Source Test Report

Recirculation Tank Emissions Testing

Western States Petroleum Association

901 Tower Way #300
Bakersfield, CA

October 2015

The world's leading sustainability consultancy

ERM

SOURCE TEST REPORT

Recirculation Tank Emissions Test Report

Prepared for:

Western States Petroleum Association

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acfm	actual cubic feet per minute
CO_2	carbon dioxide
CO2e	carbon dioxide equivalent
dscfm	dry standard cubic feet per minute
dscf	dry standard cubic feet
EPA	U.S. Environmental Protection Agency
FSC	frac-sand cleanout
H_2O	water
N_2	nitrogen
NIST	National Institute of Standards and Technology
O_2	oxygen
POP	Put on Production
ppmv	parts per million by volume
QA/QC	quality assurance/quality control
scf	standard cubic feet
scfh	standard cubic feet per hour
RM	Reference Method
Wt%	percentage by weight

EXECUTIVE SUMMARY

ERM-West, Inc. (ERM) prepared this source test report on behalf of the Western States Petroleum Association (WSPA) for internal research purposes – to understand the quantity of methane emissions resulting from recirculation tanks used during and after well stimulation events. Two types of tests were conducted: 1) Source test (capture and measurement) per WSPA/ERM protocol (see attached) and 2) Proposed flash liberation test method by California Air Resources Board (CARB). The report presents the test results from testing performed on recirculation tanks used during and after well stimulation treatments.

Testing was performed by ERM personnel at two facilities in the San Joaquin Valley. Testing was conducted at the first facility (Facility 1) from 30 July to 7 August 2015 and at the second facility (Facility 2) on 25 to 27 August 2015. Flash Liberation testing was performed simultaneously by personnel from BC Laboratories Inc. Recirculation tanks were tested under normal operating conditions.

Two types of events were tested. At Facility 1, three tests were conducted on recirculation tanks used *during* well stimulation events and two tests were conducted on recirculation tanks used *after* well stimulation events. . At Facility 2, three tests were conducted on recirculation tanks used *after* well stimulation events. Two types of tanks were tested – SandX tank and Shaker tank.

Tables ES-1 and ES-2 present summaries of the results from the recirculation tank methane testing.

Table ES-1 Facility 1 Methane Source Test Results Summary, SandX and Shaker Recirculation Tanks

Source	Date	Facility	Event	Duration (minutes)	Total Methane Emitted	
					SCF	CO2e MT
SandX Recirculation Tank	7/30-31/2015	1	Frac #1	683	10.49	0.0043
SandX Recirculation Tank	8/1/2015	1	Frac #2	531	14.00	0.0058
SandX Recirculation Tank	8/5/2015	1	Frac #3	660	5.50	0.0023
Shaker Recirculation Tank	8/4/2015	1	POP #1	232	417.6	0.1719
Shaker Recirculation Tank	8/7/2015	1	POP #2	339	130.7	0.0538

Table ES-2 Facility 2 Methane Source Test Results Summary, SandX Recirculation Tank

Source	Date	Facility	Event	Duration (minutes)	Total Methane Emitted	
					SCF	CO2e MT
SandX Recirculation Tank	8/25/2015	2	FSC #1	311	3067	1.262
SandX Recirculation Tank	8/26/2015	2	FSC #2	353	222.86	0.0917
SandX Recirculation Tank	8/27/2015	2	FSC #3	419	889.60	0.3662

Table ES-3 Flash Liberation Emissions Test Results Summary

Source	Date	Facility	Event	Gas to Water Ratio (scf/STB)	Total Methane (mol%)	Methane to Water Ratio (scf/STB)
SandX Recirculation Tank	7/30-31/2015	1	Frac #1	0.000	ND*	0.000
SandX Recirculation Tank	8/1/2015	1	Frac #2	0.000	ND*	0.000
SandX Recirculation Tank	8/5/2015	1	Frac #3	0.000	ND*	0.000
Shaker Recirculation Tank	8/4/2015	1	POP #1	0.049	44.96	0.022
Shaker Recirculation Tank	8/7/2015	1	POP #2	0.000	ND*	0.000
SandX Recirculation Tank	8/25/2015	2	FSC #1	0.348	12.40	0.043
SandX Recirculation Tank	8/26/2015	2	FSC #2	0.000	ND*	0.000
SandX Recirculation Tank	8/27/2015	2	FSC #3	0.000	ND*	0.000

* These samples are marked None Detected (ND) because no gas was liberated from the sample to analyze

Summary of Data Analysis and Discussion

1. Based on the capture and measure test, methane emissions were significantly less than 1 MT CO2e per event.

2. No significant difference was seen between methane emissions observed during and after well stimulation.

3. Methane emissions ranged from 0.002 MT CO2e to 1.262 MT CO2e per event.

4. Average methane emissions were observed to be 0.245 MT CO2e per event.

5. Flash gas was liberated from two tests only (POP #1 and FSC #1). These two tests also were the only tests that had maximum methane concentrations >10,000 ppmv.

6. Amount of gas emitted ranged from approximately 0.006 MSCF to 3.519 MSCF per event.

1.0 INTRODUCTION

ERM-West, Inc. (ERM) prepared this source test report on behalf of the Western States Petroleum Association (WSPA) for internal research purposes – to understand the quantity of methane emissions resulting from recirculation tanks used during and after well stimulation events. Two types of tests were conducted: 1) Source test (capture and measurement) per WSPA/ERM protocol and 2) Proposed flash liberation test method by California Air Resources Board (CARB). The report presents the test results from testing performed on recirculation tanks used during and after well stimulation.

