URS

1600 Perimeter Park Drive
Morrisville, NC 27560
919-461-1100

Introduction

On July 14, 2004 Ron McCulloch of URS Corporation conducted emissions measurements for total filterable particulate matter (PM), ammonia (NH_3), ammonium particulates (NH_4^+), and volatile organic amines (VOA) from the gasifier that was operated at the North Carolina State University Animal and Poultry Waste Management Center (APWMC) on Lake Wheeler Road in Raleigh, NC. The gasifier, manufactured by BGP (Figure 1), employs a down draft burner, which directly heats a secondary, or lower chamber. Heat is transferred through a conducting plate into the feedstock chamber above. As feedstock gasifies, the product gases are drawn out of the primary chamber and into the flame in the secondary chamber, thereby providing the fuel to sustain the process.

Figure 1. BGP Gasifier Schematic

Appendices to this report include a list of abbreviations (Appendix A), summary spreadsheet printouts (Appendix B); supporting portable analyzer data and operating conditions (Appendix C); and an example calculation for PM emissions (Appendix D) to demonstrate the use of equations in the EPA reference methods.

Experimental

Gas samples were collected isokinetically, using a combination of EPA Method 5 and EPA Method CTM 027. The Method 5 train consists of a glass sampling nozzle and probe, followed by a tared Teflon filter, and an impinger train filled with approximately 200 ml of deionized water and silica gel. For the CTM027 adaptation, 0.1N sulfuric acid (H_2SO_4) solution was substituted for deionized water, to absorb the gaseous ammonia and other reduced nitrogen species present in the gas stream. For the purposes of this test program, the non-ammonia reduced nitrogen species were assumed to be volatile organic amines. Volatile organic amines were calculated as the difference between TN and the sum of NH_3 and NH_4^+ (TN-[NH_3+NH_4^+]). This combination of methods allowed for simultaneous sampling of particulate (PM, NH_4^+) and gaseous species (NH_3, TN). In addition, NCSU staff measured oxides of nitrogen (NO_X), carbon monoxide (CO), Oxygen (O_2) and carbon dioxide (CO_2) using a portable gas analyzer.

Three test runs, ranging from 148 to 272 minutes duration were conducted at each of two conditions. The first condition consisted of a 65 kg batch of hog waste, with a composition of 50% dry matter. The second condition consisted of a 40 kg batch of waste, at 75% dry matter. Both batches were loaded after the gasifier had reached a minimum operating temperature of approximately 200ºC.

After each sampling run, the probe and nozzle were rinsed, first with acetone to recover particulate matter, then with 0.1N H_2SO_4 to recover any ammonium species unaffected by the acetone rinse. The filter was recovered separately, and the impinger solution was rinsed with deionized water into a separate sample bottle. The acetone probe rinses were evaporated in a tared beaker. The beakers containing the evaporated probe rinses, and the tared filters were reweighed to a constant weight, +/- 0.0005g to determine the total particulate mass collected by each sample train. Following the gravimetric determinations, the filters were extracted in a sonic bath using approximately 50 ml of deionized water and 10 ml of methanol. The acid probe rinses were added to the filter extracts. The combined acid probe rinse and filter extract were analyzed for NH_4^+ by ion chromatograph to determine the NH_4^+ particulate content of the samples. The acid impinger solutions were analyzed for NH_4^+ and for TN to determine the NH_3 and TN content of the samples, respectively. Volatile amine content of the samples was estimated as the difference between TN and NH_3.

Results and Discussion

Emissions of PM from the gasifier increased exponentially over the duration of each waste run, with the lower moisture batch exhibiting greater PM emissions, presumably due to more ash formation. The average PM emissions for the 50% dry matter batch were 19.0 g/hour, or an estimated total of 86.1 g of PM emitted over the entire 65 kg batch (1.33 g PM/kg waste). The average PM emissions for the 75% dry matter batch were 34.0 g/hour, or an estimated total of 154.2 g for the entire 40 kg batch (3.86 g PM/kg waste).

As a basis of comparison, Federal rules for commercial and industrial solid waste incinerators (CISWI), which are typically outfitted with either a dry or wet scrubber for acid gas control and a bag filter for particulate control, require a limit of 70 mg/dscm, corrected to 7% O_2. Average emissions of PM from the gasifier were 143.1 mg/dscm @ 7% O_2 and 236.4 mg/dscm @ 7% O_2 for the 50% dry matter and 75% dry matter batches, respectively. The PM Summary table in Appendix B shows the PM emissions results for all test runs. Figures 1a and 1b show the exponential increase in PM emissions.

Emissions of nitrogen compounds initially increased at the beginning of a waste batch, then decayed logarithmically after reaching a peak. Detection limits associated with the test method limited testing to three samples per waste batch. Therefore, the decay curve was observed while testing the 50% dry matter batch, and the initial increase was observed while testing the 75% dry matter batch. Summary tables in Appendix B show the nitrogen emissions results for all test runs. Figures 2-4 show the test results for specific nitrogen species.

