Emissions Study:
ElectraTherm Power+ Generator
Compared to
Open Flaring

Prepared by
Texas A&M/Institute of Renewable Natural Resources
Under the
Houston Advanced Research Center/ Environmentally Friendly Drilling Program

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TABLE OF CONTENTS

TABLE OF CONTENTS (cont.)

FIGURES

TABLES

1. Introduction

The State of North Dakota Department of Health and the U.S. Environmental Protection Agency (US EPA) have recently begun to regulate open flaring of raw gas (untreated) and fuel gas (treated). Texas A&M/Institute of Renewal Natural Resources (IRNR) visited a Hess site in the Bakken Shale Play in North Dakota during September 8-10, 2015 to collect research data as part of an emissions research study for comparing emissions from the Gulf Coast Green Energy's (GCGE) ElectraTherm Power+ generator (Power+) system's boiler with the emissions from open flaring. The actual process includes both raw gas and fuel gas used for other functions at the site. For this study, it was assumed that all the available gas would either be sent to the treater flare or utilized to generate auxiliary power with the Power+ generator.

A meter, which reads in units of standard cubic feet per hour (scfh), was added in-line to measure the actual gas flow rate to the Power+ boiler. Gas flowrate data[1] was recorded at 30-minute intervals for use in determining emissions from both sources (see photographs - Appendix C). Emissions for both the flare and boiler were estimated using standard US EPA approved emission factors and methods. Both emissions from flaring and the Power+ boiler are considered external combustion emission sources and therefore emit most of the same criteria pollutants[2] - Nitrous Oxides (NO_x), Carbon Monoxide (CO), Volatile Organic Compounds (VOC).

[1]From the heater treater unit's data acquisition systems and the Power+ boiler's flow meter.
[2]Pollutants for which the federal government has set National Ambient Air Quality Standards (NAAQS) or that contribute to the formation of those pollutants (e.g., VOCs in the formation of ozone).

2. Research Plan

This report is not intended to detail the operations of any of the process units but to evaluate emissions and other benefits of a technology alternative to open flaring. Innovations such as the ElectraTherm Power+ generator are necessary to replace flaring as these regulations go into effect. The Power+ generator system utilizes a patented technology to produce organic Rankine cycle power with minimum water flow (e.g., 200 gallons per minute (gpm) versus conventional 1,000 gpm) and simple design (i.e., no gear box or oil pump) to produce power from raw gas or fuel gas which would otherwise be sent to an open treater flare.

Site: The site selected for this research study was Hess Corporation site HA-ROLFSUD 152-96-1720H in the North Dakota Bakken shale play. This site has five free-flowing oil and gas wells (1720H2 through 1720H6). The liquids are flowed directly to a 14-tank battery (for oil and brine). These products are loaded onto tanker trucks daily. The wet gas is sent to a series of five dedicated heater treaters (one for each well) for processing prior to flowing out to the treater flare or other units such as the ElectraTherm Power+ boiler.

Process: The oil and gas are free from a tight shale formation that is sent to various upstream units for initial processing and use. This research is focused on emissions from the entire process and does not attempt to describe the processing in detailed technical terms. Figure 1 diagrams the basic process.

