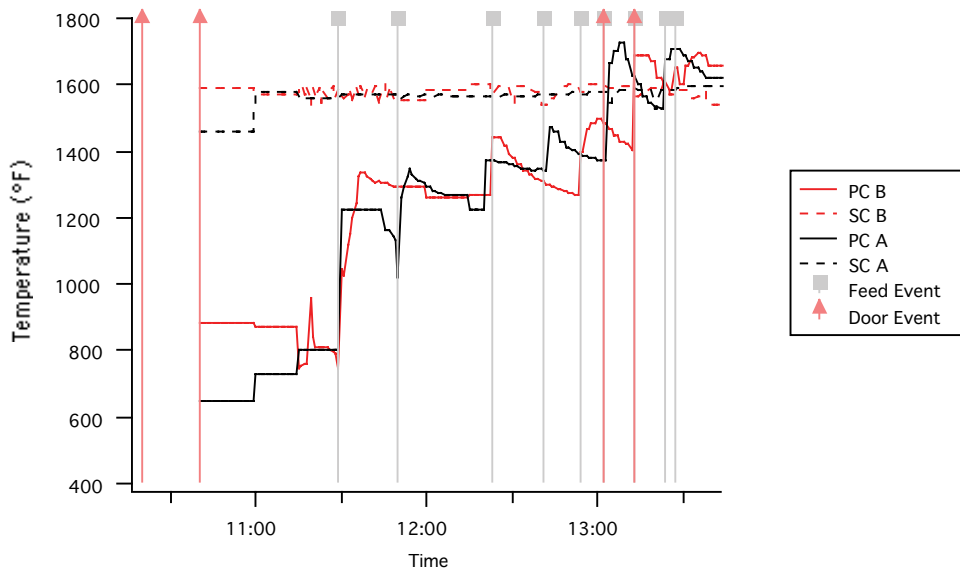


Figure 3-25. Temperatures from Test Day 4

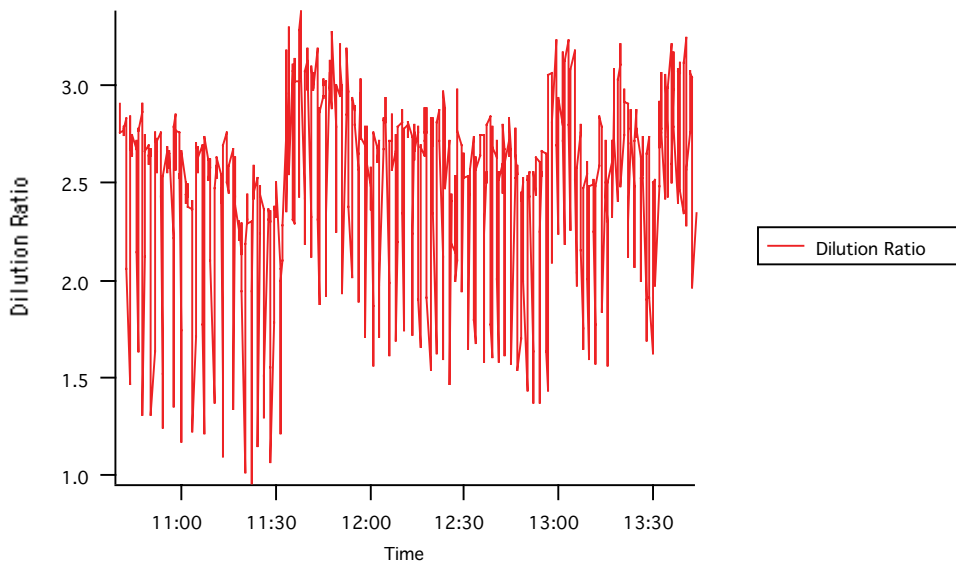


Figure 3-26. Dilution Ratio from Test Day 4 (Average = 2.50)

### 3.2.5 Correlation of Operating Parameters

For a unit primarily designed for operation in the field, with minimal on-board diagnostics, easily measured parameters should give an indication of operational effectiveness so that emissions can be minimized in the field without the need for sophisticated instrumentation, expensive gas monitoring equipment, and additional operating technicians. In order to assess the potential for indirect measurements of emissions quality, the CO and THC readings (an indication of combustion effectiveness and emissions of organic air toxics) during the carcass tests were correlated with available process measurements from the gasifier using a 2<sup>nd</sup> degree polynomial. For this correlation, the CO and THC were first corrected to 12% CO<sub>2</sub> to account for potential dilution effects. In the United States, emissions measurements are normally correlated to 7% O<sub>2</sub>. However, due to the high O<sub>2</sub> values in the stack, the correction factor based on an O<sub>2</sub> concentration would have had a large amount of associated error. For this reason, the emissions were corrected to 12% CO<sub>2</sub>, the method used in Canada. Equation (12) was used for correction:

$$C_{corrected} = C_{raw} \left( \frac{12}{CO_{2,stack}} \right) \quad (12)$$

where  $C_{corrected}$  is the corrected pollutant concentration,  $C_{raw}$  is the measured pollutant concentration, and  $CO_{2,stack}$  is the stack concentration, in volume percent, of CO<sub>2</sub>.

Both CO and THC correlate favorably ( $R^2=0.638$  for CO and  $R^2 = 0.741$  for THC) with the average of the temperatures of the two PCs. Figures 3-27 and 3-28 show the correlations between PC temperature and the CO and THC stack measurements. These correlations suggest that, at the feed rates observed during these tests, as long as the PC chamber temperatures are maintained above 900 °F (482 °C), CO and THC will be maintained below 100 ppm corrected to 12% CO<sub>2</sub>. Any additional testing should investigate this possibility further.

### 3.3 Test Timeline and Average Concentrations

Table 3-7 lists the sample train start and stop times, as well as the average temperatures and gas concentrations over those periods. Note that no extractive sampling trains were operated on Test Day 4 (March 6, 2008), while the wheat straw was being burned. The original intention was to perform the full suite of sampling/analysis activities for the plant materials; however, once the material that was delivered was examined, the extremely lightweight nature of the wheat

straw would obviously not be amenable to feeding through the macerator. The need to manually charge through the front doors would cause problems with the gasifier operation due to rapid combustion and transient operation as well as safety problems. The test team decided that more valuable data would be gathered by attempting different feed procedures while continuous gas sampling and opacity monitoring via EPA Method 9 were used to diagnose the operation of the gasifier, an additional side effect of having the shakedown of the unit truncated due to schedule limitations. Table 3-8 lists the average values of the CEMs over the test days. Note: unlike the analysis of PC temperature vs. CO and THC, all concentrations in the following discussion are reported in raw units on a dry basis (i.e., no correction for dilution was made). Table 3-9 lists the stack velocities and flow rates as well as the estimated dilution flow rates.