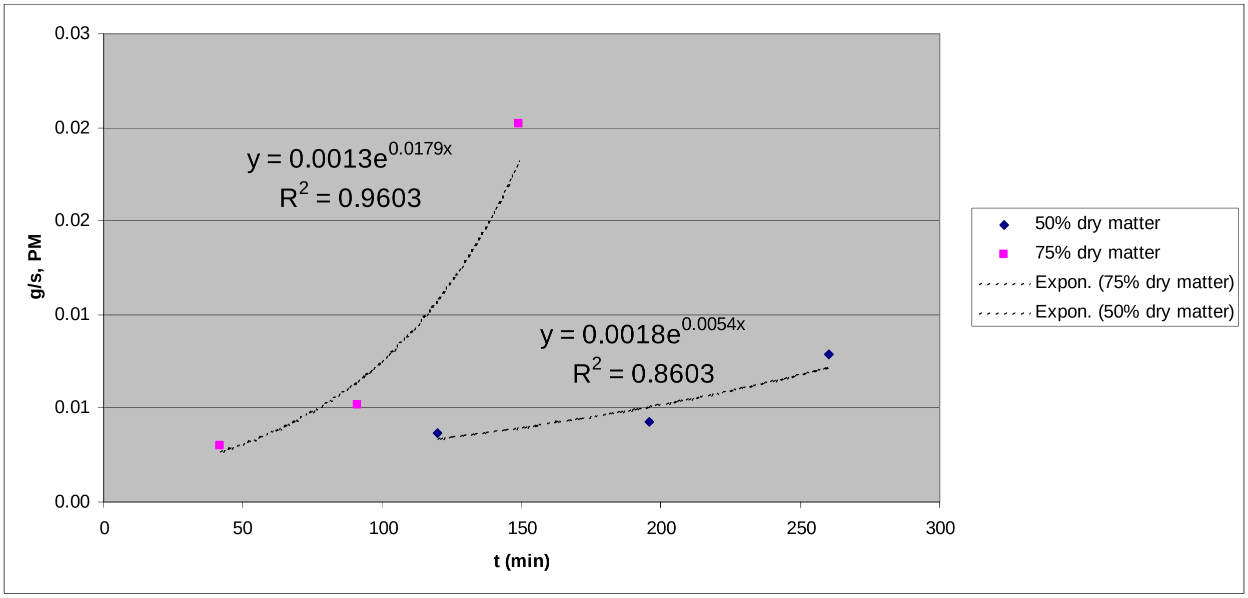

Figure 1a. PM Emissions vs. Time

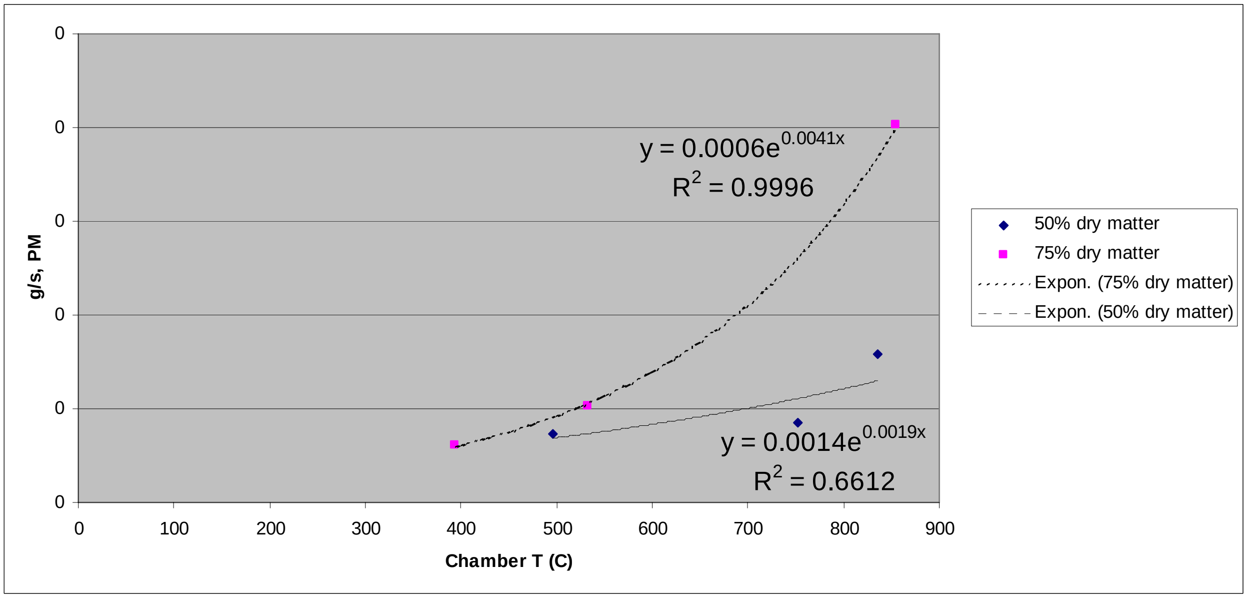

Figure 1b. PM Emissions vs. Temperature

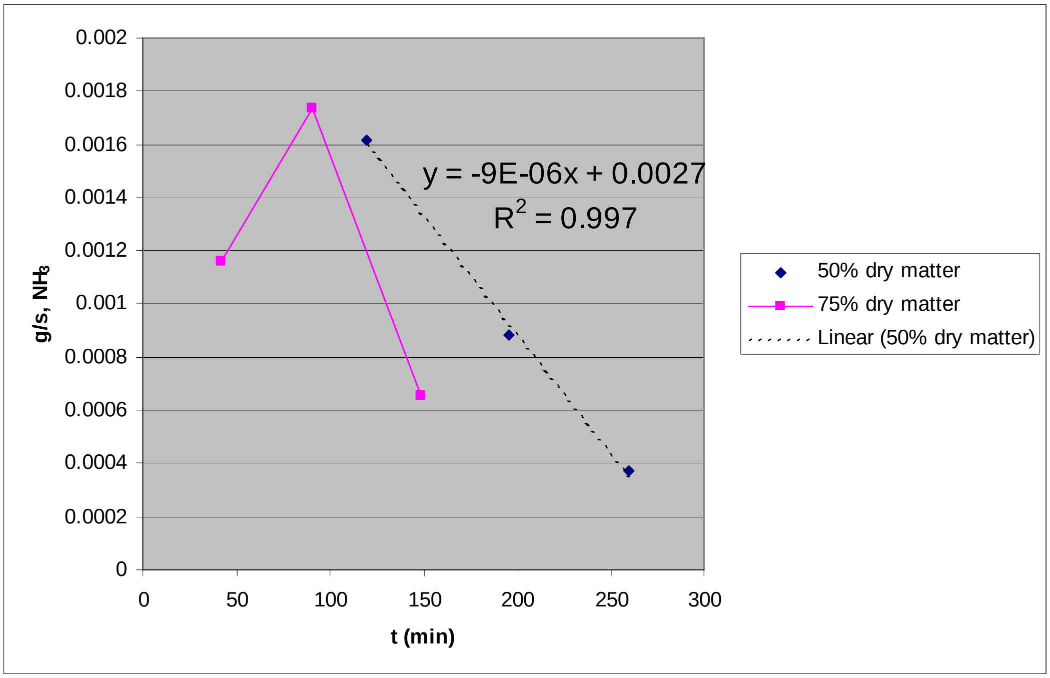

Figure 2a. NH3 Emissions vs. Time

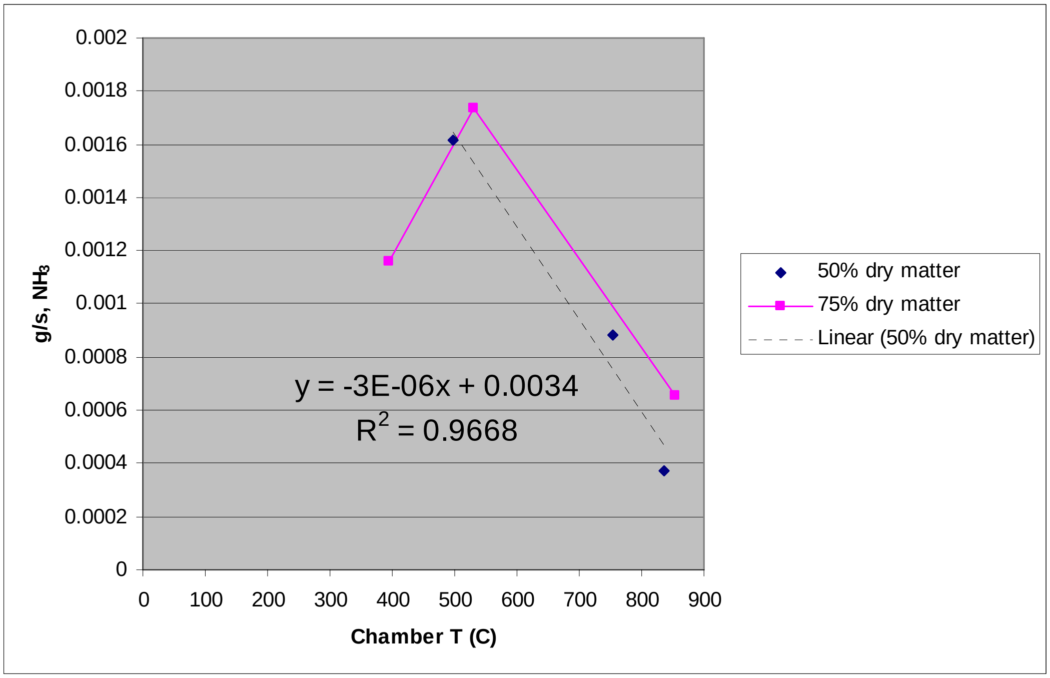

Figure 2b. NH_3 Emissions vs. Temperature

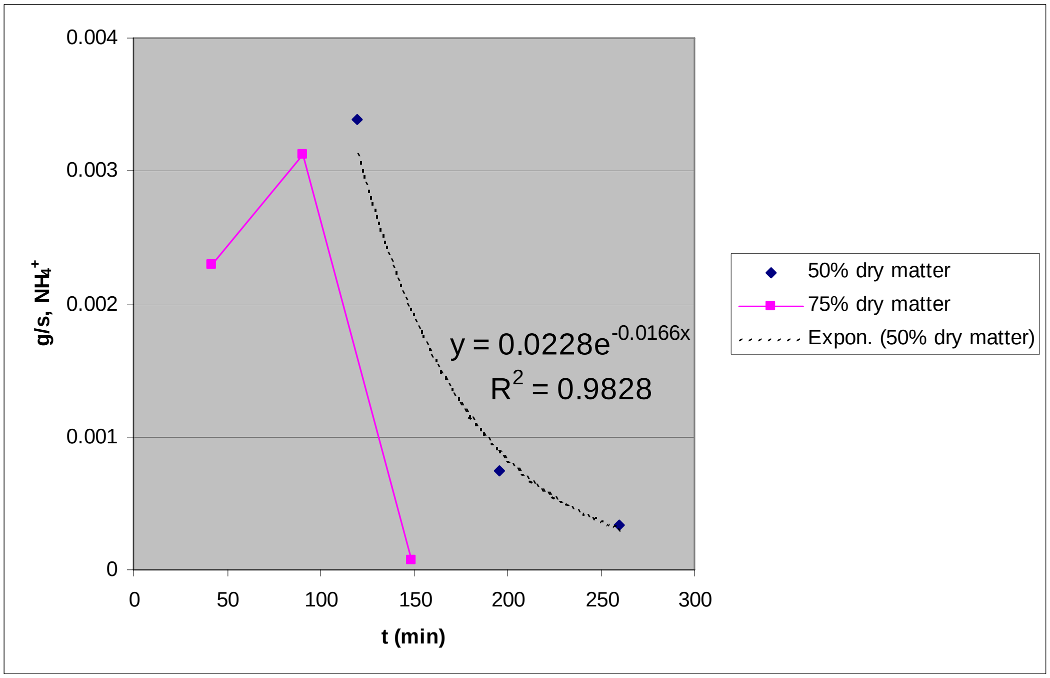

Figure 3a. NH_4^+ Emissions vs. Time

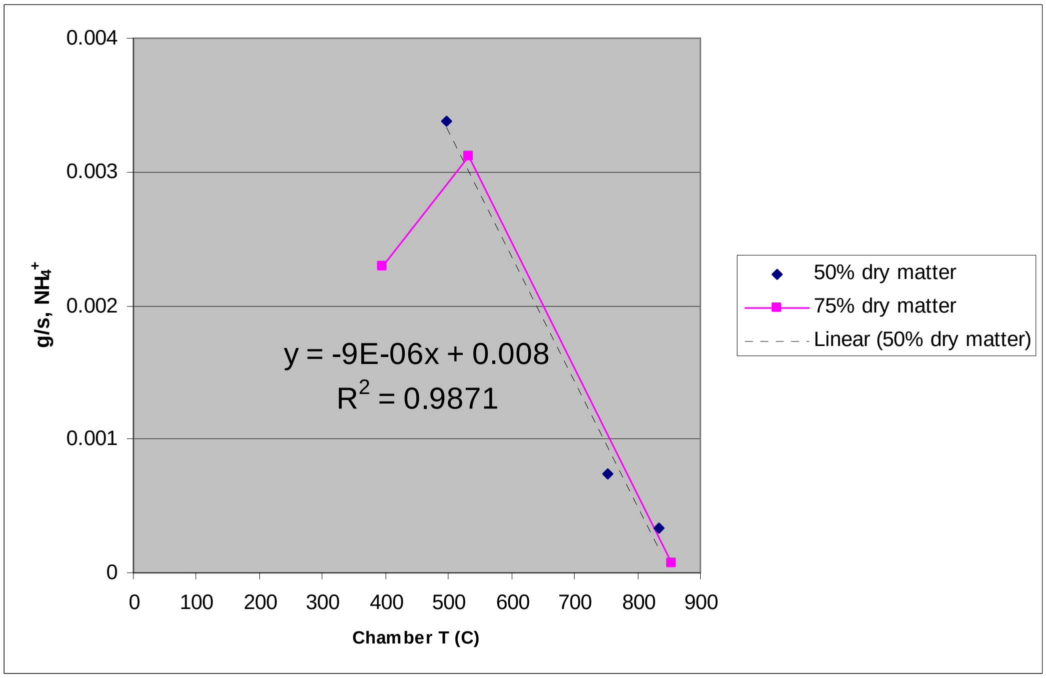

Figure 3b. NH_4^+ Emissions vs. Temperature

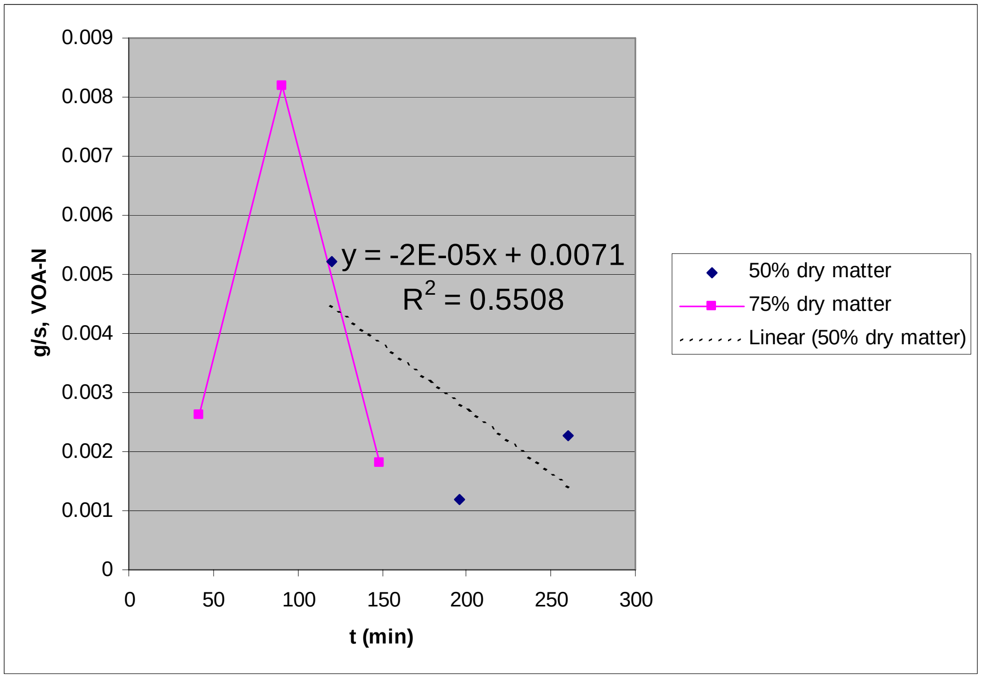

Figure 4a. VOA Emissions vs. Time

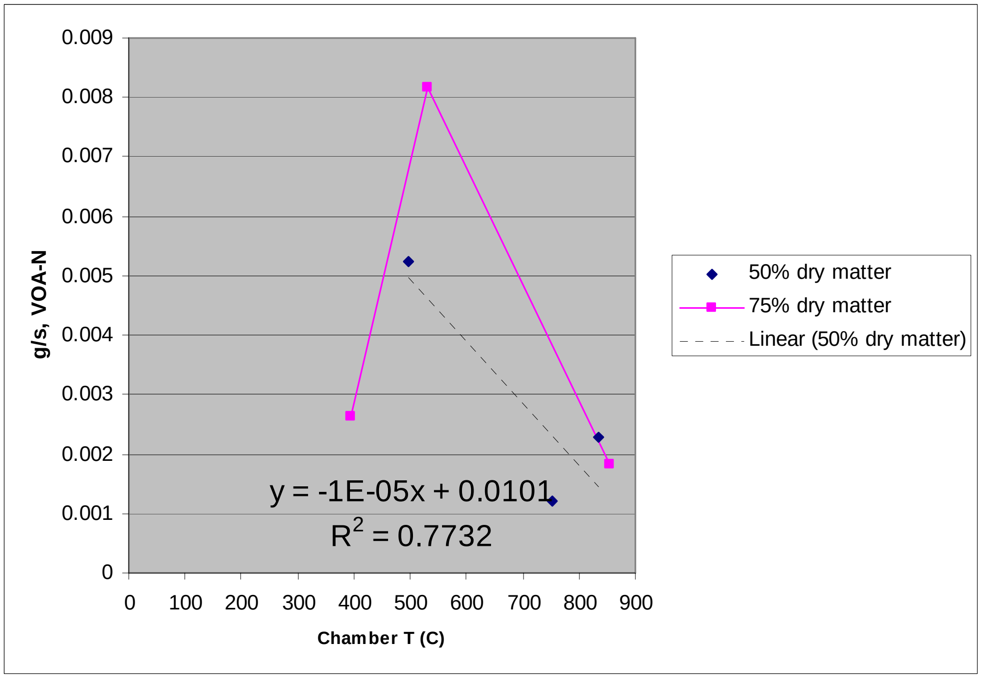