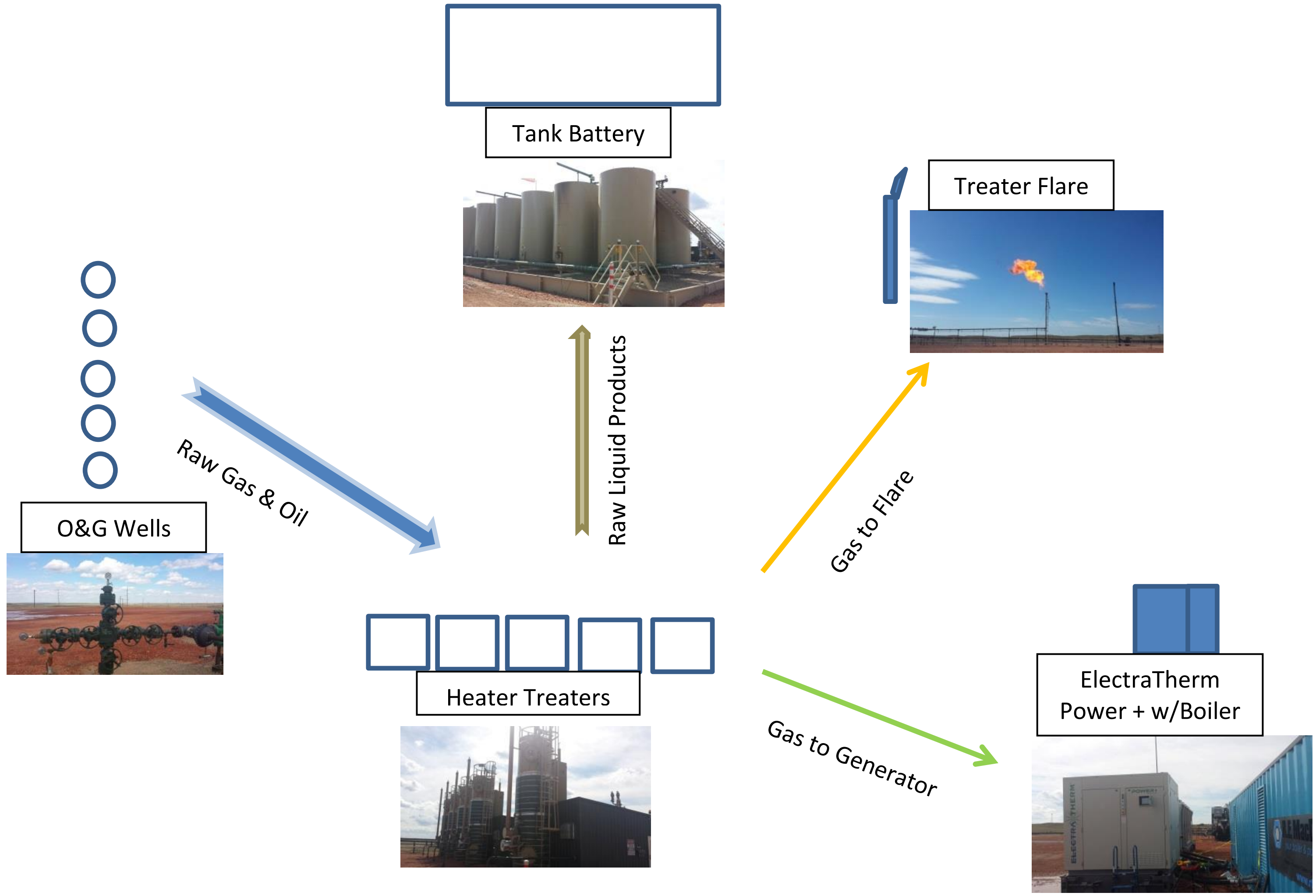


FIGURE 1. Process Diagram

3. Data Collection/Post Processing

Data collection consisted of readings for each of the of the five heater treater units (thousands of cubic feet per day or MCF/day) off the data acquisition system display and gas meter usage readings for Power+ boiler (standard cubic feet per hour or scfh). Readings were taken at approximate 30-minute intervals. The heater treater production flowrates were converted to scfh to match the boiler consumption rate units as shown in the example below:

Run 1 - Heater Treater #4 10:35 AM:

331.81 MCF/day x 24 hr/d x 1000/M = 13,825.4 scfh

The five individual production values (in scfh) were then summed to determine the overall production rate value for each of the first five runs as shown in the example for Run 1 below:

Run 1 – Heater Treater #2 - #6:

SUM (16,750.8, 29,851.3, 13,825.4, 13,824.6, and 23,567.9) = 122,520.0 scfh

The percentage of the total available gas used by the boiler was also calculated for each run as shown in the example for Run 1 below:

Run 1 – Boiler Hourly Flowrate (scfh): 1,951 scfh

1,951 / 122,520 x 100 = 1.6%

In addition, a raw gas and fuel gas analyses were provided by Hess (dated 8/27/2015) for this site. The dry basis heating value of 1655.93 Btu/scf was utilized to calculate emissions using CleaverBrooks® emissions data for the 30 ppm NOx 150 Hp boiler and US EPA AP-42 emission factors document (for comparison).

Boiler plate specifications and process information was also collected during the site survey.