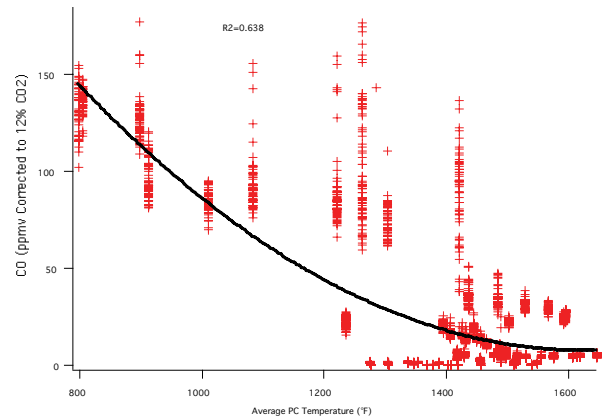


Figure 3-27. PC Temperature vs. CO

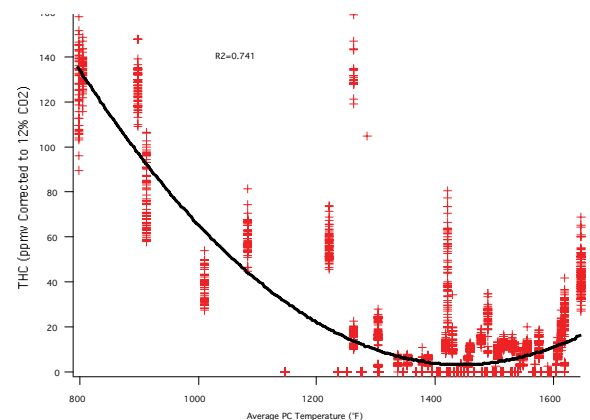


Figure 3-28. PC Temperature vs. THC

**Table 3-7. Sample Train Start/Stop Times and Average Stack Gas Concentrations, Dry Basis**

Test Day	Method	Run No.	Start Time	Stop Time	Avg O <sub>2</sub> (%)	Avg CO <sub>2</sub> (%)	Avg CO (ppm)	Avg SO <sub>2</sub> (ppm)	Avg NO <sub>x</sub> (ppm)	Avg THC (ppm)	Avg PCT B (°F)	Avg SCT B (°F)	Avg PCT A (°F)	Avg SCT A (°F)
1	Dioxins/Furans	1	10:21	13:55	17.4	2.9	5	18	33	0	1463	1613	NA	1542
		2	14:52	17:52	17.1	2.7	22	32	59	15	1079	1579	NA	1534
	Filterable PM/Acid Gases	1	12:24	13:54	17.4	2.9	7	18	28	0	1539	1641	NA	1535
		2	16:43	18:13	17.3	2.5	25	28	66	24	906	1568	NA	1518
	Metals	1	10:21	11:52	17.6	2.8	4	15	34	0	1431	1586	NA	1549
		2	14:51	16:21	16.9	2.8	19	34	51	7	1230	1590	NA	1553
	PM <sub>10</sub> , Condensable PM	1	10:21	17:21	17.3	2.8	11	23	43	4	1333	1601	NA	1540
	Ambient PM <sub>10</sub>	1	7:56	18:51	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Syngas Composition	1	13:10	14:01	NA	NA	NA	NA	NA	NA	1438	1585	1031	1529
		2	15:07	18:47	NA	NA	NA	NA	NA	NA	1139	1572	604	1533
2	Dioxins/Furans	1	8:12	11:12	16.3	3.5	0	44	39	1	1211	1647	1508	1613
		2	12:09	15:09	15.9	3.8	2	59	35	4	1516	1653	1544	1696
	Filterable PM/Acid Gases	1	10:02	11:32	15.8	3.9	0	62	44	1	1309	1690	1493	1663
		2	14:05	15:35	16.0	3.6	1	47	29	7	1583	1641	1635	1694
	Metals	1	8:11	9:41	16.7	3.1	0	30	33	0	1167	1610	1574	1570
		2	12:08	13:38	15.9	3.9	2	67	41	5	1458	1661	1463	1699
	PM <sub>10</sub> , Condensable PM	1	8:21	15:06	16.1	3.6	1	52	37	2	1364	1653	1527	1655
	Ambient PM <sub>10</sub>	1	7:06	18:15	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Syngas Composition	1	9:05	10:19	NA	NA	NA	NA	NA	NA	1192	1644	1518	1606
3	Dioxins/Furans	1	8:59	11:59	15.8	3.8	0	71	36	0	1446	1758	1390	1761
		2	12:57	15:57	16.0	3.8	0	57	31	1	1478	1801	1579	1778
	Filterable PM/Acid Gases	1	10:48	12:18	15.8	4.1	0	69	37	0	1473	1776	1515	1792
		2	14:36	16:08	16.0	3.7	0	61	29	2	1460	1831	1555	1754
	Metals	1	8:58	10:28	16.0	3.4	0	68	34	0	1414	1737	1294	1728
		2	12:56	14:26	15.9	3.9	0	55	34	0	1494	1773	1579	1800
	PM <sub>10</sub> , Condensable PM	1	8:54	15:45	15.9	3.8	0	63	34	0	1457	1778	1498	1769
	Ambient PM <sub>10</sub>	1	6:59	16:54	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Syngas Composition	1	9:55	11:05	NA	NA	NA	NA	NA	NA	1417	1776	1356	1782	

NA – Not available

**Table 3-8. CEM Average Measurements, Dry Basis**

Test Day	Time	Stack O <sub>2</sub> (%)	Stack CO <sub>2</sub> (%)	Stack CO (ppm)	Stack NO <sub>x</sub> (ppm)	Stack SO <sub>2</sub> (ppm)	Stack THC (ppm)	SC O <sub>2</sub> (%)	SC CO <sub>2</sub> (%)
1	10:21-13:55	17.4	2.6	0	34	12	0	13.2	6.4
1	14:52-17:52	16.7	3.1	19	39	42	6	11.9	7.3
2	8:12-11:12	17.0	3.0	0	34	30	0	10.8	7.9
2	12:09-15:09	16.2	3.7	0	41	70	4	9.8	8.6
3	8:59-11:59	16.4	4.0	0	41	75	0	6.5	10.8
3	12:57-15:57	16.5	3.9	NA*	42	62	0	7.3	10.6