Figure 4b. VOA Emissions vs. Temperature

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Appendix A
List of Abbreviations

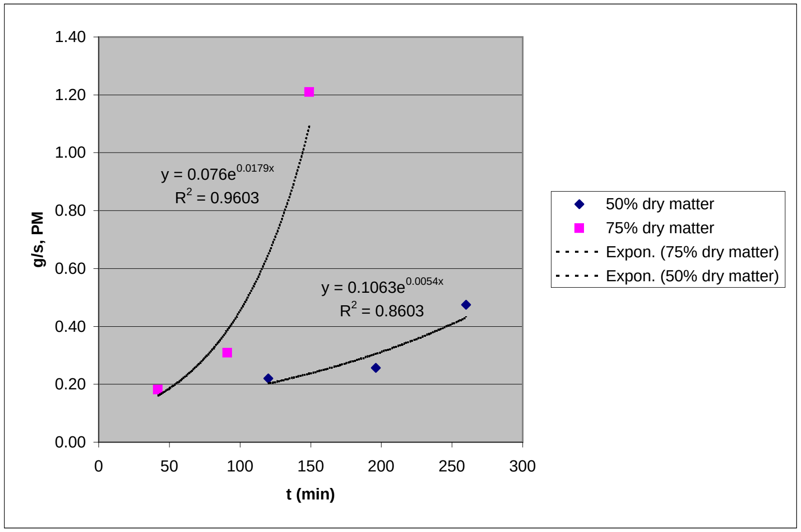
PM	Particulate matter (filterable)
NH_3	Ammonia
NH_4^+	Ammonium
TN	Total nitrogen
VOA	Volatile organic amines
NO_X	Oxides of nitrogen
CO	Carbon monoxide
O_2	Oxygen
CO_2	Carbon dioxide
APWMC	Animal and Poultry Waste Management Center
g	Grams
kg	Kilograms
CISWI	Commercial and industrial solid waste incinerators
0.1N H_2SO_4	Sulfuric acid, 0.1N concentration

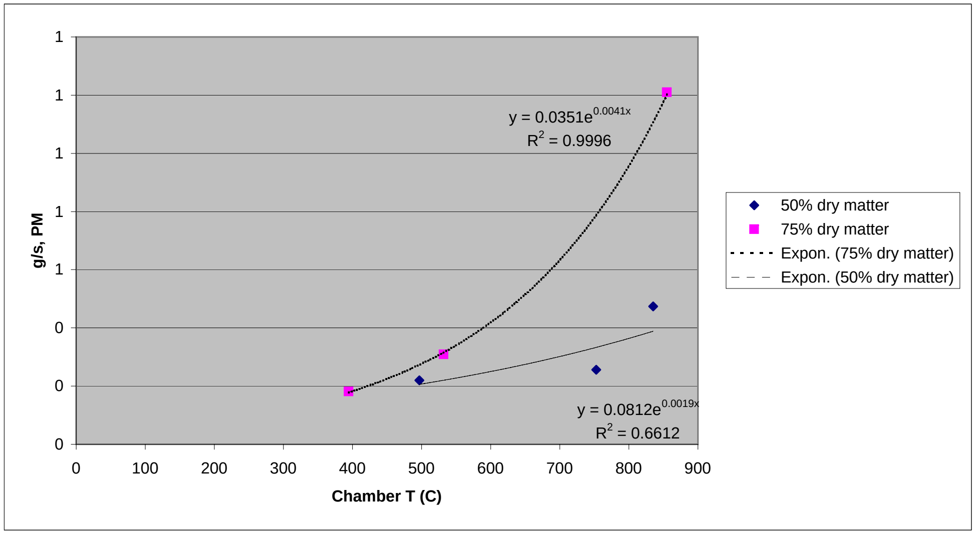
Appendix B
Summary Spreadsheet Printouts