4. Emissions Calculation Methods

NO_x, CO, and VOC were the contaminants of concern for this study. Emissions from sulfur compounds such as SO_2 (sulfur dioxide), H_2S (hydrogen sulfide) and PM (particulate matter) were not evaluated since the sulfur content of the treated fuel is minimal and particulate matter emissions cannot be compared due to the fact that flaring emission factors are considered soot/smoke versus actual sized particulate matter (represented by the boiler emission factors). Furthermore, sized particulate would be required for comparison to the standard (e.g., National Ambient Air Quality Standard for particulate matter less than 10 micron or PM_{10}). Emissions of NO_x, CO, and VOC were calculated for both sources and both fuel types (raw gas and fuel gas).

A. Boiler Emissions

Model specific factors for the 30 PPM natural gas Power+ 150 Hp CleaverBrooks® boiler were from the operators manual (Table A10-8).

Table A10-8. Model CBR Boiler Emission Data

POLLUTANT		ESTIMATED LEVELS - UNCONTROLLED				
		NATURAL GAS		NO. 2 OIL[B]		NO. 6 OIL[C]
		60 PPM System	30 PPM System	60 PPM SYSTEM	30 PPM SYSTEM	
CO	ppm[A]	50/150[B]	50/150[B]	50	50	95
	Lb/MMBtu	0.04/0.11	0.04/0.11	0.04	0.04	0.075
NOx	ppm[A]	60	30	185	140	502
	Lb/MMBtu	0.07	0.035	0.25	0.187	0.67
SOx	ppm[A]	1	1	278	278	278
	Lb/MMbtu	0.001	0.001	0.52	0.52	0.52
HC/VOCs	ppm[A]	10	10	4	4	70
	Lb/MMBtu	0.004	0.004	0.002	0.002	0.035
PM	ppm[A]	-		-	-	-
	Lb/MMBtu	0.01	0.01	0.025	0.256	0.160

NOTES:
Refer to Section E for detailed emission information.
A. ppm levels are given on a dry volume basis and corrected to 3% oxygen (15% excess air)
B. CO emission is 50 ppm when boiler is operating above 50% of rated capacity. CO emission is 150 ppm when boiler is operating below 50% of rated capacity.
Based on fuel constituent levels of:
Fuel-bound nitrogen content = 0.05% by weight
Sulfur content = 0.5% by weight
Ash content = 0.01% by weight
Conradson carbon residue = 16% by weight

TABLE 1. Cleaver Brooks Emission Factors

These values were converted from the values reported (lb pollutant/MMBtu) to lb pollutant/MMscf using the dry basis heating value of both the raw and fuel gas for direct comparison the US EPA emission factors (AP-42, Table 1.4-1 and Table 1.4-2) for boilers in this size range (less than 100 MMBtu/hr). For the most part, the CleaverBrooks® emission factor values were comparable or lower except for VOC which was more than twice the EPA value. See boiler emissions factor tables below.

EMISSION FACTORS			
	AP-42 Table 1-4.2	CleaverBrooks® Fuel Gas	CleaverBrooks® Raw Gas
	lb/MMscf	lb/MMscf[1]	lb/MMscf[1]
CO	84.00	58.17	66.24
NOx	50.00	50.89	57.96
VOC	5.50	14.54	16.96

[1]Conversion to lb/MMscf based on dry basis heating values

TABLE 2. Boiler Emission Factors

Boiler emissions were calculated as follows:

Flowrate (_____ scf/hr or scfh) x MM/1,000,000 x Emission Factor (lb pollutant/MMscf) = lb pollutant/hr

B. Flaring Emissions

Flare emissions were calculated based on the assumption that **all** raw gas or fuel gas was available for flaring and producing emissions from flaring. Emission factors from US EPA Emissions Factor document (AP-42) were used to determine emission of NO_x, CO, and VOC.

Total HC/VOC lb/MMBtu	CO lb/MMBtu	NOx lb/MMBtu
0.140	0.370	0.068

US EPA AP-42, Table 13.5-1

TABLE 3. Flare Emission Factors

Emissions from flaring were calculated as follows:

Gas dry basis heating value (____ Btu/scf) x Flowrate (_____scfh) x MM/1,000,000 x Emission Factor (lb pollutant/MMBtu)

5. Results

A. Boiler Emissions

Emissions from the boiler for each of the five (5) runs are reported in the table below for both raw gas and fuel gas. Note: Emission values are shown for hourly emission rates based on the CleaverBrooks® emissions test factors.