The test program has been designed for determining methane emissions to the atmosphere resulting from the use of the SandX and Shaker recirculation tanks during and immediately after well stimulation events.

Services provided by ERM included test plan development, sampling system design and build, project management, field sampling, collection of field data, and preparation of the final report. Table 1-1 presents a sampling matrix for the research testing.

Mr. Larry Hottenstein served as the Principal-in-Charge, Mr. Patrick King was the Senior Engineer and Project Manager for ERM, assisted by Mr. Matthew Eaton and Mr. David Torres of ERM. Table 1-2 lists the primary project personnel and their contact information.

Table 1-1 WSPA Bakersfield – Research Sampling Matrix

Sample Location	Maximum No. of Runs	Sample/Type Pollutant	Sampling Method	Run Time (minutes)	Analytical Method
Recirculation Tank					
SandX and Shaker Recirculation Tank Exhaust	12	Velocity	EPA M1-2	n/a	Pitot/Differential Pressure
	12	Moisture Content	EPA M4	n/a	WetBulb
	12	Methane	Modified EPA M18	60	GC/FID

FID = Flame ionization detector
GC = Gas chromatograph
n/a = Not applicable

Table 1-2 Project Personnel and Contact Information

Firm	Contact	Title	Phone No.
ERM	Larry Hottenstein	Principal-in-Charge	(949) 623-4700
ERM	Patrick King	Project Manager	(626) 773-7561

2.0 SOURCE INFORMATION

Two types of tanks were used for recirculation of water during and after a well stimulation event.

1. At Facility 1, the SandX recirculation tank was used *during* the well stimulation operation. At Facility 2, the SandX recirculation tank was used *after* the completion of a well stimulation operation.

2. Facility 1 also used a Shaker recirculation tank *after* the completion of a well stimulation event.

A description of equipment and process is provided below.

2.1 EQUIPMENT/PROCESS DESCRIPTION

2.1.1 SandX

The SandX (Figure 2-1) consists of a 500 bbl. portable tank and a recirculation pumping system. At Facility 1, the SandX was used *during* the well stimulation operation. After each section was stimulated, water was pumped down the well to remove excess sand and debris. This water was collected by the SandX.

At Facility 2, the SandX was used *after* the completion of a well stimulation operation to circulate water to clear sand and debris from the well. This operation is referred to as the frac-sand cleanout (FSC) by Facility 2.

In both cases, the sand and debris entrained in the water from the operation settled to the bottom of a submerged hopper within the SandX tank and was removed with an auger, which is integral to the system. The water at the bottom of the SandX is recirculated with pumps back to the well and SandX. As the water entered the SandX tank, it passed through an open air device at the top of the tank referred to as the Collection Box (Figure

2-2). As the water passed through the Collection Box, methane dissolved or otherwise entrained in the water would be released into the atmosphere. In order to measure potential methane emissions from the SandX, a temporary capture/exhaust system enclosed this area (Figure 2-3) and drew air and vapors through a sample duct where they were measured (Figure 2-4).

2.1.2 Shaker Recirculation Tank

The Shaker recirculation tank (Figure 2-5) is an open top tank with a shaker box at one end and a pumping system at the other end. This was used at Facility 1 *after* the well stimulation event and is the same as the FSC operation at Facility 2. This operation is referred by the acronym POP (Put on Production) by Facility 1. The Shaker Recirculation Tank open-top design required the entire top of the tank, including the shaker, to be enclosed (Figure 2-6).

2.2 *CAPTURE/EXHAUST SYSTEM DESCRIPTION*

In order to capture potential vapors, the open areas of each system were enclosed (tented) using plastic sheeting and a series of two fans exhausted air from this enclosure through a flexible duct connected to a sampling duct. The sampling duct consisted of a round duct with sampling ports located 90-degrees from one another. The location of the sample ports was designed to be a minimum of eight duct diameters from any upstream flow disturbance and two duct diameters from any downstream flow disturbance. This creates a valid sampling location to collect all pertinent flow data. From the sampling duct, the vapors were directed to the fans and away from personnel using additional flexible ducting.

2.3 *SAMPLING POINT LOCATIONS*

Sampling was performed at the SandX and Shaker exhaust stack for determination of methane emission rate. The exhaust stack is an 8-inch-internal-diameter horizontal duct. Two 3/8-inch-diameter sampling ports were installed and located 90 degrees apart on the same cross sectional plane. The sample ports were located 96 inches (12 duct diameters) downstream and 22 inches (2.75 duct diameters) upstream from the nearest flow disturbances. Based on U.S. Environmental Protection Agency (EPA) Reference Method (RM) 1, an 8-point velocity traverse was performed. Figure 2-7 presents a simplified schematic of the SandX and Shaker exhaust stack sampling location and the 8-point traverse layout.