NA - Not Available - CO monitor operating at secondary combustion zone

**Table 3-9. Stack Velocities and Flow Rates**

Run Number	Gas Velocity	Volumetric Flowrate	Volumetric Flowrate
	ft/sec	acfm	scfm
I-M5/26A-1	13.6	5141	2280
I-M5/26A-2	14.9	5636	2516
II-M5/26A-1	14.5	5501	2279
II-M5/26A-2	14.8	5583	2338
III-M5/26A-1	13.9	5277	2334
III-M5/26A-2	14.4	5439	2330
I-M29-1	13.4	5067	2233
I-M29-2	14.2	5380	2311
II-M29-1	14.7	5561	2323
II-M29-2	16.1	6082	2598
III-M29-1	14.3	5396	2551
III-M29-2	14.4	5459	2433
I-M23-1	14.6	5540	2379
I-M23-2	14.9	5628	2446
II-M23-1	15.0	5684	2504
II-M23-2	13.9	5252	2264
III-M23-1	14.3	5410	2410
III-M23-2	14.6	5535	2338
<b>Average</b>	<b>14.5</b>	<b>5476</b>	<b>2382</b>

The pollutant concentrations were converted into mass emission rates using the following equation:

$$\text{Mass Emissions} = \frac{C_i M_i Q_s}{10^6 RT} \quad (13)$$

where  $C_i$  is the concentration of pollutant  $i$  in ppm,  $M_i$  is the molecular mass of pollutant  $i$ ,  $Q_s$  is the stack flow rate in standard cubic feet per hour,  $R$  is the ideal gas constant, and  $T$  is the temperature (for standard conditions, 68 °F [20 °C]).

### 3.4 Particulate Matter

#### 3.4.1 Ambient Particulate

Table 3-10 lists the results from the ambient sampler. These data reflect the amount of  $PM_{10}$  that was being pulled into the dilution air of the stack. The results from March 3 and March 4 are similar, with the Test Day 3 (March 5, 2008) results significantly lower, possibly due to a heavy rain the night before. Overall, the ambient particulate loading represented no more than 1 mg/m<sup>3</sup> on any given day.

#### 3.4.2 Total Filterable Particulate

Table 3-11 lists the results for the total filterable particulate for Test Day 1 through Test Day 3. Based on the ambient  $PM_{10}$  measurements, approximately 5% of this particulate resulted from material being pulled into the dilution air from

the ambient surroundings. These results show an average of 26 mg/Nm<sup>3</sup> with a standard deviation of 9 mg/Nm<sup>3</sup>. The average emission rate was 0.224 lb/hr over the three test days of burning animal carcasses, with a standard deviation of 0.077 lb/hr.

#### 3.4.3 Filterable Particulate Matter and Condensable Particulate Matter

Table 3-12 shows the results from the filterable particulate (EPA Method 5) and condensable particulate (EPA Method 202). Total particulate averaged 21.9 mg/Nm<sup>3</sup> (not corrected for dilution). No particulate matter with an aerodynamic diameter greater than 10 μm was observed. Note that the total filterable particulate results are slightly different in Table 3-12 than in Table 3-11, because the sample train in Table 3-12 was run for 420 minutes as opposed to 90 minutes for the results shown in Table 3-11. Approximately 1/3 of the total particulate was condensable, and of that fraction, approximately 15% was organic, so approximately 30% of the particulate was composed of condensable sulfates and nitrates. Note that the contribution of ambient particulate (approximately 1 mg/Nm<sup>3</sup>) was not subtracted from the total filterable particulate, although based on the dilution ratios (which averaged 2.34 over Test Days 1 through 3) and results from the ambient sampling, ambient particulate would be expected to contribute roughly 1.34 mg/Nm<sup>3</sup> or approximately 5% of the total filterable particulate.

**Table 3-10.** Ambient  $PM_{10}$  Results

Test Day	Run Duration (min)	Sample Volume (m <sup>3</sup> )	Filter Catch (μg)	PM10 (μg/m <sup>3</sup> )
1	674.4	864.94	849,900	982.6
2	564.6	725.34	710,600	979.7
3	590.4	761.32	38,290	50.3

**Table 3-11.** Total Filterable Particulate Results

Test Day	Run	Concentration (mg/Nm <sup>3</sup> )	Emission Rate (lb/hr)
1	1	15.1	0.129
1	2	13.7	0.129
2	1	34.6	0.295
2	2	33.5	0.294
3	1	27.5	0.240
3	2	29.3	0.256

### 3.4.4 Visible Emissions

Opacity measurements were taken with EPA Method 9 on Day 4, and on Days 1 through 3, intermittent opacity measurements were taken (approximately 15 minutes per hour of sampling), although the sample frequency and duration criteria for EPA Method 9 were not satisfied on those days due to personnel limitations. On Days 1 through 3,

no measurable opacity was observed during any of the time periods where visible emissions observations were taken. On Day 4, during the vegetable matter burns, EPA Method 9 measurements were taken according to the method. These measurements are listed in Table 3-13. The peak smoke number observed during the vegetative matter burns was 15%, with the peak opacity over the test day at 9.4%.

**Table 3-12.** Particulate Matter Emissions Measurements

	Day 1	Day 2	Day 3	Average
<b>FILTERABLE PARTICULATE &lt; 10µm</b>				
Concentration, gr/DSCF	2.04E-03	7.29E-03	8.27E-03	5.87E-03
Concentration, mg/DSCM	4.68	16.69	18.92	13.43
Emission Rate, lb/hr	0.1045	0.3645	0.4226	0.2972
<b>ORGANIC CONDENSABLE PARTICULATE</b>				
Concentration, gr/DSCF	4.69E-04	7.58E-04	7.03E-05	4.33E-04
Concentration, mg/DSCM	1.07	1.74	0.16	0.99
Emission Rate, lb/hr	0.0240	0.0379	0.0036	0.0218
<b>INORGANIC CONDENSABLE PARTICULATE</b>				
Concentration, gr/DSCF	2.94E-03	3.42E-03	7.35E-04	2.36E-03
Concentration, mg/DSCM	6.7	7.8	1.7	5.4
Emission Rate, lb/hr	0.2	0.2	0.0	0.1
<b>TOTAL PARTICULATE &lt; 10µm</b>				
Concentration, gr/DSCF	5.45E-03	1.15E-02	9.07E-03	8.66E-03
Concentration, mg/DSCM	12.5	26.2	20.8	19.8
Emission Rate, lb/hr	0.3	0.6	0.5	0.4
<b>TOTAL FILTERABLE PARTICULATE</b>				
Concentration, gr/DSCF	2.04E-03	7.29E-03	8.27E-03	5.87E-03
Concentration, mg/DSCM	4.68	16.69	18.92	13.43
Emission Rate, lb/hr	0.104	0.364	0.423	0.297
<b>TOTAL PARTICULATE</b>				
Concentration, gr/DSCF	5.45E-03	1.15E-02	9.07E-03	8.66E-03
Concentration, mg/DSCM	12.5	26.2	20.8	19.8
Emission Rate, lb/hr	0.3	0.6	0.5	0.4

**Table 3-13.** Visible Emissions During Vegetable Matter Tests (Day 4)

Start Time	End Time	Opacity (%)
11:14	12:14	0
13:33	14:42	9.4

### 3.4.5 Particle Size Distributions

Table 3-14 shows the particle size distributions for Test Days 1 through 3. The particulate matter was very fine, with an average of 58.1% by mass ending up on the backup filter. Virtually all the particulate had an aerodynamic diameter less than 0.5  $\mu\text{m}$ . Figure 3-29 shows the cumulative mass percent versus particle size for the average of the three runs.