BOILER EMISSIONS			
Run #	**Pollutant**	**Raw Gas lb/hr**	**Fuel Gas lb/hr**
RUN 1	CO	0.129	0.113
	NOx	0.113	0.099
	VOC	0.032	0.28
RUN 2	CO	0.171	0.15
	NOx	0.149	0.13
	VOC	0.043	0.37
RUN 3	CO	0.179	1.57
	NOx	0.156	0.137
	VOC	0.045	0.039
RUN 4	CO	0.143	0.125
	NOx	0.125	0.110
	VOC	0.036	0.031
RUN 5	CO	0.160	0.138
	NOx	0.140	0.121
	VOC	0.040	0.035

TABLE 4. Boiler Emissions

B. Flaring Emissions

Emissions from both raw gas and fuel gas based on the total available for flaring for each of the five (5) runs are reported in the table below. Note: Emissions were based on the higher flowrate which was the first five data collection runs (RUNs 1 - 5) which was 150,674 scfh or 3.6 MMscfd. This was also corresponds to the timeframe for which the Power+ boiler was in operation.

FLARE EMISSIONS			
Run #	Pollutant	Fuel Gas lb/hr	Raw Gas lb/hr
RUN 1	CO	65.92	75.07
	NOx	12.11	13.80
	VOC	24.94	28.40
RUN 2	CO	79.11	90.09
	NOx	14.54	16.56
	VOC	29.93	34.09
RUN 3	CO	95.62	108.89
	NOx	17.57	20.01
	VOC	36.18	41.20
RUN 4	CO	66.70	75.95
	NOx	12.26	13.96
	VOC	25.24	28.74
RUN 5	CO	98.00	111.60
	NOx	18.01	20.51
	VOC	37.08	42.23

TABLE 5. Flare Emissions

Emissions are typically reported on an annual basis in addition to the short-term hourly values. Annual emissions are not included since the annual operating hours for the boiler and the flare would need to be tracked in order calculate annual emission for any given year. Potential to emit (which is usually a gross overestimate) can be calculated by simply multiplying by an assumed fulltime operating schedule of 8760 hours per year.

6. Conclusion

A direct comparison of emissions based on the amounts of raw gas and fuel gas consumed by the boiler compared to the total available for flaring (1.57%) is provided in the table below. It is important to note that the emissions from the Power+ boiler are lower (comparatively less harmful to the environment) and would provide the added utility of power generated for use from the raw gas or fuel gas which would otherwise be wasted.

Run #	Pollutant	Flare	Boiler	% of Flare
RUN 1	CO	1.18	0.13	10.9
	NOx	0.22	0.11	52.2
	VOC	0.45	0.03	7.2
RUN 2	CO	1.41	0.17	12.1
	NOx	0.26	0.15	57.3
	VOC	0.54	0.04	8.0
RUN 3	CO	1.71	0.18	10.5
	NOx	0.31	0.16	49.7
	VOC	0.65	0.05	7.0
RUN 4	CO	1.19	0.14	12.0
	NOx	0.22	0.13	57.0
	VOC	0.45	0.04	8.0
RUN 5	CO	1.75	0.16	9.1
	NOx	0.32	0.14	43.5
	VOC	0.66	0.04	6.0

TABLE 6. Emissions Comparison – Raw Gas

Run #	Pollutant	Flare	Boiler	% of Flare
RUN 1	CO	1.03	0.11	10.9
	NOx	0.19	0.10	52.2
	VOC	0.39	0.03	7.2
RUN 2	CO	1.24	0.15	12.1
	NOx	0.23	0.13	57.3
	VOC	0.47	0.04	8.0
RUN 3	CO	1.50	0.16	10.5
	NOx	0.28	0.14	49.7
	VOC	0.57	0.04	7.0
RUN 4	CO	1.05	0.13	12.0
	NOx	0.19	0.11	57.0
	VOC	0.40	0.03	8.0
RUN 5	CO	1.54	0.14	9.1
	NOx	0.28	0.12	43.5
	VOC	0.58	0.03	6.0

TABLE 7. Emissions Comparison – Fuel Gas

The average percent of the emissions from the boiler compare to the flare for either fuel is presented in the table below. In terms of emission reductions: CO would be 10.9% of flaring – 89.1% reduction, NOx would be 51.9% of flaring – 48.1% reduction, and VOC would be 7.2% of flaring – 92.8% reduction.