URS

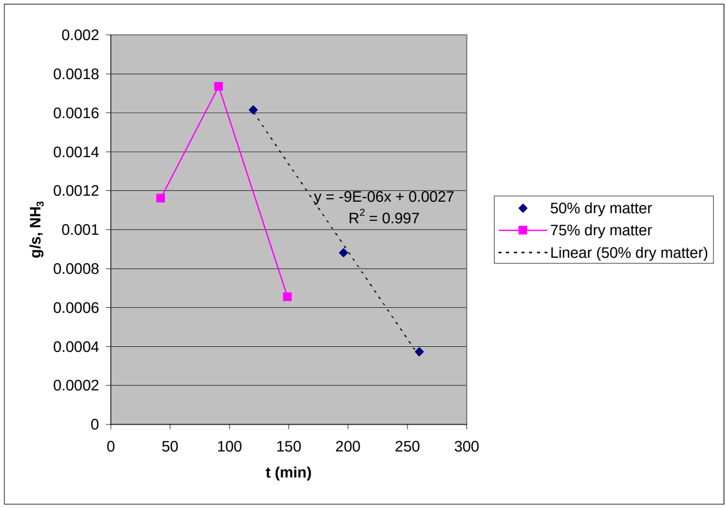
Date	7/14/2004	7/14/2004	7/14/2004	7/14/2004	7/14/2004	7/14/2004
Location/Condition	Gasifier	Gasifier	Gasifier	Gasifier	Gasifier	Gasifier
Run	1	2	3	4	5	6
Worksheet Tab Name	**Gasifier R1**	**Gasifier R2**	**Gasifier R3**	**Gasifier R4**	**Gasifier R5**	**Gasifier R6**
Start Time	10:24	11:40	12:59	13:53	14:42	15:40
End Time	11:24	12:40	13:29	14:23	15:12	16:10
Source Area (ft^2)	1.07	1.07	1.07	1.07	1.07	1.07
Nozzle Diameter (")	0.430	0.430	0.430	0.430	0.430	0.430
DGM Calibration Factor (Y_D)	1.035	1.035	1.035	1.035	1.035	1.035
ΔH@	1.627	1.627	1.627	1.627	1.627	1.627
Pitot (Cp)	1	1	1	1	1	1
Stack Barometric Pressure ("Hg)	29.94	29.94	29.94	29.94	29.94	29.94
Static Pressure ("H_2O)	0.0	0.0	0.0	0.0	0.0	0.0
Test Duration (min)	60	60	30	30	30	30
Minutes per point	5	5	5	5	5	5
Meter Volume x DGMCF (ft^3)	26.354	28.543	13.919	14.245	12.453	13.774
Impinger Mass Gain (g)	29.4	19.7	11.3	7.6	16.8	12.8
Meter Temperature (R)	561.4	567.4	567.5	566.1	565.8	565.2
Average ΔH (in H_2O)	0.49	0.59	0.56	0.55	0.46	0.53
Meter Pressure ("Hg)	29.98	29.98	29.98	29.98	29.97	29.98
% H_2O at saturation	99.9	99.9	99.9	99.9	99.9	99.9
% H_2O	5.3	3.4	3.9	2.6	6.4	4.5
% CO_2	1.7	1.7	1.6	1.8	1.8	1.6
% O_2	18.5	18.4	18.5	18.7	18.1	18.3
% N_2	79.8	79.9	79.9	79.6	80.1	80.1
Dry Molecular Weight (mw_{dry})	29.0	29.0	29.0	29.0	29.0	29.0
Source Molecular Weight (mw_g)	28.4	28.6	28.6	28.7	28.3	28.5
Avg. SQRT Delta P	0.13	0.14	0.14	0.14	0.13	0.15
Avg. Source Temperature (R)	779.9	808.0	846.2	820.7	803.4	922.0
Avg. Source Pressure ("Hg)	29.94	29.94	29.94	29.94	29.94	29.94
Gas Velocity (ft/s)	10.3	11.5	12.0	11.8	10.7	13.1
Stack Gas Flow Rate (acfm)	659	739	771	757	687	838
Stack Gas Flow Rate (dscfm)	423	467	462	474	423	459
Standard Sample Volume (dscf)	24.820	26.604	12.968	13.305	11.636	12.885
Average Isokinetic %	103.7	100.7	99.1	99.1	97.2	99.3
Average sqrt(ΔH)	0.70	0.76	0.75	0.74	0.67	0.73
Y(qa)	0.999	1.013	1.017	0.986	1.020	0.996
ΔY (± 5%)	-3.4%	-2.1%	-1.7%	-4.7%	-1.4%	-3.7%

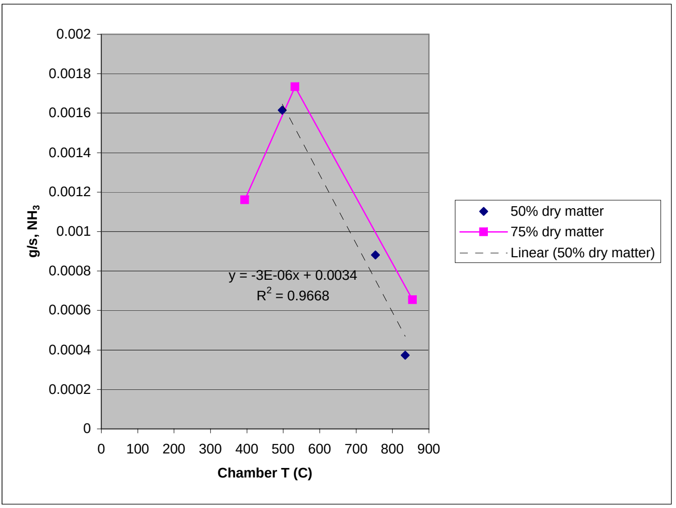
					mass / sample		Sample Volume	Emission Concentration	Volumetric Flow Rate	Emission Rate		O_2	Emission Concentration	Production Rate	Emission Rate
Sample	Pollutant	Date	Start	End	g	gr	dscf	gr/dscf	dscfm	lb/hr	g/s	%	gr/dscf @ 7% O2	/hour	lb/
Gasifier R1	PM	7/14/2004	10:24	11:24	0.0129	0.199	24.820	0.0080	423	0.029	0.220	18.5	0.047		#DIV/0!
Gasifier R2	PM	7/14/2004	11:40	12:40	0.0146	0.225	26.604	0.0085	467	0.034	0.256	18.4	0.047		#DIV/0!
Gasifier R3	PM	7/14/2004	12:59	13:29	0.0133	0.205	12.968	0.0158	462	0.063	0.474	18.5	0.093		#DIV/0!
Average, 50% dry matter waste run					0.0136	0.210	21.464	0.0108	451	0.042	0.317	18.5	0.063	#DIV/0!	#DIV/0!
Gasifier R4	PM	7/14/2004	13:53	14:23	0.0051	0.079	13.305	0.0059	474	0.024	0.182	18.7	0.037		#DIV/0!
Gasifier R5	PM	7/14/2004	14:42	15:12	0.0085	0.131	11.636	0.0113	423	0.041	0.309	18.1	0.055		#DIV/0!
Gasifier R6	PM	7/14/2004	15:40	16:10	0.0340	0.525	12.885	0.0407	459	0.160	1.210	18.3	0.218		#DIV/0!
Average, 75% dry matter waste run					0.0159	0.245	12.609	0.0193	452	0.075	0.567	18.3	0.103	#DIV/0!	#DIV/0!



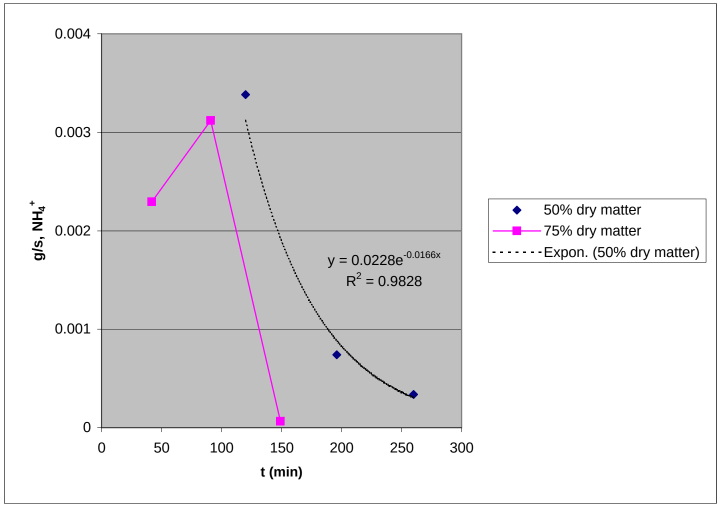


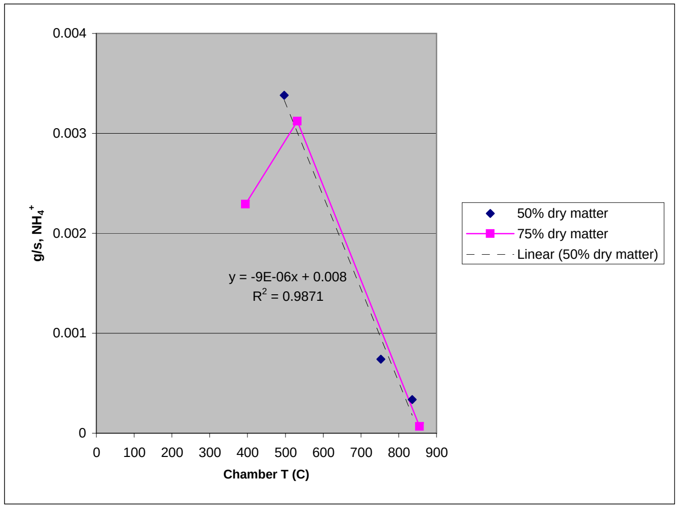
URS					mass / sample		Sample Volume	Emission Concentration	Volumetric Flow Rate	Emission Rate	
Sample	Pollutant	Date	Start	End	ug	gr	dscf	gr/dscf	dscfm	lb/hr	g/s
Gasifier R1	NH_3	7/14/2004	10:24	11:24	94.8	1.46E-03	24.820	5.90E-05	423	2.14E-04	1.62E-03
Gasifier R2	NH_3	7/14/2004	11:40	12:40	50.2	7.75E-04	26.604	2.91E-05	467	1.17E-04	8.82E-04
Gasifier R3	NH_3	7/14/2004	12:59	13:29	10.5	1.61E-04	12.968	1.25E-05	462	4.93E-05	3.73E-04
Average, 50% dry matter waste run					51.8	8.00E-04	21.464	3.35E-05	451	1.27E-04	9.57E-04
Gasifier R4	NH_3	7/14/2004	13:53	14:23	32.6	5.03E-04	13.305	3.78E-05	474	1.54E-04	1.16E-03
Gasifier R5	NH_3	7/14/2004	14:42	15:12	47.7	7.36E-04	11.636	6.33E-05	423	2.29E-04	1.73E-03
Gasifier R6	NH_3	7/14/2004	15:40	16:10	18.4	2.84E-04	12.885	2.20E-05	459	8.66E-05	6.54E-04
Average, 75% dry matter waste run					32.9	5.08E-04	12.609	4.10E-05	452	1.57E-04	1.18E-03