Figure 2-1 SandX Recirculation Tank

Figure 2-2 Collection Box on SandX Recirculation Tank

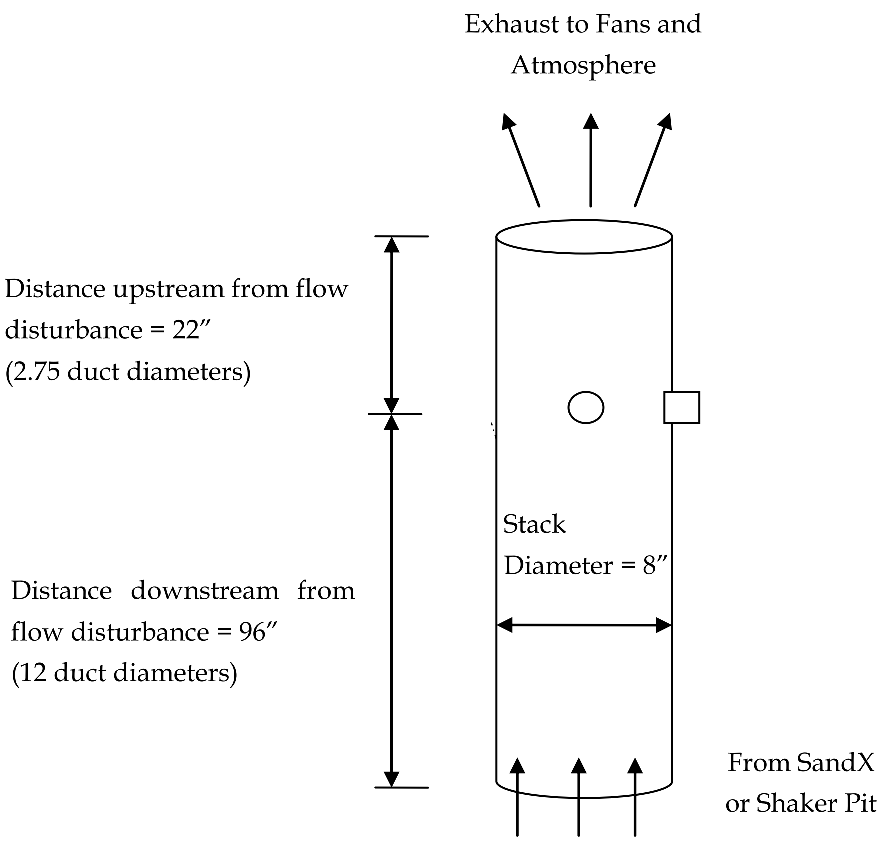
Figure 2-3 SandX Temporary Enclosure

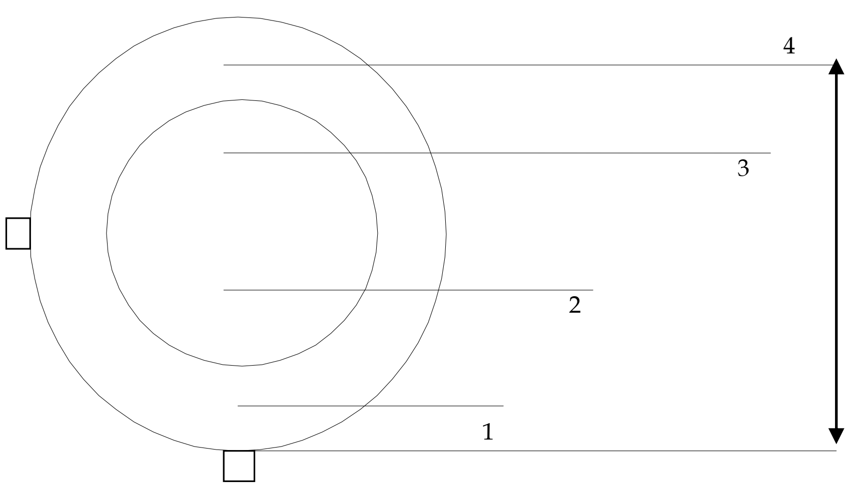
Figure 2-4 Sample Duct

Figure 2-5 Shaker Recirculation Tank

Figure 2-6 Shaker Recirculation Tank Enclosure

Figure 2-7 Exhaust Sample Location and Traverse Point Layout





Traverse Point No.	Distance from Inner Wall
1	0.5″
2	2.0″
3	6.0″
4	7.5″

3.0 *SUMMARY OF EVENTS AND TEST RESULTS*

3.1 *SUMMARY OF EVENTS*

The purpose of this test program was to determine a methane emission rate for the SandX and Shaker recirculation tanks by:

- Monitoring and collecting samples during various operations to determine the concentrations of methane at the recirculation tank exhaust location using modified EPA Method 18 in conjunction with flow rate determinations utilizing EPA Method 1-2.
- Flash Liberation testing was performed simultaneously, at an independent sampling point, on the recirculation tanks by BC Laboratories Inc.

Testing was conducted at two facilities in the San Joaquin Valley.

3.1.1 Facility 1

A total of five methane emissions tests were conducted at Facility 1 from 30 July to 7 August 2015. The emissions of methane from two types of events were tested. Three tests were conducted to determine methane emissions from the SandX recirculation tank during well stimulation events. Two tests were conducted to determine methane emissions from the Shaker recirculation tank during POP events.

3.1.2 Facility 2

Three methane emissions tests were conducted at Facility 2 from 25 to 27 August 2015. All three were conducted to determine methane emissions from the SandX recirculation tank during frac-sand cleanout events.

3.2 *SUMMARY OF RESULTS*

Tables 3-1 to 3-8 below present a summary of results from each of the recirculation tank emissions tests. Table 3-9 presents a summary of results from each of the flash liberation emissions tests.