CO avg%	89.1
NOx avg%	48.1
VOC avg%	92.8

TABLE 8. Percent Reduction

Combustion of gas in boilers powering organic Rankine cycle generators has the distinct advantage of reducing emissions of key air pollutants by factors ranging from half to less than 10% when compared to open flaring. Scaling up the boiler sizing and/or using the latest generation of boiler technology, such as low NO_x burners, would reduce emissions further.

The real benefit is the power generated by raw gas or fuel gas which would otherwise be wasted by open flaring. Furthermore, this new technology would meet the goals of the US EPA and North Dakota Department of Health – Air Quality by reducing emissions and providing energy by reuse of the produced raw gas or fuel gas.

7. References

a. US EPA AP-42, Chapter 1.4 – External Combustion Sources, 7/1998
b. US EPA AP-42, Chapter 13.5 – Industrial Flares, 9/1991 (reformatted 1/1995)
c. HESS Corporation, Fuel Analyses, Raw Gas and Fuel Gas, 8/27/2015
d. CleaverBrooks®, Model CBR – 125-800 HP Boilers Operators Manual, 1/2011
e. On-site Data Collection – Texas A&M/IRNR (J. Alonzo), 9/8/15 through 9/10/15.

APPENDIX A

RAW DATA

HESS CORP. SITE - HA-ROLFSUD 152-96-1720H (H2-H6)

10-Oct-15

POWER+ BOILER ON

9/10/2015 10:35	RUN 1					
Unit	Daily Flowrate (mcf/d)	Current Day (mcf)	Previous Day (mcf)	Hourly Flowrate (scf/h)		
H2	402.02	160.53	585.45	16,750.8		
H3	716.43	265.47	971.81	29,851.3		
H4	331.81	113.45	417.14	13,825.4		
H5	924.59	263.39	959.84	38,524.6		
H6	565.63	210.55	764.56	23,567.9	122,520.0	scfh (total production)
Boiler				1,951.0	1,951.0	scfh (boiler consumption)
				1.6	%	percent of total

9/10/2015 11:05	RUN 2					
Unit	Flowrate (mcf/d)	Current Day (mcf)	Previous Day (mcf)	Flowrate (scf/h)		
H2	640.02	169.69	585.45	26,667.5		
H3	916.63	281.25	971.81	38,192.9		
H4	452.9	120.67	417.14	18,870.8		
H5	870.82	278.11	959.84	36,284.2		
H6	648.39	222.39	764.56	27,016.3	147,031.7	scfh (total production)
Boiler				2,578.0	2,578.0	
				1.75	%	percent of total

9/10/2015 11:30	RUN 3					
Unit	Flowrate (mcf/d)	Current Day (mcf)	Previous Day (mcf)	Flowrate (scf/h)		
H2	1157.56	181.25	585.45	48,231.7		
H3	1459.68	299.75	971.81	60,820.0		
H4	310.71	128.3	417.14	12,946.3		
H5	770.6	296.86	959.84	32,108.3		
H6	566.67	237.36	764.56	23,611.3	177,717.5	scfh (total production)
Boiler				2,699.0	2,699.0	
				1.52	%	percent of total

9/10/2015 11:55	RUN 4					
Unit	Flowrate (mcf/d)	Current Day (mcf)	Previous Day (mcf)	Flowrate (scf/h)		
H2	565.66	188.906	585.45	23,569.2		
H3	871.77	314.781	971.81	36,323.8		
H4	322.01	134.19	417.14	13,417.1		
H5	412.189	310.375	959.84	17,174.5		
H6	803.458	248.797	764.56	33,477.4	123,962.0	scfh (total production)
Boiler				2,157.0	2,157.0	
				1.74	%	percent of total