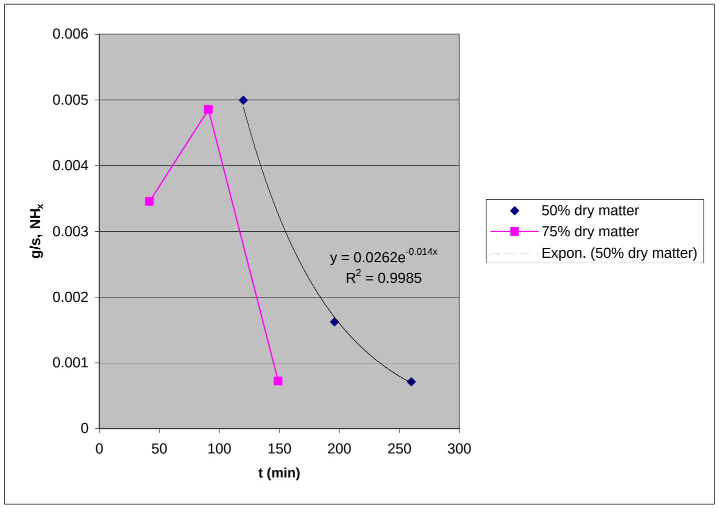
URS					mass / sample		Sample Volume	Emission Concentration	Volumetric Flow Rate	Emission Rate	
Sample	Pollutant	Date	Start	End	ug	gr	dscf	gr/dscf	dscfm	lb/hr	g/s
Gasifier R1	NH_4^+	7/14/2004	10:24	11:24	198.6	3.06E-03	24.820	1.23E-04	423	4.47E-04	3.38E-03
Gasifier R2	NH_4^+	7/14/2004	11:40	12:40	42.2	6.51E-04	26.604	2.45E-05	467	9.79E-05	7.40E-04
Gasifier R3	NH_4^+	7/14/2004	12:59	13:29	9.4	1.46E-04	12.968	1.12E-05	462	4.45E-05	3.36E-04
Average, 50% dry matter waste run					83.4	1.29E-03	21.464	5.31E-05	451	1.97E-04	1.49E-03
Gasifier R4	NH_4^+	7/14/2004	13:53	14:23	64.3	9.92E-04	13.305	7.46E-05	474	3.03E-04	2.29E-03
Gasifier R5	NH_4^+	7/14/2004	14:42	15:12	85.8	1.32E-03	11.636	1.14E-04	423	4.13E-04	3.12E-03
Gasifier R6	NH_4^+	7/14/2004	15:40	16:10	1.9	2.88E-05	12.885	2.23E-06	459	8.77E-06	6.63E-05
Average, 75% dry matter waste run					50.7	7.82E-04	12.609	6.36E-05	452	2.42E-04	1.83E-03

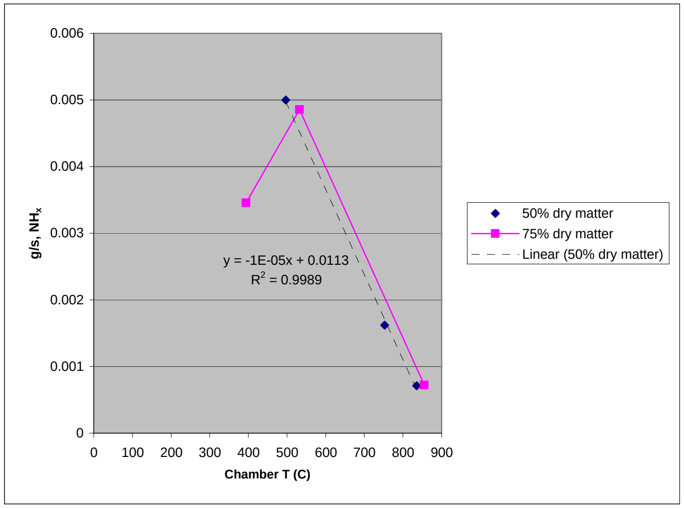




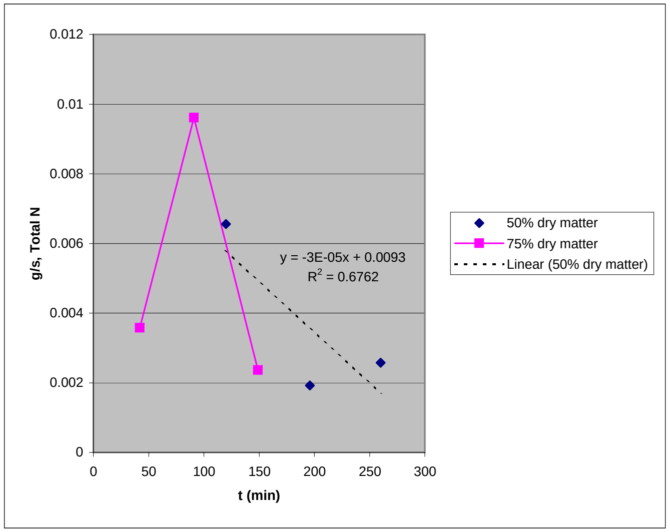
grams emitted

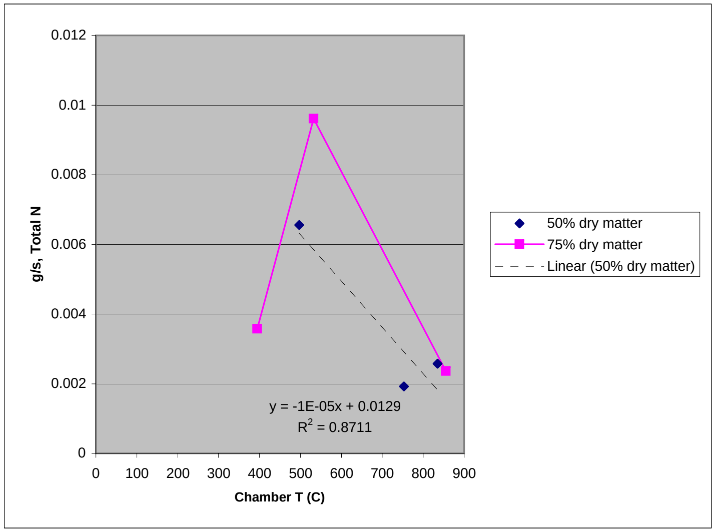
URS					mass / sample		Sample Volume	Emission Concentration	Volumetric Flow Rate	Emission Rate	
Sample	Pollutant	Date	Start	End	ug	gr	dscf	gr/dscf	dscfm	lb/hr	g/s
Gasifier R1	NH_x	7/14/2004	10:24	11:24	293.4	4.53E-03	24.820	1.82E-04	423	6.61E-04	5.00E-03
Gasifier R2	NH_x	7/14/2004	11:40	12:40	92.4	1.43E-03	26.604	5.36E-05	467	2.15E-04	1.62E-03
Gasifier R3	NH_x	7/14/2004	12:59	13:29	19.9	3.07E-04	12.968	2.37E-05	462	9.39E-05	7.10E-04
Average, 50% dry matter waste run					135.2	2.09E-03	21.464	8.66E-05	451	3.23E-04	2.44E-03
Gasifier R4	NH_x	7/14/2004	13:53	14:23	96.9	1.49E-03	13.305	1.12E-04	474	4.57E-04	3.45E-03
Gasifier R5	NH_x	7/14/2004	14:42	15:12	133.6	2.06E-03	11.636	1.77E-04	423	6.42E-04	4.85E-03
Gasifier R6	NH_x	7/14/2004	15:40	16:10	20.3	3.13E-04	12.885	2.43E-05	459	9.53E-05	7.21E-04
Average, 75% dry matter waste run					83.6	1.29E-03	12.609	1.05E-04	452	3.98E-04	3.01E-03



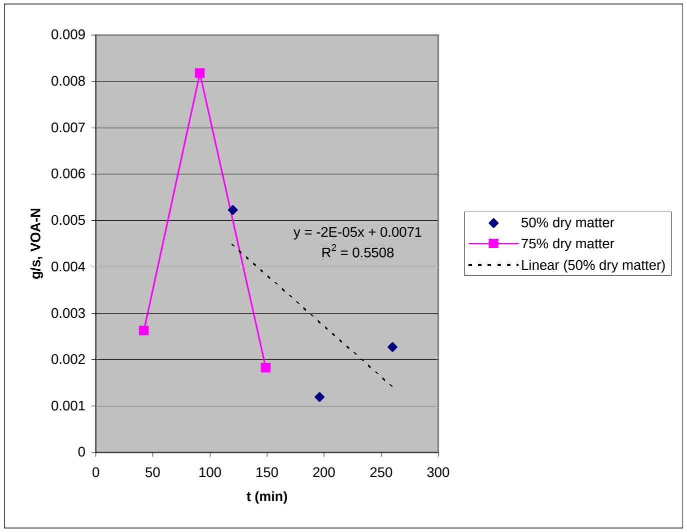


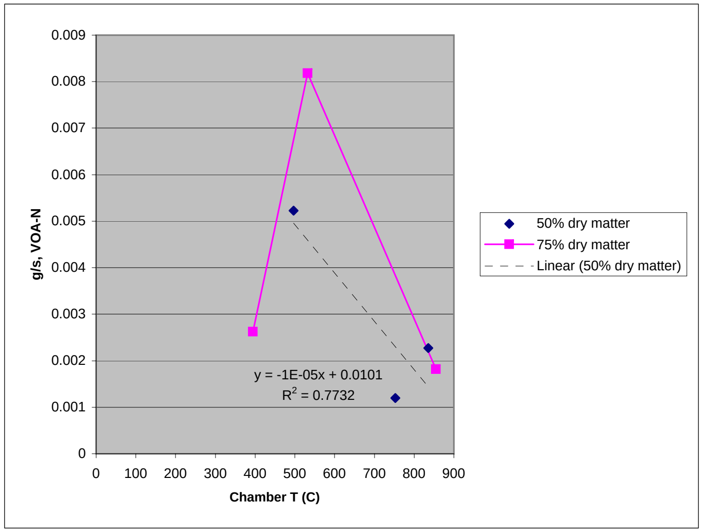
URS					mass / sample		Sample Volume	Emission Concentration	Volumetric Flow Rate	Emission Rate	
Sample	Pollutant	Date	Start	End	**ug**	gr	dscf	gr/dscf	dscfm	lb/hr	g/s
Gasifier R1	Total N	7/14/2004	10:24	11:24	385.0	5.94E-03	24.820	2.39E-04	423	8.68E-04	6.56E-03
Gasifier R2	Total N	7/14/2004	11:40	12:40	109.5	1.69E-03	26.604	6.35E-05	467	2.54E-04	1.92E-03
Gasifier R3	Total N	7/14/2004	12:59	13:29	72.3	1.12E-03	12.968	8.61E-05	462	3.41E-04	2.58E-03
Average, 50% dry matter waste run					189.0	2.92E-03	21.464	1.30E-04	451	4.88E-04	3.69E-03
Gasifier R4	Total N	7/14/2004	13:53	14:23	100.3	1.55E-03	13.305	1.16E-04	474	4.73E-04	3.58E-03
Gasifier R5	Total N	7/14/2004	14:42	15:12	264.3	4.08E-03	11.636	3.51E-04	423	1.27E-03	9.61E-03
Gasifier R6	Total N	7/14/2004	15:40	16:10	66.3	1.02E-03	12.885	7.94E-05	459	3.12E-04	2.36E-03
Average, 75% dry matter waste run					143.6	2.22E-03	12.609	1.82E-04	452	6.85E-04	5.18E-03