Table 3-1 Facility 1 Frac 1 SandX Recirculation Tank Emissions Test Results Summary

Facility:	Facility 1		Date:	7/30-31/2015
Source:	SandX		Engineer(s):	DTJ/PJK
Event:	Frac #1		T std:	60°
Run #	Duration	Flow	Methane Concentration	Methane Emitted
	(minutes)	(scfm)	(ppmv)	(scf)
1	60	542	6.2	0.20
2	60	542	15.4	0.50
3	60	532	44.7	1.43
4	60	512	12.8	0.39
5	60	521	34.7	1.08
6	60	519	7.3	0.23
7	60	501	6.0	0.18
8	60	508	3.8	0.12
9	43	501	2.6	0.06
10	60	536	162	5.21
11	60	536	29	0.93
12	40	526	7.8	0.16
Total/Average	683	523	29.4	10.49
Average Methane Emission Rate During Operation (scfh)			0.92	

ppmv = parts per million by volume

Table 3-2 Facility 1 Frac 2 SandX Recirculation Tank Emissions Test Results Summary

Facility:	Facility 1		Date:	8/1/2015
Source:	SandX		Engineer(s):	DTJ/PJK
Event:	Frac #2		T std:	60°
Run #	Duration	Flow	Methane Concentration	Methane Emitted
	(minutes)	(scfm)	(ppmv)	(scf)
1	60	545	2.5	0.08
2	60	520	2.6	0.08
3	60	532	3.7	0.12
4	60	527	4.6	0.15
5	60	531	207.0	6.60
6	60	545	155.0	5.07
7	60	522	50.0	1.57
8	60	527	5.6	0.18
9	51	533	6.3	0.17
Total/Average	531	531	49.6	14.00
Average Methane Emission Rate During Operation (scfh)			1.58	

Table 3-3 Facility 1 Frac 3 SandX Recirculation Tank Emissions Test Results Summary

Facility:	Facility 1		Date:	8/5/2015
Source:	SandX		Engineer(s):	DTJ/PJK
Event:	Frac #3		T std:	60°
Run #	Duration	Flow	Methane Concentration	Methane Emitted
	(minutes)	(scfm)	(ppmv)	(scf)
1	60	537	3.3	0.11
2	60	535	127.0	4.08
3	60	540	9.0	0.29
4	60	531	11.6	0.37
5	60	529	7.7	0.24
6	60	513	4.3	0.13
7	60	514	2.7	0.08
8	60	513	2.8	0.09
9	60	516	2.1	0.07
10	60	505	1.6	0.05
11	60	493	0.0	0.00
Total/Average	660	521	16.0	5.50
Average Methane Emission Rate During Operation (scfh)			0.50	

Table 3-4 Facility 1 POP 1 Shaker Recirculation Tank Emissions Test Results Summary

Facility:	Facility 1		Date:	8/4/2015
Source:	Shaker		Engineer(s):	DTJ/PJK
Event:	POP #1		T std:	60°
Run #	Duration	Flow	Methane Concentration	Methane Emitted
	(minutes)	(scfm)	(ppmv)	(scf)
1	60	540	10,900	353.16
2	60	544	1,510	49.29
3	60	525	139	4.38
4	52	506	409	10.76
Total/Average	232	530	3,399	417.6
Average Methane Emission Rate During Operation (scfh)			108.00	

Table 3-5 Facility 1 POP 2 Shaker Recirculation Tank Emissions Test Results Summary

Facility:	Facility 1		Date:	8/7/2015
Source:	Shaker		Engineer(s):	DTJ/PJK
Event:	POP #2		T std:	60°
Run #	Duration	Flow	Methane Concentration	Methane Emitted
	(minutes)	(scfm)	(ppmv)	(scf)
1	60	540	1200	38.88
2	60	547	1080	35.45
3	60	528	817	25.88
4	60	545	492	16.09
5	60	537	244	7.86
6	39	519	323	6.54
Total/Average	339	537	718	130.7
Average Methane Emission Rate During Operation (scfh)			23.13	

Table 3-6 Facility 2 FSC #1 SandX Recirculation Tank Emissions Test Results Summary

Facility:	Facility 2		Date:	8/25/2015
Source:	SandX		Engineer(s):	SW/PJK
Event:	FSC #1		T std:	60°
Run #	Duration	Flow	Methane Concentration	Methane Emitted
	(minutes)	(scfm)	(ppmv)	(scf)
1	60	534	14700	471.0
2	60	537	41200	1327
3	60	520	26500	826.8
4	60	519	11400	355.0
5	60	511	2600	79.72
6	11	506	1180	6.57
Total/Average	311	524	18833	3067
Average Methane Emission Rate During Operation (scfh)			591.61	

Table 3-7 Facility 2 FSC #2 SandX Recirculation Tank Emissions Test Results Summary

Facility:	Facility 2		Date:	8/26/2015
Source:	SandX		Engineer(s):	SW/PJK
Event:	FSC #2		T std:	60°
Run #	Duration	Flow	Methane Concentration	Methane Emitted
	(minutes)	(scfm)	(ppmv)	(scf)
1	60	560	1180	39.65
2	60	543	337	10.98
3	60	534	1210	38.77
4	60	516	20.3	0.63
5	60	526	3.4	0.11
6	53	525	4770	132.7
Total/Average	353	534	1182	222.9
Average Methane Emission Rate During Operation (scfh)			37.88	

Table 3-8 Facility 2 FSC #3 SandX Recirculation Tank Emissions Test Results Summary

Facility:	Facility 2		Date:	8/27/2015
Source:	SandX		Engineer(s):	SW/PJK
Event:	FSC #3		T std:	60°
Run #	Duration	Flow	Methane Concentration	Methane Emitted
	(minutes)	(scfm)	(ppmv)	(scf)
1	60	524	6310	198.4
2	60	533	4080	130.5
3	60	528	4570	144.8
4	60	530	4290	136.4
5	60	522	736	23.05
6	60	507	251	7.64
7	59	522	8080	248.8
Total/Average	419	524	4054	889.6
Average Methane Emission Rate During Operation (scfh)			127.39	