9/10/2015 12:30	RUN 5					
Unit	Flowrate (mcf/d)	Current Day (mcf)	Previous Day (mcf)	Flowrate (scf/h)		
H2	1093.12	203.2	585.45	45,546.7		
H3	1110.52	331.72	971.81	46,271.7		
H4	595.21	143.61	417.14	24,800.4		
H5	915.41	332.91	959.84	38,142.1		
H6	657.07	265.94	764.56	27,377.9	182,138.8	scfh (total production)
Boiler				2,421.0	2,421.0	
				1.33	%	percent of total

Average Fuel Gas Production	150,674.0	scfh
Average Fuel Consumption (boiler)	2,361.2	scfh
Average Percentage of Fuel Consumed	1.57	%

HESS CORP. SITE - HA-ROLFSUD 152-96-1720H (H2-H6)

10-Oct-15

POWER+ BOILER OFF

9/10/2015 13:20 **RUN 6**

Unit	Daily Flowrate (mcf/d)	Current Day (mcf)	Previous Day (mcf)	Flowrate (scf/h)		
H2	630.14	225.672	585.45	26,255.8		
H3	1233.13	376.09	971.81	51,380.4		
H4	402.72	160.02	417.14	16,780.0		
H5	1207.89	371.69	959.84	50,328.8	144,745.0	scfh (total production)
Boiler				0.0		

9/10/2015 14:00 **RUN 7**

Unit	Daily Flowrate (mcf/d)	Current Day (mcf)	Previous Day (mcf)	Flowrate (scf/h)		
H2	590.25	239.45	585.45	24,593.8		
H3	1067.96	399.03	971.81	44,498.3		
H4	391.29	169.64	417.14	16,303.8		
H5	447.75	393.64	959.84	18,656.3		
H6	1006.97	315.42	764.56	41,957.1	146,009.2	scfh (total production)
Boiler				0.0		

9/10/2015 14:25 **RUN 8**

Unit	Daily Flowrate (mcf/d)	Current Day (mcf)	Previous Day (mcf)	Flowrate (scf/h)		
H2	839.74	251.94	585.45	34,989.2		
H3	841.52	420.13	971.81	35,063.3		
H4	365.24	178.48	417.14	15,218.3		
H5	939.97	415.16	959.84	39,165.4		
H6	668.61	331.73	764.56	27,858.8	152,295.0	scfh (total production)
Boiler				0.0		

9/10/2015 14:55 **RUN 9**

Unit	Daily Flowrate (mcf/d)	Current Day (mcf)	Previous Day (mcf)	Flowrate (scf/h)		
H2	614.63	262.77	585.45	25,609.6		
H3	1084.75	437.56	971.81	45,197.9		
H4	300.96	185.8	417.14	12,540.0		
H5	685.05	431.58	959.84	28,543.8		
H6	664.36	345.73	764.56	27,681.7	139,572.9	scfh (total production)
Boiler				0.0		

9/10/2015 15:20 **RUN 10**

Unit	Daily Flowrate (mcf/d)	Current Day (mcf)	Previous Day (mcf)	Flowrate (scf/h)		
H2	528.31	274.77	585.45	22,012.9		
H3	954.11	457.19	971.81	39,754.6		
H4	439.06	194.41	417.14	18,294.2		
H5	471.49	450.63	959.84	19,645.4		
H6	586.33	360.95	764.56	24,430.4	124,137.5	scfh (total production)
Boiler				0.0		

APPENDIX B

GAS ANALYSES

FUEL (TREATED) GAS

8/27/2015 10:55

Hess Corporation
Tioga Gas Plant
Settlement

Inject Datetime: **8/27/2015 10:15**
Sample Name: **HA ROLFSRUD 152-96-1702 H-2-6 #1**
Well Number: **HA ROLFSRUD 152-96-1702 H-2-6 #1**
Producer: **HESS CORP** Boiler Fuel Gas
Secured By: **ZF**
Sample Pressure: **8**
Sample Cylinder Number: **337**

Analysis Date: **8/27/2015 10:15**
Date Sample Taken: **8/25/2015 0:00**
Effective Date: **8/27/2015 0:00**
Sample Temperature: **0**
Meter: **1**
H2S: **0**

Component Name	Mole %	GPM
Carbon dioxide	0.8568	0
Ethane	18.9281	0
Hexanes plus	1.1164	0.4579
Isobutane	1.0991	0.0549
Isopentane	0.5983	0.2182
Methane	61.7028	0
n-Butane	3.1861	1.0019
Nitrogen	2.0724	0
n-Pentane	0.885	0.32
Propane	9.5551	0.3051
Totals	**100**	**2.358**