URS					mass / sample		Sample Volume	Emission Concentration	Volumetric Flow Rate	Emission Rate	
Sample	Pollutant	Date	Start	End	**ug**	gr	dscf	gr/dscf	dscfm	lb/hr	g/s
Gasifier R1	VOA-N	7/14/2004	10:24	11:24	306.9	4.74E-03	24.820	1.91E-04	423	6.92E-04	5.23E-03
Gasifier R2	VOA-N	7/14/2004	11:40	12:40	68.2	1.05E-03	26.604	3.95E-05	467	1.58E-04	1.20E-03
Gasifier R3	VOA-N	7/14/2004	12:59	13:29	63.7	9.83E-04	12.968	7.58E-05	462	3.01E-04	2.27E-03
Average, 50% dry matter waste run					146.3	2.26E-03	21.464	1.02E-04	451	3.83E-04	2.90E-03
Gasifier R4	VOA-N	7/14/2004	13:53	14:23	73.5	1.13E-03	13.305	8.53E-05	474	3.47E-04	2.62E-03
Gasifier R5	VOA-N	7/14/2004	14:42	15:12	225.0	3.47E-03	11.636	2.98E-04	423	1.08E-03	8.18E-03
Gasifier R6	VOA-N	7/14/2004	15:40	16:10	51.2	7.90E-04	12.885	6.13E-05	459	2.41E-04	1.82E-03
Average, 75% dry matter waste run					116.6	1.80E-03	12.609	1.48E-04	452	5.57E-04	4.21E-03





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919-461-1100

Appendix C
Supporting Portable Analyzer Data and Operating Conditions

Gasification Experiments during the OPEN Team mesurements

Date	7/14/2004															
Run	1															
Set Temp, C	800															
Feedstock	Belt feces	65 kg	50 % DM													
			Flue Measurements						Secondary Chamber Measurements (Burner Chamber)							PC-T
Time of Day	Flue Temp, C	O2 %	CO ppm	CO2 %	NO	NOX	Diff P	PC-T	SC-T	O2 %	CO ppm	CO2 %	NO	NOX		
8:54	214	19.0	6	1.6	23	24	0.022	367	781	8.4	25	8.4	86	90	0:00	
9:10	209	19.0	5	1.4	22	23	0.021	350	800	8.0-12.3	11	6.3	142	149	0:16	
9:25	188	18.8	5	1.2	21	22	0.019	352	800	8.0-11.7	11	7.9	139	145	0:31	
9:41	194	19.0	7	1.5	24	25	0.021	363	803	7.8-11.7	8	6.7	152	159	0:47	
9:55	223	18.6	11	1.6	28	29	0.019	376	800	8.7-11.7	7	6.9	145	152	1:01	
10:10	209	18.8	8	1.8	31	32	0.018	398	802	8.4-11.0	5	7.7	171	179	1:16	
10:26	209	18.6	9	1.5	33	34	0.015	420	800	7.5-11.0	5	8.2	181	190	1:32	496.8
10:41	191	18.5	13	1.5	33	34	0.016	447	797	9.5-10.5	7	7.3	175	183	1:47	
10:55	212	18.3	15	1.8	42	44	0.016	477	802	9.8-10.4	5	7.1	253	165	2:01	
11:11	194	18.8	16	1.8	45	47	0.017	520	804	8.5	5	8.2	309	324	2:17	
11:25	184	18.5	16	1.8	43	45	0.016	620	820	8.6	6	8	307	322	2:31	
11:41	193	19.0	16	1.5	31	32	0.014	613	799	10.6	6	8.6	197	206	2:47	752.8
11:56	226	18.9	21	1.3	37	38	0.021	651	800	9.7	3	7.3	195	204	3:02	
12:11	187	18.2	14	1.6	26	27	0.020	707	800	7.9	4	7.3	189	198	3:17	
12:26	230	18.0	1	2.1	13	13	0.021	867	800	10.3	2	7.1	38	39	3:32	
12:41	295	18.0	1	2.0	10	10	0.021	926	794	8.5-12.7	1	7.1	33	34	3:47	
12:56	271	18.1	0	2.0	25	26	0.016	887	789	9.2-12.2	0	5.2	60	63	4:02	835.3333
13:11	219	18.4	0	1.4	13	13	0.020	831	791	10.3-14.8	1	6.1	37	38	4:17	
13:26	225	19.1	0	1.3	12	12	0.022	788	785	10.6-14.8	6	6.7	44	46	4:32	
end of Run 1																
272	min total															
Run	2															
Set Temp, C	800															
Feedstock	Belt feces	40 kg	74.8 % DM													
			Flue Measurements						Secondary Chamber Measurements (Burner Chamber)							
Time of Day	Flue Temp, C	O2 %	CO ppm	CO2 %	NO	NOX	Diff P	PC-T	SC-T	O2 %	CO ppm	CO2 %	NO	NOX		
13:53	198	19.3	51	1.7	31	32	0.016	350	731	7.8	32	9.9	229	240	0:00	394.3333
14:08	233	18.0	15	2.2	62	65	0.016	398	819	7.5	15	8.8	321	337	0:15	
14:21	177	18.7	22	1.4	45	47	0.016	435	839	7.7	9	8.6	298	312	0:28	
14:37	215	17.6	17	2.0	78	80	0.016	482	849	7.7	2	8.4	308	323	0:44	532
14:51	210	17.8	26	1.9	55	57	0.016	546	858	8.8	4	8.3	305	320	0:58	
15:06	161	18.8	34	1.5	31	32	0.018	568	855	8.9	11	8.0	285	299	1:13	
15:21	186	18.6	34	1.3	38	40	0.015	630	883	5.8	2	10.2	259	271	1:28	
15:37	428	15.7	10	3.0	110	115	0.022	863	952	7.7	7	9.0	231	242	1:44	855
15:51	243	19.0	1	1.3	13	13	0.021	969	808	13.6	7	4.5	49	51	1:58	
16:06	234	19.0	0	1.0	15	15	0.021	827	795	13.9-15.5	0	4.2	40	42	2:13	
16:21	211	19.5	0	1.0	19	19	0.021	761	788	11.8-15.9	0	4.9	54	56	2:28	
end of Run 2																
148	min total															

Gasification Experiments during the OPEN Team mesurements

Date 7/14/2004

Run 1

Time of Day	Flue Temp, C	O2 %	CO ppm	CO2 %	NO	NOX	Diff P	Flue Temp	O2 %	CO ppm	CO2 %	NO	NOX
8:54	214	19.0	6	1.6	23	24	0.022						
9:10	209	19.0	5	1.4	22	23	0.021						
9:25	188	18.8	5	1.2	21	22	0.019						
9:41	194	19.0	7	1.5	24	25	0.021						
9:55	223	18.6	11	1.6	28	29	0.019						
10:10	209	18.8	8	1.8	31	32	0.018						
10:26	209	18.6	9	1.5	33	34	0.015	198	18.54	13.8	1.68	39.2	40.8
10:41	191	18.5	13	1.5	33	34	0.016						
10:55	212	18.3	15	1.8	42	44	0.016						
11:11	194	18.8	16	1.8	45	47	0.017						
11:25	184	18.5	16	1.8	43	45	0.016						
11:41	193	19.0	16	1.5	31	32	0.014	226.2	18.42	10.6	1.70	23.40	24
11:56	226	18.9	21	1.3	37	38	0.021						
12:11	187	18.2	14	1.6	26	27	0.020						
12:26	230	18.0	1	2.1	13	13	0.021						
12:41	295	18.0	1	2.0	10	10	0.021						
12:56	271	18.1	0	2.0	25	26	0.016	238.3	18.53	0	1.57	16.67	17
13:11	219	18.4	0	1.4	13	13	0.020						
13:26	225	19.1	0	1.3	12	12	0.022						

end of Run 1

Run 2

Time of Day	Flue Temp, C	O2 %	CO ppm	CO2 %	NO	NOX	Diff P						
13:53	198	19.3	51	1.7	31	32	0.016	202.7	18.67	29.33	1.77	46.00	48.0
14:08	233	18.0	15	2.2	62	65	0.016						
14:21	177	18.7	22	1.4	45	47	0.016						
14:37	215	17.6	17	2.0	78	80	0.016	195.3	18.07	25.67	1.80	54.67	56.3
14:51	210	17.8	26	1.9	55	57	0.016						
15:06	161	18.8	34	1.5	31	32	0.018						
15:21	186	18.6	34	1.3	38	40	0.015						
15:37	428	15.7	10	3.0	110	115	0.022	279.0	18.30	2.75	1.58	39.25	40.5
15:51	243	19.0	1	1.3	13	13	0.021						
16:06	234	19.0	0	1.0	15	15	0.021						
16:21	211	19.5	0	1.0	19	19	0.021						

end of Run 2

1600 Perimeter Park Drive
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919-461-1100

Appendix D
Example Calculation for PM Emissions

Example PM Emission Calculations, Based on Gasifier Run #1

Barometric Pressure at the Sampling Location, Corrected (EPA Method 2, Section 6.5)

$$P_{bar} = P_{bar,meas} - (Elev \times 0.1/100)$$

$P_{bar,meas}$ = Barometric pressure as measured = 29.94 in. Hg
Elev = elevation of sampling location relative to barometer = 0 feet
P_{bar} = Barometric pressure at the sampling site = 29.94 in. Hg

$$P_{bar} = 29.94 - \left(\frac{0 \times 0.1}{100}\right)$$

$$P_{bar} = 29.94$$

Barometric Pressure at the Sampling Location, Corrected (EPA Method 2, Section 6.5)