Table 3-9 Flash Liberation Emissions Test Results Summary

Source	Date	Facility	Event	Gas to Water Ratio (scf/STB)	Total Methane (mol%)	Methane to Water Ratio (scf/STB)
SandX Recirculation Tank	7/30-31/2015	1	Frac #1	0.000	ND*	0.000
SandX Recirculation Tank	8/1/2015	1	Frac #2	0.000	ND*	0.000
SandX Recirculation Tank	8/5/2015	1	Frac #3	0.000	ND*	0.000
Shaker Recirculation Tank	8/4/2015	1	POP #1	0.049	44.96	0.0220
Shaker Recirculation Tank	8/7/2015	1	POP #2	0.000	ND*	0.000
SandX Recirculation Tank	8/25/2015	2	FSC #1	0.348	12.40	0.0432
SandX Recirculation Tank	8/26/2015	2	FSC #2	0.000	ND*	0.000
SandX Recirculation Tank	8/27/2015	2	FSC #3	0.000	ND*	0.000

* These samples are marked None Detected (ND) because no gas was liberated from the sample to analyze

3.3 DATA ANALYSIS

1. Methane emissions from each event were calculated as MT CO2e using Global Warming Potential of 21.

2. A one-sample statistical t-test was conducted to assess if the methane emissions were significantly less than 1 MT CO2e. Null Hypothesis: The mean methane emissions from each event are equal to 1 MT CO2e. The level of significance (α) was set at 0.05.

3. A two-sample statistical t-test was conducted to assess if the methane emissions were significantly different between recirculation events during or after well stimulation events. Null Hypothesis: The difference between mean methane

emissions from events before and after well stimulation events is zero. The level of significance (α) was set at 0.05.

3.4 DISCUSSION

1. Based on the capture and measure test, methane emissions were significantly less than 1 MT CO2e per event (α = 0.05).

t-Test: Two-Sample Assuming Unequal Variances		
	Observed CH4 (MT CO2e)	*Theoretical CH4 (MT CO2e)*
Mean	0.24476165	1
Variance	0.1841176	0
Observations	8	8
Hypothesized Mean Difference	0	
df	7	
t Stat	-4.978303572	
P(T<=t) one-tail	0.000802027	
t Critical one-tail	1.894578605	
P(T<=t) two-tail	0.001604054	
t Critical two-tail	2.364624252	

2. No statistical significant difference was seen between methane emissions observed during and after well stimulation (α = 0.05).

t-Test: Two-Sample Assuming Unequal Variances	Compared During and After Well Stimulation	
	Observed CH4 During Well Stimulation (MT CO2e)	*Observed CH4 After Well Stimulation (MT CO2e)*
Mean	0.00019601	0.018530901
Variance	7.00948E-09	0.000573043
Observations	3	5
Hypothesized Mean Difference	0	
df	4	
t Stat	-1.712636796	
P(T<=t) one-tail	0.080969968	
t Critical one-tail	2.131846786	
P(T<=t) two-tail	0.161939937	
t Critical two-tail	2.776445105	

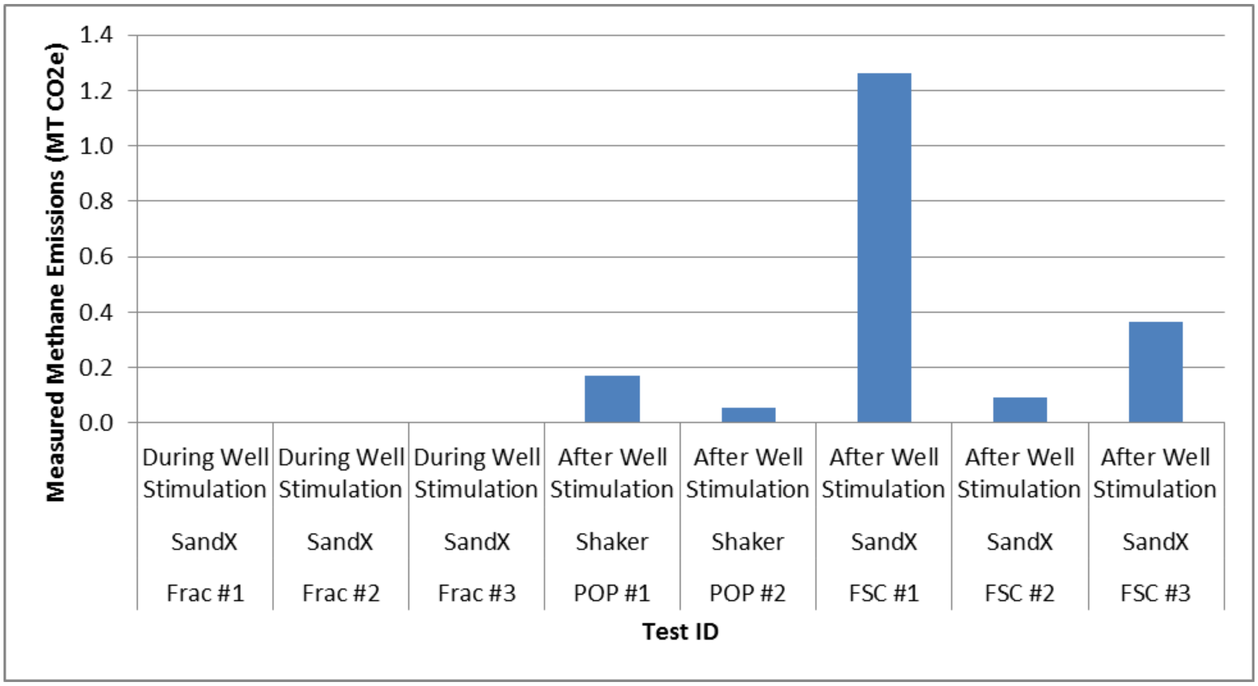


Figure 3-1 Measured Methane Emissions Results from the Source Test in MT CO2e (GWP = 21) for each recirculation event