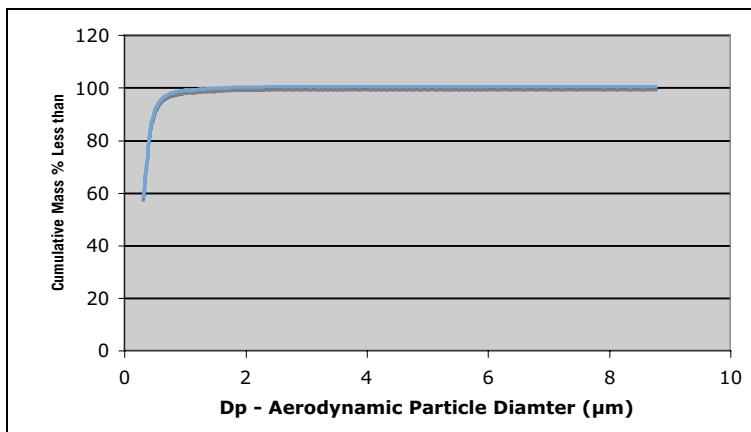
$\text{Nm}^3$  with a standard deviation of 0.486  $\text{mg}/\text{Nm}^3$ . The average emission rate of HCl was 0.27  $\text{lb}/\text{hr}$  with a standard deviation of 0.17  $\text{lb}/\text{hr}$  and the average emission rate of  $\text{Cl}_2$  was 0.0015  $\text{lb}/\text{hr}$  with a standard deviation of 0.0014  $\text{lb}/\text{hr}$ . These particular pollutants showed a relatively high degree of variability, with the higher emissions occurring at the higher animal carcass feed rates. This variability may result from differences in the feed that the gasified animals were fed.

### 3.5 Hydrogen Chloride and Chlorine

Table 3-15 lists the hydrogen chloride (HCl) and chlorine ( $\text{Cl}_2$ ) emissions. HCl averaged 30.8  $\text{mg}/\text{Nm}^3$  with a standard deviation of 19.2  $\text{mg}/\text{Nm}^3$ , and  $\text{Cl}_2$  averaged 0.173  $\text{mg}/$

**Table 3-14.** Particle Size Distribution Data (Mass Basis)

Stage	Aerodynamic Particle Size ( $\mu\text{m}$ )	Day 1		Day 2		Day 3		Average	
		Mass % of Total	Cum. Mass % Less Than	Mass % of Total	Cum. Mass % Less Than	Mass % of Total	Cum. Mass % Less Than	Mass % of Total	Cum. Mass % Less Than
1	8.79	0.4	99.6	0.0	100.0	0.0	100.0	0.1	99.9
2	5.47	0.0	99.6	0.0	100.0	0.0	100.0	0.0	99.9
3	3.71	0.0	99.6	0.0	100.0	0.0	100.0	0.0	99.9
4	2.54	0.0	99.6	0.0	100.0	0.0	100.0	0.0	99.9
5	1.62	0.0	99.6	0.8	99.2	0.7	99.3	0.5	99.4
6	0.77	0.7	98.9	4.8	94.5	0.8	98.6	2.1	97.3
7	0.49	11.9	87.0	11.8	82.6	3.8	94.7	9.2	88.1
8	0.33	32.2	54.8	38.7	43.9	19.2	75.5	30.1	58.1
Backup	< 0.33	54.8	0.0	43.9	0.0	75.5	0.0	58.1	0.0
Total		100.0		100.0		100.0		100.0	



**Figure 3-29.** Particle Size Distribution

**Table 3-15.** Hydrogen Chloride and Chlorine

Test Day	Run	HCl (mg/Nm <sup>3</sup> )	HCl Emission Rate (lb/hr)	Chlorine as Cl <sub>2</sub> (mg/Nm <sup>3</sup> )	Chlorine Emission Rate (lb/hr)
1	1	13.8	0.118	0.066	0.00056
1	2	4.1	0.039	0.092	0.00086
2	1	32.0	0.273	0.469	0.00400
2	2	57.8	0.507	0.127	0.00112
3	1	37.1	0.324	0.112	0.00098
3	2	39.8	0.348	ND	ND

ND - Not Detected

### 3.6 Metals

Metals concentrations were low, being comparable to or lower than the New Source Performance Standards (NSPS) for metals for small municipal waste combustors [Federal Register, 2000]. Table 3-16 lists the concentrations and emission rates of metals at the stack. Antimony, beryllium,

cobalt, and mercury were not detected. The source of cadmium is not known – animal carcasses are not expected to have much Cd, and the fuel oil had none. Cd may be a component in the materials of construction of the gasifier or the macerator.