P_{bar} = Barometric pressure at the sampling site = 29.94 in. Hg
P_g = Stack Static Pressure = 0.00 in. H_2O
P_s = Absolute Stack Pressure = 29.94 in. Hg

$$P_s = 29.94 + \left(\frac{0.0}{13.6}\right)$$

$$P_s = 29.94$$

Volume of Water Vapor Condensed, corrected to standard conditions, ft^3 (US EPA Method 5, Eq. 5-2)

$$V_{w(std)} = \frac{V_{1c} \times R_w \times R \times T_{std}}{M_w \times P_{std}}$$

V_{1c} = Total weight of liquid collected = 29.4 g

R_w = Density of water = 0.002201 lb/ml

R = Ideal Gas Constant = 21.85 inHg - ft^3/degR - lbmole

T_{std} = Standard absolute temperature = 527.69 deg R

M_w = Molecular Weight of Water = 18.00 lb/lbmole

P_{std} = Standard absolute pressure = 29.92 inHg

$$V_{w(std)} = \frac{29.4 \times 0.002205 \times 21.85 \times 527.69}{18 \times 29.92}$$

$$V_{w(std)} = 1.388$$

Moisture Content, proportion, by volume (US EPA Method 5, Eq. 5-3)

$$B_{ws} = \frac{V_{w(std)}}{V_{m(std)} + V_{w(std)}}$$

$V_{w(std)}$ = Volume of water vapor condensed = 1.388 ft^3

$V_{m(std)}$ = Dry Gas Volume = 24.820 ft^3

$$B_{ws} = \frac{1.388}{24.820 + 1.388}$$

$$B_{ws} = 0.053$$

Moisture content at saturation:

From ASME 1967 Steam Tables (Lookup Table)

$$B_{ws}\text{ (sat)} = \frac{e_s}{P_{bar} + P_g / 13.6}$$

e_s = Saturation vapor pressure at source temperature = 29.92 in. Hg

P_{bar} = Barometric pressure at the sampling site = 29.94 in. Hg

P_g = Stack Static Pressure = 0.00 in. Hg

$$B_{ws}\text{ (sat)} = \frac{29.92}{29.94 + (0.00/13.6)}$$

$$B_{ws}\text{ (sat)} = 0.999$$

For further calculations:

$$B_{ws} = 0.053$$

Dry Molecular Weight of Stack Gas, lb/lb-mole (US EPA Method 3, Eq. 3-1)

$$M_d = MW_{CO2}(\%CO_2) + MW_{O2}(\%O_2) + MW_{N2}(\%N_2)$$

MW_{CO2}= Molecular weight of CO_2, divided by 100	=	0.44	lb/lb-mole
$\%CO_2$ = Percent CO_2 by volume, dry basis	=	1.7	%
MW_{O2} = Molecular weight of O_2, divided by 100	=	0.32	lb/lb-mole
$\%O_2$ = Percent O_2 by volume, dry basis	=	18.5	%
MW_{N2} = Molecular weight of N2, divided by 100	=	0.28	lb/lb-mole
$\%N_2$ = 100% - %CO - $\%CO_2$ - $\%O_2$ - %H2 - %CH4	=	79.8	%

$$M_d = (0.44 \times 1.7) + (0.32 \times 18.5) + (0.28 \times 79.8)$$

$$M_d = 29.01 \text{ lb/lb-mole}$$

Molecular Weight of stack gas, lb/lb-mole (US EPA Method 2, Eq. 2-6)

$$M_s = M_d (1-B_{ws})+18.0(B_{ws})$$

M_d= Dry molecular weight of stack gas	=	29.01	lb/lb-mole
B_{ws}= Proportion of water vapor, by volume	=	0.0529	proportion
18.0 = Molecular Weight of H_2O	=	18.00	lb/lb-mole

$$M_s = 29.01 \times (1 - 0.053) + (18.00 \times 0.053)$$

$$M_s = 28.43$$

Dry Gas Volume, corrected to actual conditions, ft^3

$$\mathbf{V_{m(actual)}} = V_m \times Y$$

V_m = Volume of gas sample, dry = 25.463 ft^3

Y = Dry gas meter calibration factor = 1.035

$$\mathbf{V_{m(actual)}} = 25.463 \times 1.035$$

$$\mathbf{V_{m(actual)}} = 26.354$$

Dry Gas Volume, corrected to standard conditions, ft^3 (US EPA Method 5, Eq. 5-1)

$$\mathbf{V}_{m(std)} = V_m \times Y \times \frac{T_{std} \times (P_{bar} + (\text{deltaH} / 13.6))}{T_m \times P_{std}}$$

V_m = Volume of gas sample, dry = 25.463 ft^3

Y = Dry gas meter calibration factor = 1.035

Tstd = Standard Temperature = 527.69 deg R

P_{bar} = Barometric pressure at the sampling site = 29.94 in. Hg

ΔH = Average pressure differential across the orifice meter = 0.49 in. H_2O

13.6 = Conversion factor 13.6 in. H_2O/in. Hg

Tm = Absolute average DGM temperature 561.36 deg R

$$\mathbf{V_{m(std)}} = \frac{25.463 \times 1.035 \times 527.69 \times (29.94 + (0.49 / 13.6))}{561.4 \times 29.92}$$

$$\mathbf{V_{m(std)}} = 24.820$$

Average Stack Gas Velocity, ft/sec (US EPA Method 2, Eq. 2-7)

$\mathbf{v_S} = K_p \times C_p \times \text{Sqrt}\Delta P_{avg} \times \text{sqrt}(T_s/(P_s \times M_s))$

K_p= Velocity equation constant	=	85.49	ft/sec[((lb/lb-mole)(in.Hg))/((degR)(in.H2O))]$^{1/2}$
C_p = S type pitot tube coefficient	=	1.00	
SqrtΔP_{avg}=ave. sqrt. of the velocity head of stack gas	=	0.13	in.H_2O
T_s = Absolute stack temperature	=	779.86	deg R
P_s = Absolute stack pressure	=	29.94	in. Hg
M_s = Molecular Weight of stack gas	=	28.43	lb/lb-mole

$$\mathbf{v_S} = 85.49 \times 1.00 \times 0.13 \times \left(\frac{779.9}{29.94 \times 28.43}\right)^{0.5}$$

$\mathbf{v_S}$ = 10.28 ft/sec

Average Stack Gas Volumetric Flow Rate, Actual Conditions

$\mathbf{Q_{actual}} = v_s \times A$

v_s= Average stack gas velocity	=	10.28	ft/sec
A = Cross sectional area of stack	=	1.07	ft^2

$\mathbf{Q_{actual}}$ = 10.28 x 1.07

$\mathbf{Q_{actual}}$ = 11 cubic feet per second

$\mathbf{Q_{actual}}$ = 659 cubic feet per minute

$\mathbf{Q_{actual}}$ = 39565 cubic feet per hour

Average Stack Gas Dry Volumetric Flow Rate, dscf/hr (US EPA Method 2, Eq. 2-8)

$$Q = \frac{3600 \times (1-B_{ws}) \times v_s \times A \times T_{std} \times P_s}{T_s \times P_{std}}$$

3600= Conversion factor	=	3600	sec/hr
B_{ws} = Proportion of water vapor, by volume	=	0.053	proportion
v_s= Average stack gas velocity	=	10.28	ft/sec
A = Cross sectional area of stack	=	1.07	ft^2
T_{std} = Standard absolute temperature	=	527.69	degR
P_s = Absolute stack pressure	=	29.94	in. Hg
T_s = Absolute stack temperature	=	779.9	degR
P_{std} = Standard absolute pressure	=	29.92	in. Hg

$$\mathbf{Q_s} = \frac{3600 \times (1.00 - 0.053) \times 10.28 \times 1.069 \times 528 \times 29.94}{779.9 \times 29.92}$$

$\mathbf{Q_s}$ = 25,371 dscf/hr

= 423 dscf/min

Average Stack Gas Wet Basis Volumetric Flow Rate (scf/hr)

$$\mathbf{Q_w} = \frac{Q}{(1-Bws)}$$

Q = Average Stack Gas Dry Volumetric Flow Rate	=	25,371	dscf/hr
B_{ws} = Proportion of water vapor, by volume	=	0.053	proportion

$$\mathbf{Q_w} = \frac{25,371}{(1.00 - 0.053)}$$

$\mathbf{Q_w}$ = 26,790 wscf/hr

= 446 wscf/min

Isokinetic Variation, % (US EPA Method 5, Eq. 5-8)

$$\mathbf{I} = \frac{100 \ \mathrm{x} \ T_s \ \mathrm{x} \ V_{m(std)} \ \mathrm{x} \ P_{std}}{60 \ \mathrm{x} \ T_{std} \ \mathrm{x} \ P_s \ \mathrm{x} \ v_s \ \mathrm{x} \ A_n \ \mathrm{x} \ \mathrm{min} \ \mathrm{x} \ (1 - B_{ws})}$$