3. Methane emissions ranged from 0.002 MT CO2e to 1.262 MT CO2e per event.

4. Average methane emissions were observed to be 0.245 MT CO2e per event.

5. Flash gas was liberated from two tests only (POP #1 and FSC #1). These two tests also were the only tests that had maximum methane concentrations >10,000 ppmv.

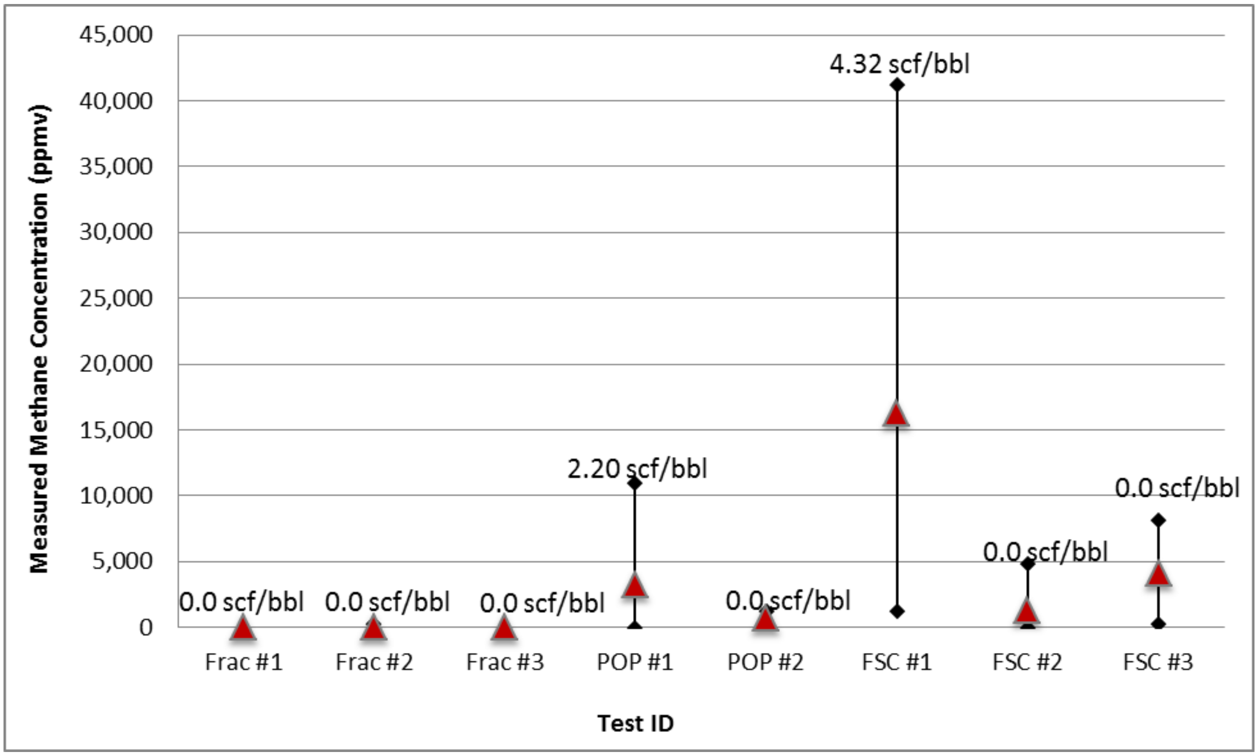


Figure 3-2 Range of Measured Methane Emissions Results from the Source Test in ppmv for each recirculation event and corresponding gas to water ratio in scf/bbl from flash liberation test.

6. Amount of gas emitted ranged from approximately 0.006 MSCF to 3.519 MSCF per event.

4.0 SOURCE TESTING PROCEDURES

The test procedures used for this project are based on EPA reference test methods found in the applicable Source Test Manuals and the appendices of 40 CFR 60.

4.1 EPA METHODS 1 AND 2: DETERMINATION OF STACK GAS VELOCITY AND VOLUMETRIC FLOW RATE

EPA Method 2 was used to obtain stack gas velocity and volumetric flow rate at sample locations following a traverse point matrix determined using Method 1. The flow rates were determined by measuring the average velocity head with a standard pitot tube connected to a calibrated Magnehelic differential pressure gauge or inclined manometer. The average temperatures were measured using a type-K chromel-alumel thermocouple connected to a calibrated potentiometer. The flow measuring equipment was leak tested prior to and immediately after each use.

These flow rates were used, along with concentration measurements, to calculate emissions rates for each parameter quantified.