**Table 3-16. Metals Results**

	Day1 Run 1	Day 1 Run 2	Day 2 Run 1	Day 2 Run 2	Day 3 Run 1	Day 3 Run 2	Average
<b>Antimony</b>							
Concentration, µg/Nm <sup>3</sup>	ND	ND	ND	ND	ND	ND	ND
Emission Rate, lb/hr	ND	ND	ND	ND	ND	ND	ND
<b>Arsenic</b>							
Concentration, µg/Nm <sup>3</sup>	0.49	0.84	0.77	1.41	1.31	1.99	1.13
Emission Rate, lb/hr	4.07E-06	7.28E-06	6.67E-06	1.38E-05	1.25E-05	1.81E-05	1.04E-05
<b>Barium</b>							
Concentration, µg/Nm <sup>3</sup>	5.02	2.98	5.14	4.38	10.80	ND	5.66
Emission Rate, lb/hr	4.20E-05	2.58E-05	4.47E-05	4.26E-05	1.03E-04	ND	5.16E-05
<b>Beryllium</b>							
Concentration, µg/Nm <sup>3</sup>	ND	ND	ND	ND	ND	ND	ND
Emission Rate, lb/hr	ND	ND	ND	ND	ND	ND	ND
<b>Cadmium</b>							
Concentration, µg/Nm <sup>3</sup>	13.00	23.40	5.97	1.95	25.60	2.14	12.01
Emission Rate, lb/hr	1.09E-04	2.02E-04	5.20E-05	1.89E-05	2.44E-04	1.95E-05	1.08E-04
<b>Chromium</b>							
Concentration, µg/Nm <sup>3</sup>	6.40	7.64	4.83	6.53	5.97	9.25	6.77
Emission Rate, lb/hr	5.35E-05	6.62E-05	4.20E-05	6.36E-05	5.70E-05	8.43E-05	6.11E-05
<b>Cobalt</b>							
Concentration, µg/Nm <sup>3</sup>	ND	ND	ND	ND	ND	ND	ND
Emission Rate, lb/hr	ND	ND	ND	ND	ND	ND	ND
<b>Lead</b>							
Concentration, µg/Nm <sup>3</sup>	3.00	2.52	6.06	8.35	7.20	8.79	5.99
Emission Rate, lb/hr	2.51E-05	2.18E-05	5.27E-05	8.13E-05	6.88E-05	8.01E-05	5.50E-05
<b>Manganese</b>							
Concentration, µg/Nm <sup>3</sup>	2.84	2.14	6.06	4.18	14.10	1.22	5.09
Emission Rate, lb/hr	2.37E-05	1.85E-05	5.27E-05	4.06E-05	1.35E-04	1.11E-05	4.69E-05
<b>Mercury</b>							
Concentration, µg/Nm <sup>3</sup>	ND	ND	ND	ND	ND	ND	ND
Emission Rate, lb/hr	ND	ND	ND	ND	ND	ND	ND
<b>Nickel</b>							
Concentration, µg/Nm <sup>3</sup>	15.30	6.80	5.98	8.56	19.80	9.94	11.06
Emission Rate, lb/hr	1.28E-04	5.89E-05	5.20E-05	8.33E-05	1.89E-04	9.06E-05	1.00E-04
<b>Selenium</b>							
Concentration, µg/Nm <sup>3</sup>	2.11	3.13	4.75	7.01	4.22	5.73	4.49
Emission Rate, lb/hr	1.76E-05	2.71E-05	4.14E-05	6.82E-05	4.03E-05	5.22E-05	4.11E-05
<b>Silver</b>							
Concentration, µg/Nm <sup>3</sup>	0.16	0.69	0.92	0.74	1.46	0.76	0.79
Emission Rate, lb/hr	1.36E-06	5.95E-06	8.01E-06	7.21E-06	1.39E-05	6.97E-06	7.23E-06

ND - Not Detected

### 3.7 PCDDs/Fs

The measured dioxins and furans were very low, with concentrations in the picogram per normal cubic meter range (pg/Nm<sup>3</sup>). As a reference, the NSPS for dioxins from small municipal waste combustors [Federal Register, 2000] is 13 ng/Nm<sup>3</sup> total PCDD/F, which is approximately an order of magnitude higher than the observed gasifier emissions, when corrected to 12 % CO<sub>2</sub>. Table 3-17 lists the concentrations of

PCDDs/Fs as well as the concentration in Toxic Equivalency (TEQ) units, which represent a weighted concentration based on World Health Organization (WHO) 2005 toxicity equivalency factor (TEF) weights (Van den Berg et al., 2006). Table 3-18 lists the mass emission rates of PCDDs/Fs in lb/hr, including TEQ units. Note that averaging is based on setting non-detects to zero.

**Table 3-17. PCDD/F Concentrations (pg/Nm<sup>3</sup>)**

	Day 1 Run 1	Day 1 Run 2	Day 2 Run 1	Day 2 Run 2	Day 3 Run 1	Day 3 Run 2	Average
<b>2,3,7,8-TCDD</b>	ND	ND	ND	ND	ND	ND	ND
<b>1,2,3,7,8-PeCDD</b>	ND	ND	ND	ND	ND	ND	ND
<b>1,2,3,4,7,8-HxCDD</b>	ND	ND	ND	ND	ND	ND	ND
<b>1,2,3,6,7,8-HxCDD</b>	ND	ND	ND	ND	ND	ND	ND
<b>1,2,3,7,8,9-HxCDD</b>	ND	ND	ND	ND	ND	ND	ND
<b>1,2,3,4,6,7,8-HpCDD</b>	2.6	ND	ND	ND	2.5	ND	0.8
<b>OCDD</b>	6.2	7.0	ND	8.0	4.5	5.9	5.3
<b>2,3,7,8-TCDF</b>	5.7	5.7	1.2	1.3	0.8	ND	2.4
<b>1,2,3,7,8-PeCDF</b>	3.7	4.2	ND	ND	ND	ND	1.3
<b>2,3,4,7,8-PeCDF</b>	7.8	15.4	ND	ND	ND	ND	3.9
<b>1,2,3,4,7,8-HxCDF</b>	3.6	7.7	ND	ND	ND	ND	1.9
<b>1,2,3,6,7,8-HxCDF</b>	2.4	3.7	ND	ND	ND	ND	1.0
<b>2,3,4,6,7,8-HxCDF</b>	3.5	6.1	ND	ND	ND	ND	1.6
<b>1,2,3,7,8,9-HxCDF</b>	ND	ND	ND	ND	ND	ND	ND
<b>1,2,3,4,6,7,8-HpCDF</b>	4.5	6.3	ND	ND	2.5	3.3	2.8
<b>1,2,3,4,7,8,9-HpCDF</b>	ND	ND	ND	ND	ND	ND	ND
<b>OCDF</b>	5.8	ND	ND	ND	ND	ND	1.0
<b>TEQ</b>	4.1	7.1	0.1	0.1	0.1	0.0	1.9
<b>Other TCDD</b>	16.5	21.3	59.5	104.0	89.0	79.8	61.7
<b>Other PeCDD</b>	ND	4.7	11.4	10.2	10.8	13.3	8.4
<b>Other HxCDD</b>	ND	ND	ND	ND	4.1	5.0	1.5
<b>Other HpCDD</b>	2.2	5.1	ND	ND	3.4	ND	1.8
<b>Total PCDD</b>	27.5	38.1	70.9	122.2	114.2	104.0	79.5
<b>Other TCDF</b>	125.0	44.4	62.4	79.6	70.6	88.2	78.4
<b>Other PeCDF</b>	46.2	65.0	15.8	15.1	13.2	18.1	28.9
<b>Other HxCDF</b>	14.9	27.2	4.0	7.3	6.6	9.5	11.6
<b>Other HpCDF</b>	9.4	6.3	1.4	1.4	2.5	3.3	4.1
<b>Total PCDF</b>	232.6	192.0	84.8	104.7	96.2	122.3	138.8