100 = Conversion to Percent	=	100	
T_s = Absolute stack temperature	=	779.9	degR
$V_{m(std)}$ = Dry Gas Volume	=	24.820	ft^3
P_{std} = Standard absolute pressure	=	29.920	in. Hg
60 = Sec/Min	=	60	Sec/Min
T_{std} = Standard absolute temperature	=	527.69	degR
P_s = Absolute stack pressure	=	29.94	in. Hg
v_s = Average stack gas velocity	=	10.28	ft/sec
A_n = Cross-sectional Area of nozzle	=	0.001008	ft^2
min = Total sampling time	=	60	minutes
B_{ws} = Proportion of water vapor, by volume	=	0.053	proportion

$$\mathbf{I} = \frac{100 \ \mathrm{x} \ 779.9 \ \mathrm{x} \ 24.820 \ \mathrm{x} \ 29.92}{60.00 \ \mathrm{x} \ 527.69 \ \mathrm{x} \ 29.94 \ \mathrm{x} \ 10.28 \ \mathrm{x} \ 0.001008 \ \mathrm{x} \ 60 \ \mathrm{x} \ (1 - 0.053)}$$

$$\mathbf{I} = 103.70$$

Post-Test Calibration Check (US EPA Approved Alternate Method ALT-009)

$$\mathbf{Y_{qa}} = \mathrm{min} / \mathrm{Vm} \ \mathrm{x} \sqrt{\frac{0.0319 \ \mathrm{x} \ T_m}{\Delta H_@ \ \mathrm{x} \ (P_{bar} + \Delta H/13.6)} \quad \frac{29}{M_d}} \ \mathrm{x} \ (\Delta H)^{1/2}_{avg}$$

min = Total sampling time	=	60	minutes
$V_{m(actual)}$ = Dry gas volume, actual conditions	=	26.354	ft^3
Tm = Absolute average DGM temperature	=	561.357	degR
$\Delta H_@$ = Meter orifice pressure at 0.75 ft^3/min sampling rate	=	1.63	in. H_2O
P_{bar} = Barometric pressure at the sampling site	=	29.94	in. Hg
ΔH = Average pressure differential across the orifice meter	=	0.49	in. H_2O
$(\Delta H)^{1/2}_{avg}$ = Average of square root values of ΔH	=	0.700	
M_d= Dry molecular weight of stack gas	=	29.01	lb/lb-mole

$$\mathbf{Y_{qa}} = \mathrm{min} / \mathrm{Vm} \ \mathrm{x} \sqrt{\frac{0.0319 \ \mathrm{x} \ 561.357}{1.63 \ \mathrm{x} \ (29.94 + 0.49/13.6)} \quad \frac{29}{29.01}} \ \mathrm{x} \ 0.700$$

$$\mathbf{Y_{qa}} = 0.966$$

Emission Concentration Calculation

$$C_e = \frac{M_{poll} \quad x \quad CF}{V_{m(std)}}$$

Mass units of measurement: **g**

Conversions (gr/UNIT)		
Unit	**Abbrev.**	**Factor**
gram	g	15.43236
milligram	mg	0.015432
nanogram	ng	1.54E-08
picogram	pg	1.54E-11
microgram	ug	1.54E-05

M_{poll} = mass of pollutant in recovered sample = 1.29E-02 g /sample

CF = conversion factor = 1.54E+01 gr/ g

$V_{m(std)}$ = Dry Gas Volume = 24.820 ft^3

$$C_e = \frac{1.29E\text{-}02 \quad x \quad 1.54E\text{+}01}{24.820}$$

C_e = 8.02E-03 gr/dscf

Oxygen Correction Calculation

$$C@\ x\%\ O2 = C_e \quad x \quad \frac{(20.9\text{-}CB_{O2})}{(20.9\text{-}O_2)}$$

C_e = concentration of specified pollutant emitted = 8.02E-03 gr/dscf

CB_{O2} = Oxygen concentration correction basis = 7 % O_2

O_2 = Measured oxygen concentration = 18.5 %

$$C@\ 7\%O2 = 8.02E\text{-}03 \quad x \quad \frac{(20.9 - 7)}{(20.9 - 18.54)}$$

C@ 7%O2 = 4.72E-02 gr/dscf

Mass Emission Calculations

$$E_{mass} = C_e \times Q_s \times 60 \times CF$$

C_e = concentration of specified pollutant emitted = 8.02E-03 gr/dscf
Qs = Stack gas dry, standard volumetric flow rate = 423 dscfm
60 = min/hr = 60 min/hr
CF = Conversion factor = 1.43E-04 lb/gr

$$E_{mass} = 8.02E\text{-}03 \times 423 \times 60 \times 1.43E\text{-}04$$

$$E_{mass} = 2.91E\text{-}02 \text{ lb/hr}$$

Production Based Mass Emission Calculations

$$E_{process} = E_{mass} \times R_{process}$$

E_{mass} = Mass emissions = 2.91E-02 lb/hr
$R_{process}$ = Process production rate = 0 /hr

$$E_{process} = 2.91E\text{-}02 \times 0$$

$$E_{process} = \#DIV/0! \text{ lb/}$$

Addendum
Prepared By: Wayne P. Robarge
To
URS Report of Gaseous Emission From Hog Waste Gasifier
Submitted By
Mr. Ron McCulloch, MS, QEP
Senior Scientist
URS
Morrisville, NC

Introduction

Gasification of hog waste for elimination of swine waste solids and the potential recovery of value-added products has been proposed for consideration as an alternative environmentally superior technology for handling swine waste in North Carolina. On July 14, 2004, Mr. Ron McCulloch of URS Corporation (Morrisville, NC) was commissioned to evaluate ammonia emissions from a gasifier operated at the NCSU Animal and Poultry Waste Management Center on Lake Wheeler Road in Raleigh, NC. Gaseous emissions were evaluated for two charges of hog waste (50% and 75% dry matter content) using three test runs per charge ranging from 148 to 272 minutes. Nitrogen containing gaseous species that were measured include: ammonia (NH3), ammonium (NH4+)-containing PM (particulate matter), and volatile organic amines (VOAs) that are defined as non-ammonia reduced nitrogen species. Further details regarding experimental design, definitions, methodology, calculations and specific results can be found in the attached reported submitted by Mr. McCulloch.

Results and Discussion

Table A3 contains a summary of the N-loading and N-emissions measured during evaluation of the gasifier on July 14, 2004. Chemical analyses of the ash from the gasifier (Source: J. B. Koger and L. Bull, Principal Investigators, Department of Animal Science, NCSU, Raleigh, NC) suggests that essentially all the N loaded into the gasifier is emitted in the gaseous phase, either as N-containing species or associated with emitted particulate matter (PM). Gaseous emissions of reduced N-containing species represented a relatively small fraction of total emissions ranging from 0.7 to 1.4 % for ammonia, 1.2 to 4.5% for ammonium-containing PM, and 2.8 to 5.1% for VOAs. Emissions appeared to be a function of DM content, with lower relative emissions associated with 75% DM content. Between 89 to 95% of N gaseous emissions appear to be oxidized species, probably NO and NOx. This conclusion is consistent with the observed gaseous concentrations of NOx in the flue gas, which exceeded 300 ppm during the first 100 minutes of the gasification procedure (Source: J. B. Koger and L. Bull, Principal Investigators, Department of Animal Science, NCSU, Raleigh, NC). At > 100 minutes during the gasification procedure, the concentration of observed NOx dropped precipitously and remained at relatively low levels (< 50 ppm). Such an observation is consistent with the release of ammonia during the initial stages of the gasification procedure and subsequent conversion of ammonia to NOx with temperatures in excess of 700˚C. During the evaluation by Mr. McCulloch from the URG Corporation, highest release rates of ammonia were at the 100-minute mark. Rates dropped to the lowest rate at the 150 minute mark, when temperatures exceeded 600˚C (See report submitted by URG Corporation).

Table A3. Summary of N-loading and N-emissions from gasification of hog waste conducted on July 14, 2004 at the NCSU Animal and Poultry Waste Management Center on Lake Wheeler Road in Raleigh, NC.

Category	**Dry Matter Content**	
	50%	**75%**
Waste Loading	**- grams -**	**- grams -**
Hog Waste - Moist	65,000	40,000
Hog Waste - Dry	32,500	30,000
Ash - Dry[#] (12.2% Ash Content)	3,965	3,660
N-Content	**- grams -**	**- grams -**
	Total Nitrogen (TN)	
Hog Waste* - Dry	1,414	1,305
Ash[@] - Dry	1	1
TN-Loss (Hog Waste – Ash)	1,413	1,304
	Ammonium (NH4) Nitrogen	
Hog Waste* - Dry	22	21
Ash[@] - Dry	0.1	0.1
NH4-N-Loss (Hog Waste – Ash)	22	21
Gaseous Emissions	**- grams -**	**- grams -**
Ammonia (NH3-N)	20	9
Ammonium (NH4-N) - PM	63	15
VOAs-N	72	36
Sub-Total	155	60
Other (e.g. NO, NOx; N-Loss – Sub-Total)	1,258	1,244
% Emissions of TN-Loss	**- % -**	**- % -**
Ammonia (NH3)	1.4	0.7
Ammonium - PM	4.5	1.2
VOAs-N	5.1	2.8
Sub-Total	11.0	4.7
Other (e.g. NO, NOx)	89.0	95.3
% Emissions of NH4-N-Loss		
Ammonia (NH3)	91	43
Ammonium - PM	286	71
Ammonia + Ammonium - PM	377	114

[#] - Source: Drs. J. Koger and L. Bull, NCSU, Dept. Animal Science, Principal Investigators.

* - Calculations based on Total-N content = 4.35% and Ammonium-N content = 0.069% for hog waste on a dry matter basis (Source: Ms. Lynn Worley-Davis, NCSU Animal and Poultry Waste Management Center, Raleigh, NC).

[@] - Based on Total-N content = 0.017% and Ammonium-N content = 0.0016% for ash on a dry matter basis (Source: Ms. Lynn Worley-Davis).

Summary

Ammonia emissions during gasification of hog waste appear to be dependent on DM content of waste feed to the gasifier. For 75% DM content, 114% of original ammonia content of hog waste was emitted either as ammonia gas or ammonium-containing PM. For 50% DM content, 377% of original ammonia content of hog waste was emitted either as ammonia gas or ammonium-containing PM. In other words, using the 50% DM content material increased ammonia emissions beyond the original ammonium content of hog waste. However, the combined reduced-N gaseous emissions from the gasifier were relatively small compared to the total gaseous N emissions, amounting to only 4.7% for the 75% DM content waste, and 11% for the 50% DM content waste. Compared to the conventional lagoon system for handling swine waste (where theoretically all the N contained in the waste could be lost by ammonia volatilization), use of the gasifier can reduce ammonia emissions between 89 to 95%. However, this reduction in ammonia emissions is apparently achieved through conversion of most of the input-N in the waste to primarily nitric oxides (NO+NOx), a known precursor for ozone formation.