4.2 EPA METHOD 4: DETERMINATION OF MOISTURE CONTENT IN STACK GASES

ERM used wet bulb and dry bulb temperature measurements coupled with a psychrometric chart analysis and a saturation vapor pressure over water curve to calculate moisture content. The relative humidity was determined from the psychrometric chart from the intersection of the wet and dry bulb temperatures. The saturation vapor pressure was then obtained from the saturation vapor pressure over water curve at the dry bulb temperature. The moisture content of the stack gas was then calculated by multiplying the relative humidity by the saturation vapor pressure, then dividing by the absolute stack pressure.

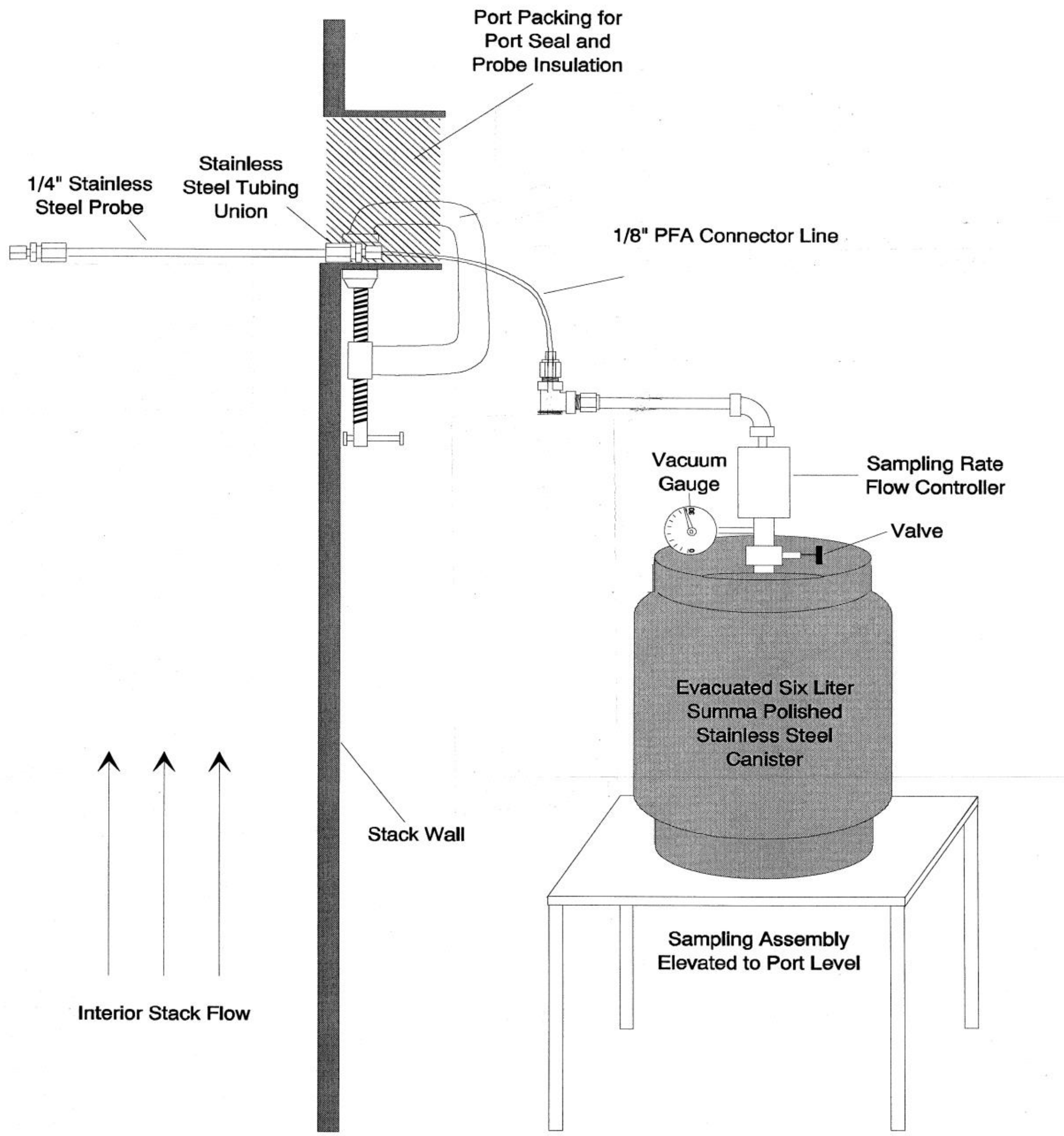
4.3 EPA METHOD 18: MEASUREMENT OF GASEOUS ORGANIC COMPOUNDS EMISSIONS BY GAS CHROMATOGRAPHY

Quantification of methane at the temporary recirculation tank exhaust was conducted according to the procedures of a modified EPA Method 18.

The sampling train consisted of a teflon sampling line connected to a flow controller and an evacuated 6-liter Summa canister. The samples were collected at a constant rate for 60 minutes or, in the case of the last sample of each event, until the event ended. Leak checks were performed before and after sampling. Following completion of the sampling run and leak check the Summa canisters were disconnected, capped, and prepped for delivery to the laboratory. Figure 5-1 presents a diagram of the sampling apparatus. Note that in this case the stainless sample probe was not necessary as the sampling duct was at ambient temperature.

Summa canisters were sent for analysis under chain-of-custody to the selected analytical laboratory.