ND – Not Detected

**Table 3-18. PCDD/F Mass Emission Rate (lb/hr)**

	Day 1 Run 1	Day 1 Run 2	Day 2 Run 1	Day 2 Run 2	Day 3 Run 1	Day 3 Run 2	Average
<b>2,3,7,8-TCDD</b>	ND	ND	ND	ND	ND	ND	ND
<b>1,2,3,7,8-PeCDD</b>	ND	ND	ND	ND	ND	ND	ND
<b>1,2,3,4,7,8-HxCDD</b>	ND	ND	ND	ND	ND	ND	ND
<b>1,2,3,6,7,8-HxCDD</b>	ND	ND	ND	ND	ND	ND	ND
<b>1,2,3,7,8,9-HxCDD</b>	ND	ND	ND	ND	ND	ND	ND
<b>1,2,3,4,6,7,8-HpCDD</b>	2.26E-11	ND	ND	ND	2.22E-11	ND	7.47E-12
<b>OCDD</b>	5.51E-11	6.38E-11	ND	6.75E-11	4.02E-11	5.19E-11	4.64E-11
<b>2,3,7,8-TCDF</b>	5.09E-11	5.18E-11	1.16E-11	1.07E-11	7.08E-12	ND	2.20E-11
<b>1,2,3,7,8-PeCDF</b>	3.26E-11	3.85E-11	ND	ND	ND	ND	1.19E-11
<b>2,3,4,7,8-PeCDF</b>	6.96E-11	1.40E-10	ND	ND	ND	ND	3.49E-11
<b>1,2,3,4,7,8-HxCDF</b>	3.21E-11	7.05E-11	ND	ND	ND	ND	1.71E-11
<b>1,2,3,6,7,8-HxCDF</b>	2.16E-11	3.37E-11	ND	ND	ND	ND	9.22E-12
<b>2,3,4,6,7,8-HxCDF</b>	3.06E-11	5.60E-11	ND	ND	ND	ND	1.44E-11
<b>1,2,3,7,8,9-HxCDF</b>	ND	ND	ND	ND	ND	ND	ND
<b>1,2,3,4,6,7,8-HpCDF</b>	3.97E-11	5.70E-11	ND	ND	2.28E-11	2.88E-11	2.47E-11
<b>1,2,3,4,7,8,9-HpCDF</b>	ND	ND	ND	ND	ND	ND	ND
<b>OCDF</b>	5.15E-11	ND	ND	ND	ND	ND	8.58E-12
<b>TEQ</b>	3.60E-11	6.49E-11	1.16E-12	1.09E-12	1.17E-12	3.04E-13	1.75E-11
<b>Other TCDD</b>	1.46E-10	1.94E-10	5.58E-10	8.80E-10	8.04E-10	6.99E-10	5.47E-10
<b>Other PeCDD</b>	ND	4.24E-11	1.07E-10	8.63E-11	9.73E-11	1.17E-10	7.50E-11
<b>Other HxCDD</b>	ND	ND	ND	ND	3.72E-11	4.36E-11	1.35E-11
<b>Other HpCDD</b>	1.94E-11	4.66E-11	ND	ND	3.02E-11	ND	1.60E-11
<b>Total PCDD</b>	2.43E-10	3.47E-10	6.65E-10	1.03E-09	1.03E-09	9.12E-10	7.05E-10
<b>Other TCDF</b>	1.11E-09	4.05E-10	5.85E-10	6.75E-10	6.38E-10	7.72E-10	6.98E-10
<b>Other PeCDF</b>	4.10E-10	5.92E-10	1.48E-10	1.28E-10	1.19E-10	1.58E-10	2.59E-10
<b>Other HxCDF</b>	1.33E-10	2.48E-10	3.72E-11	6.20E-11	5.91E-11	8.29E-11	1.04E-10
<b>Other HpCDF</b>	8.37E-11	5.70E-11	1.35E-11	1.21E-11	2.28E-11	2.88E-11	3.63E-11
<b>Total PCDF</b>	2.07E-09	1.75E-09	7.95E-10	8.88E-10	8.69E-10	1.07E-09	1.24E-09

ND – Not Detected

### 3.8 Synthesis Gas Composition

The analyses of the synthesis gas were inconclusive because the analytical results did not indicate a gas that resembled a typical gasifier synthesis gas. The composition of the gas indicated that nearly complete combustion had occurred by the time the gases were sampled. Nearly complete combustion could have occurred due to infiltration of ambient air into the PCs via leaks between the SC and PC, or perhaps an overabundance of ambient air was allowed to enter the primary chambers through the ports in the doors, or a recirculation zone from the burner region could have resulted in air being mixed into the back end of the PC through turbulent mixing. At any rate, the high oxygen concentration

in some of the samples indicated that significant quantities of ambient air were being pulled into the chambers. It was not possible to determine which situation had occurred, although it is possible that the truncated shakedown schedule resulted in sub-optimal stoichiometric ratios in the primary chambers. Table 3-19 lists the results from the analysis of the synthesis gas samples.

### 3.9 Ash Analysis

The ash samples that were subjected to TCLP analysis (Table 3-20) mostly showed non-detects for all target metals. The amino acid analytical results for the ash (Table 3-21) showed all amino acids below reportable detection limits.

**Table 3-19.** Synthesis Gas Composition

	H <sub>2</sub> (%)	CO <sub>2</sub> (%)	O <sub>2</sub> (%)	N <sub>2</sub> (%)	CO (%)	Methane (ppm)	Non-Methane Organic Compounds (ppm)	H <sub>2</sub> O (mg/L)
Day 1 Run 1	ND	6.9	14.7	84.8	ND	20	436	221
Day 1 Run 2	ND	9.5	7.9	76.6	ND	1923	2507	334
Day 2 Run 1	ND	9.1	12.7	86.2	ND	1503	1063	11424
Day 3 Run 1	ND	ND	23.2	83.7	ND	453	1351	100

**Table 3-20.** TCLP Results for Ash (mg/L)

	As	Ba	Cd	Cr	Pb	Hg	Se	Ag
Day 2 Side A	<0.015	0.05	< 0.0006	< 0.05	<0.015	< 0.001	< 0.03	< 0.06
Day 2 Side B	<0.015	0.04	< 0.0006	< 0.05	<0.015	< 0.001	< 0.03	< 0.06
Day 3 Side A	<0.015	< 0.03	< 0.0006	0.08	<0.015	< 0.001	< 0.03	< 0.06
Day 3 Side B	<0.015	0.05	< 0.0006	< 0.05	<0.015	< 0.001	< 0.03	< 0.06
Day 4 Side A	<0.015	<0.03	< 0.0006	< 0.05	<0.015	< 0.001	< 0.03	< 0.06
Day 4 Side B	<0.015	0.06	< 0.0006	< 0.05	<0.015	< 0.001	< 0.03	< 0.06

**Table 3-21. Amino Acid Analytical Results for Ash (mg/g)**

	Day 2 Side A	Day 2 Side B	Day 3 Side A	Day 3 Side B	Day 4 Side A	Day 4 Side B
Alanine	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Arginine	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Aspartic Acid	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Glutamic Acid	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Glycine	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Histidine	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Isoleucine	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Leucine	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Lysine	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Methionine	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Phenylalanine	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Proline	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Serine	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Threonine	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Tryptophan	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Tyrosine	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Valine	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5

### 3.10 Estimated Emissions of Pollutants Per Mass of Carcass Fed

Taking the average emissions of each pollutant in pounds per hour and dividing by the average carcass feed rate (0.32 tons/hr) yields the estimated emissions in emission factor

units. These results are shown in Table 3-22. Note that these results apply only to the animal carcass feed, since extractive sampling was not performed during the plant matter tests for reasons described earlier.