GPM For Pentanes+:	**1.00375**
GPM For Butanes+:	**2.37477**
GPM For Propane+:	**5.02055**
Calculated BTUs (Dry Basis):	**1454.13**
Calculated BTUs (Wet Basis):	**1428.82**
Specific Gravity (Calculated w/H2S - Ideal):	**0.87299**
Specific Gravity (Calculated w/H2S - Real):	**0.87333**
Pressure Base:	**14.73**

RAW (UNTREATED) GAS

8/27/2015 10:55

Hess Corporation
Tioga Gas Plant
Settlement

Inject Datetime: **8/27/2015 10:38**
Sample Name: **HA ROLFSRUD 152-96-1702 H-2-6 #2**
Well Number: **HA ROLFSRUD 152-96-1702 H-2-6 #2**
Producer: **HESS CORP** Flare Gas
Secured By: **ZF**
Sample Pressure: **39**
Sample Cylinder Number: **258**

Analysis Date: **8/27/2015 10:38**
Date Sample Taken: **8/25/2015 0:00**
Effective Date: **8/27/2015 0:00**
Sample Temperature: **0**
Meter: **2**
H2S: **0.00025**

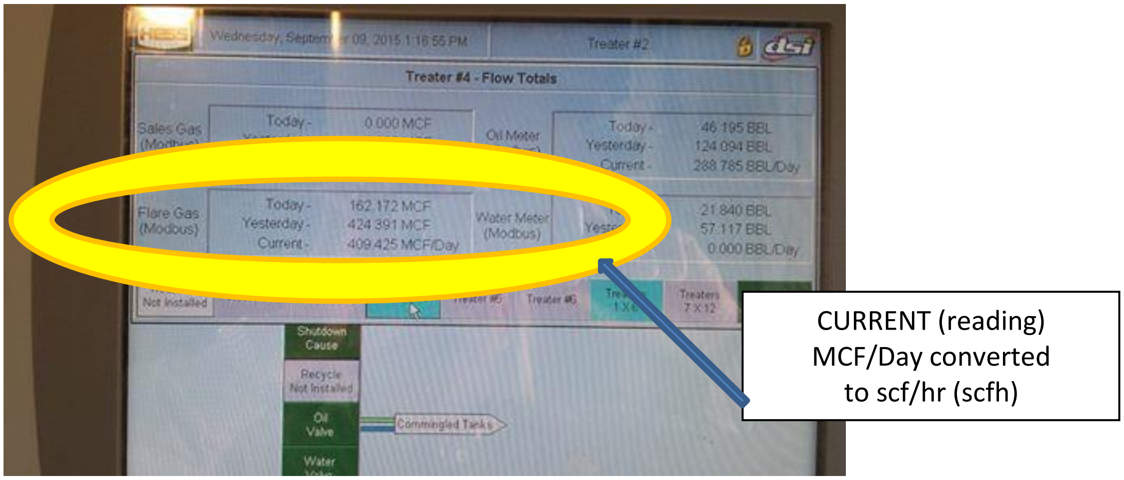
Component Name	Mole %	GPM
Carbon dioxide	0.6479	0
Ethane	15.7246	0
Hexanes plus	1.7328	0.7108
Isobutane	2.2186	0.1109
Isopentane	2.0035	0.7308
Methane	47.4666	0
n-Butane	8.0568	2.5335
Nitrogen	6.035	0
n-Pentane	3.2116	1.1612
Oxygen	1.0835	0
Propane	11.8191	0.3774
Totals	**100**	**5.6246**

GPM For Pentanes+: **2.62935**
GPM For Butanes+: **5.92023**
GPM For Propane+: **9.20121**
Calculated BTUs (Dry Basis): **1685.26**
Calculated BTUs (Wet Basis): **1655.93**
Specific Gravity (Calculated w/H2S - Ideal): **1.07399**
Specific Gravity (Calculated w/H2S - Real): **1.07423**
Pressure Base: **14.73**

APPENDIX C

PHOTOS

Heater Treater Data Acquisition System Flow Totals



Power+ Boiler Gas Meter