**Table 3-22. Estimated Emissions**

	Average lb/hr	Average lb/ton of carcass
<b>Total Filterable Particulate</b>	0.297	0.93
<b>PM<sub>10</sub></b>	0.297	0.93
<b>Organic Condensable Particulate</b>	0.022	0.07
<b>Inorganic Condensable Particulate</b>	0.120	0.37
<b>Total Particulate</b>	0.439	1.37
<b>Hydrogen Chloride</b>	0.27	0.84
<b>Chlorine as Cl<sub>2</sub></b>	0.173	0.54
<b>Antimony</b>	ND	ND
<b>Arsenic</b>	1.04E-05	3.25E-05
<b>Barium</b>	5.16E-05	1.61E-04
<b>Beryllium</b>	ND	ND
<b>Cadmium</b>	1.08E-04	3.38E-04
<b>Chromium</b>	6.11E-05	1.91E-04
<b>Cobalt</b>	ND	ND
<b>Lead</b>	5.50E-05	1.72E-04
<b>Manganese</b>	4.69E-05	1.47E-04
<b>Mercury</b>	ND	ND
<b>Nickel</b>	1.00E-04	3.13E-04
<b>Selenium</b>	4.11E-05	1.28E-04
<b>Silver</b>	7.23E-06	2.26E-05
<b>PCDD/F Total</b>	1.24E-09	3.88E-09
<b>PCDD/F TEQ</b>	1.75E-11	5.47E-11

ND = Not detected.

# 4.0 Quality Assurance/Quality Control Evaluation Report

This project was conducted under an approved Category III QAPP titled Source Sampling for Transportable Gasifier for Animal Carcasses and Contaminated Plant Material (November 2007). Measurement Quality Objectives (MQOs) established in the QAPP in terms of accuracy, precision, and completeness are shown in Table 4-1 of the QAPP.

Flow rates of stack gas and dilution air were determined using EPA Methods 1 and 2. MQOs were evaluated by pre- and post-test leak checks. All leak checks performed during the course of sampling passed method criteria. Moisture content of the stack gas was determined using EPA Method 4. MQOs were evaluated by pre- and post-test leak checks. All leak checks that were performed passed method criteria. These measurements were 100% complete.

## 4.1 CEMs (CO<sub>2</sub>/O<sub>2</sub>, SO<sub>2</sub>, NO<sub>x</sub>, CO, THCs)

CEMs were calibrated prior to each test day at three points and pre-test and post-test bias checks were performed. Direct calibration MQOs were established at ±2% error. All values measured for O<sub>2</sub>, CO, SO<sub>2</sub> and NO<sub>x</sub> were within the MQOs. For CO<sub>2</sub>, one measured value was slightly outside the MQO at 2.3%. THC values were routinely outside the ±2% limit, ranging from 0 to 6.2%. The bias check MQO was established at ±5% for all CEMs and was routinely met for all instruments with the exception of the THC analyzer, which ranged from 0 to 13.9% error. The MQO for zero/drift checks was established at ±3% and measured on the CO<sub>2</sub>, O<sub>2</sub>, SO<sub>2</sub>, and CO CEMs daily. The MQOs were met for all measurements with the exception of one CO<sub>2</sub> and one SO<sub>2</sub> measurement, which were slightly above the MQO at ±4.2%. In conclusion, CEM measurements met 90% completeness with the exception of THC.

## 4.2 HCl, Cl<sub>2</sub> (Method 26/26A)

Samples were analyzed for HCl and Cl<sub>2</sub> using EPA Method 26A by Resolution Analytics. Results from QC samples were included with the analytical report. Reagent blanks and field blanks for HCl were all below method detection limits. For Cl<sub>2</sub>, the reported catch on the field blank was 0.048 mg. Because Cl<sub>2</sub> sample results were low, this blank value is significant. A matrix spike was performed by the addition of a known amount of chloride standard. Recoveries ranged from 90 to 103%, which met acceptance criteria for accuracy. Precision was assessed by replicate injection of laboratory control samples and the replicate injections resulted in a 1.5% difference, which meets established MQOs. These analyses were 100% complete.

## 4.3 Filterable Particulate (Method 5)

Tare weights for filters were obtained by ARCADIS on 02/29/08 and analyzed by Resolution Analytics. Final weights were obtained on 04/30/08. For each weighing session the balance was zeroed and a 5.0000 mg calibration weight was weighed before and after the sample filters. One sample filter (Filter No. 5830786) was also processed as a blank. Accuracy was assessed by comparing the observed weight of the 5.0000 mg calibration standard to the known value. Precision was assessed using the values from replicate weighings of the 5.0000 mg standard. MQOs were met and these measurements were 100% complete.

## 4.4 PCDDs/PCDFs (EPA Method 23)

Six samples, a field blank and reagent blanks were submitted to Analytical Perspectives for the determination of PCDD/PCDF. The laboratory report included raw data for initial calibration, calibration verifications, and daily laboratory control samples. No analytes were detected in the field blank, reagent blanks, or method blank. Internal standard and surrogate recoveries were within the acceptable range of 50–150% for all samples and met MQOs for accuracy/bias. No criteria for precision were established but standard deviations between replicate injections of laboratory control samples passed method acceptance criteria. These analyses were 100% complete.

## 4.5 Metals (EPA Method 29)

EPA Method 29 trains were sent to First Analytical Laboratories for analysis of target metals antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, lead, manganese, mercury, nickel, selenium, and silver. Barium, cobalt, and manganese were determined by Inductively Coupled Plasma Optical Emission Spectrometry (ICP). Mercury was determined by Cold Vapor Atomic Absorption Spectrophotometry (CVAA). All other compounds were determined by Graphite Furnace Atomic Absorption Spectrophotometry (GFAA).

Six sampled trains were submitted for analysis along with a field blank and reagent blanks. Normal trace amounts of barium, cadmium, chromium, and manganese were found in the blank trains. Since sample values were so low for these elements, blank concentrations are significant and samples should be blank-corrected.

Laboratory control samples consisting of initial calibration verifications (ICVs), continuing calibration verifications (CCVs) and continuing calibration blanks (CCBs) were

performed for each element. Triplicate values are obtained for each sample on the instrument and the average of these triplicate values is reported. In addition, the laboratory performed duplicate analysis and matrix spike analysis for selected samples. All laboratory control samples were within the acceptance criteria for recovery and relative standard deviation required by the method.

#### **4.6 PM<sub>10</sub>, Condensable Particulate (EPA M201A/OTM-DIM)**

These samples were analyzed by Resolution Analytics. Leak checks on the sampling trains were performed according to the method for every test. Tests were not started until leak checks passed.

#### **4.7 CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>, O<sub>2</sub>, NMOC, CH<sub>4</sub> in Synthesis Gas**

Leak checks on the sampling trains were performed according to the method for every test. Tests were not started until leak checks passed.

#### **4.8 Total Suspended Particulate**

These samples were analyzed by Resolution Analytics. Leak checks on the sampling trains were performed according to the method for every test. Tests were not started until leak checks passed.

#### **4.9 Ash Composition (EPA Method 1311/TCLP)**

Grab samples of the ash were taken from “A”-side and “B”-side on days 2 through 4. Six samples were submitted to First Analytical Laboratories for TCLP analysis for target elements arsenic, barium, cadmium, chromium, lead, mercury, selenium, and silver. Arsenic, cadmium, lead, mercury, selenium, and silver were not detectable in any of the leachates. The arsenic spike recovery was slightly low at 70%. This low recovery was not considered a problem because there were not quantifiable levels of arsenic in the samples. All of the other spike recoveries were within the acceptable range of 75–125%. All leachates were analyzed in duplicate. Results for laboratory control samples including method blanks, initial calibration verifications, continuing calibration verifications, and continuing calibration blanks were also included in the analytical report. All data were within method acceptance criteria. These analyses were 100% complete.

#### **4.10 Ash Amino Acids**

Grab samples of the ash were taken from “A”-side and “B”-side on days 2 through 4. A total of six samples were submitted to EMSL Analytical for a complete amino acid profile, which included the following:

- Acid stable amino acids;
- Sulfur amino acids; and
- Tryptophan.

For amino acids, a portion of sample was mixed with hydrochloric acid solution in a modified Kjeldahl flask. To prevent oxidation, as much oxygen as possible is removed from the flask by repeated freezing and thawing under vacuum. The neck of the flask was heat-sealed and the flask was heated in a 110 °C oven for 20 hours. Proteins in the sample were hydrolyzed to amino acids by the hot hydrochloric acid solution. Amino acids (if present) were separated on an ion exchange column and detected by reaction with ninhydrin. The concentration of each amino acid was quantitated against a standard known concentration.

The tryptophan samples were hydrolyzed with sodium hydroxide in an evacuated sealed glass vessel. Hydrolysates were analyzed on a high performance liquid chromatograph (HPLC), using UV detection and quantitated from standards of known concentration.

Results for all samples were below the laboratory reporting limit of 0.5 mg/g.

#### **4.11 Data Quality Assessment (DQA)**

An internal DQA was performed to ensure data from raw analytical reports were accurately transcribed and entered into spreadsheets. Results of laboratory quality control samples for all methods were also reviewed. An error in data entry for organic and inorganic condensable particulate was found and corrected. All laboratory control samples for all methods met method acceptance criteria.



# 5.0 Conclusions

A prototype transportable gasifier, developed by BGP for the Department of Defense TSWG, was tested in the field in March 2008. The gasifier is intended to thermally process contaminated animal carcasses and plant matter.

Samples were taken and analyzed for several targets, including:

- Fixed combustion gases, including oxygen, carbon dioxide, carbon monoxide, total hydrocarbons, sulfur dioxide, and oxides of nitrogen;
- Particulate matter, including total filterable particulate, condensable particulates, PM<sub>10</sub>, and particle size distributions;
- Metals;
- Acid gases;
- Polychlorinated dibenzo-*p*-dioxins and polychlorinated dibenzofurans;
- Leachable metals in the ash residues; and
- Amino acids in the ash residues.

The unit was deployed in the field in a rapid manner, and was operational to perform the necessary emissions testing described in the QAPP in spite of having less than a week for initial startup and shakedown. This truncated shakedown schedule resulted in several operational issues that should be addressed through minor design modifications, discussed in the Engineer's Report [BGP, 2008]. The operational issues of concern that impacted the emissions testing included:

- Failure of the ash removal auger contributed to a feed rate limitation.
- Inefficient distribution of animal matter on the hearths in the primary chamber limited the unit's maximum throughput to approximately 32% of the design capacity.
- The plant material selected as a surrogate for contaminated plant matter was not acceptable to feed through the unit's macerator. Gasifier operation with plant matter feed was therefore cut to only a few hours and extractive sampling was not performed on the plant matter tests.
- Air infiltrated into the primary chambers through some unknown mechanism, and the analyzed synthesis gas did not bear a resemblance to synthesis gas from other gasification processes, possibly due to air migrating from the secondary chambers through gaps in the hearth to the primary chamber in the vicinity of the sampling port, turbulent mixing from the burner zones, or an overabundance of air being pulled in through the ports in the doors.

- Emissions of the measured pollutants were at low levels, and the ash passed TCLP. There were slightly elevated emissions of cadmium, the source of which is unknown. There may be Cd present in the materials of construction of the gasifier or macerator, since animal carcasses are not known to contain large amounts of Cd and the fuel oil did not contain any Cd.

There are no emissions standards with which to compare this type of gasifier unit, although emissions of most pollutants were well below the NSPS for small municipal waste combustors. The particle size distribution suggested that the vast majority of the emitted particulate matter was smaller than 0.5 microns.

A very important observation was that the emissions of carbon monoxide and total hydrocarbons correlated very well with the average of the temperatures of the two primary chambers. This observation suggests that for emergency response deployment, the primary chamber temperatures could be used as a surrogate monitoring parameter to ensure minimization of emissions. Additional testing should investigate this potential advantage.

Amino acid analysis of the ash yielded non-detects for all target analytes. This observation suggests that the gasifier unit would be capable of destroying prions that could potentially cause Transmissible Spongiform Encephalopathy (TSE).

Because the unit is so simple and produces such low emissions, it is important to gain a better understanding of the reactions taking place in the primary chambers. It is also unknown whether the low emissions will persist as the unit is brought up to its full operating capacity, although by normalizing the results versus the feed rate into emission factor units, the estimated emissions should be conservative. In addition, operation at full capacity may result in significant reduction in auxiliary fuel usage. Further testing at full capacity would be very desirable.

According to the introduction, the purposes of this emissions test were:

- To provide a basis for comparison with other combustion devices;
- To address public concerns about environmental impacts from carcass disposal operations;
- To give state and local environmental agencies information to support their responsibilities in siting and operating combustion equipment; and
- To allow the permanent siting of such devices at industrial settings in the agricultural industry (e.g., at rendering plants) for use with routine mortalities and for energy production.

The data presented in this report are of sufficient quality to allow these goals to be achieved.

The overall program objective was to deliver a prototype gasifier capable of being transported over all primary and secondary roads, for this prototype gasifier to be capable of being operational in less than 24 hours after arrival at the

site, and for this prototype gasifier to have the capability to process 25 tons per day of contaminated animal carcasses or plants.

The first two program objectives were achieved; the third objective has yet to be demonstrated.

# 6.0

## References

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