Figure 4-1 Summa Sample Train Schematic



5.0 *EXAMPLE EMISSION CALCULATIONS*

5.1 *SAMPLE VOLUME AND STACK GAS FLOW RATES*

- Sample gas volume, dry standard cubic feet (dscf)

$$Vstd = Vm * Y * \left(\frac{Tstd}{Tm}\right) * \left(\frac{Ps}{29.92}\right)$$

- Water vapor volume, scf

$$Vwcstd = Wlc * 21.85 * \left(\frac{Tstd}{29.92 * 18.0 * 454}\right)$$

- Moisture content, percent (%)

$$Bws = \frac{Vwcstd}{(Vmstd + Vwcstd)}$$

- Stack gas molecular weight, pound per pound-mole

MW_{dry} = 0.44*(CO_2%) + 0.32*(O_2%) + 0.28*(N_2%)

MW_{wet} = MW_{dry} *(1-B_{ws}) + 18*B_{ws}

- Absolute stack pressure, inches of mercury ("Hg)

$$Ps = Pbar + \frac{Pg}{13.6}$$

- Stack velocity, feet per second

$$Vs = 85.49 * Cp * \sqrt{\left(\frac{P}{Ps}\frac{Ts}{MWwet}\right)}$$

- Actual stack flow rate, actual feet per minute (acfm)

$$Q = Vs * As * 60$$

Dry standard stack gas flow rate, dry standard cubic feet per minute (dscfm)

$$Qsd = Q * (1 - Bws) * \left(\frac{Tstd}{Ts}\right) * \left(\frac{Ps}{29.92}\right)$$

5.2 NOMENCLATURE

A_s = stack area, square feet

B_{ws} = flue gas moisture content

C_p = pitot tube calibration factor

E_i = mass emissions of species *i*

H = orifice pressure differential, inches of water (“H_2O)

MW = molecular weight of flue gas

MW_i = molecular weight of species *i*:

- NO_x = 46 (NO_2)
- CO = 28
- H_2O = 18
- C = 12

θ = sample time, minutes

P = average velocity head, “H_2O

P_{bar} = barometric pressure, “Hg

P_s = stack absolute pressure, “Hg

P_g = stack static pressure, “H_2O

Q = wet stack gas flow rate at actual conditions, acfm

Q_{sd} = dry stack gas flow rate at standard conditions, dscfm

T_m = average meter temperature, °R

t_{sd} = standard temperature, °F

T_{std} = standard temperature, °R

V_s = stack gas velocity, feet per second

V_m = dry meter volume uncorrected, dcf

$V_{m\ std}$ = dry meter volume corrected to standard conditions, dscf

$V_{wc\ std}$ = volume of water vapor at standard conditions, scf

W_{lc} = weight of liquid water collected, grams

Y = meter calibration coefficient

6.0 *QUALITY ASSURANCE AND QUALITY CONTROL*

6.1 *SAMPLING PROTOCOL*

ERM is organized to facilitate sample management, analytical performance management, and data management. Personnel are assigned specific tasks to ensure implementation of the quality assurance/quality control (QA/QC) program. The Senior Project Managers in charge of air emission measurement projects report directly to the Principal-in-Charge of Air Services and are the QA officers responsible for program effectiveness and compliance.

The analysts perform the data reduction, analyses, and initial data review. Each analyst must check and initial their work, making certain that it is complete, determining that any instrumentation utilized has been properly calibrated, and ensuring that the analysis has been performed within the QA/QC limits.

The Senior Project Managers evaluate the data submitted by the analysts and verify that the data and documentation are complete, confirm that all analyses have been performed within QA criteria specific to each method, check calculations, assemble and sign the data package, and prepare the final report.

6.2 *EQUIPMENT MAINTENANCE AND CALIBRATION*

The Field Supervisor and Field Technicians are in charge of routine maintenance and calibration of all source testing equipment. Relevant calibration information is included in the appendices.

6.2.1 *Equipment Maintenance*

Maintenance logs are maintained for all major pieces of equipment, where all maintenance activities are recorded and documented. Table 6-1 shows routine maintenance performed on source testing equipment.

Table 6-1 Test Equipment - Routine Maintenance Schedule

Equipment	Acceptance Limits	Frequency of Service	Methods of Service
Pump	• Absence of leaks • Ability to draw vacuum within equipment specifications	Every 500 hours of operation or 6 months, whichever is less	• Visual inspection
Flow Meter	• Free mechanical movement • Absence of malfunction	Every 500 hours of operation or 6 months, whichever is less	• Visual inspection • Clean • Calibrate
Sampling Instrumentation	• Absence of malfunction • Proper response to zero, mid-level, and span gases	As recommended by manufacturer or when required due to unacceptable limits	• As recommended by manufacturer
Mobile Laboratory Sampling System	• Absence of leaks • Proper input flow rates to analyzers	Depends on nature of use	• Change filters • Change gas dryer • Leak check • Check for contamination
Sample Lines	• Absence of soot and particulate buildup • Adequate sample flow	Depends on nature of use	• Flush with solvents and water • Purge line with nitrogen

6.2.2 *Equipment Calibration*

Current calibration information on equipment used during testing is included in the appendices of this report.

The S-Type pitot tubes are calibrated initially upon purchase and then semiannually. Visual inspection and measurements are taken prior to each use to ensure accidental damage has not occurred. Measurements are performed using a micrometer and protractor.

Temperature sensors are uniquely identified as a unit along with the Pitot tube or sample probe they are attached to. Calibrations are performed initially and annually at three set-points including ice water, boiling water, and hot oil using a calibrated, National Institute of Standards and Technology (NIST) traceable reference thermometer or potentiometer. Field potentiometers including handheld units and permanently mounted units in meter consoles are calibrated over the range of expected temperatures using a calibrated, NIST traceable reference output thermocouple calibrator.

The field barometer is adjusted initially and semiannually to within 0.1 "Hg of the actual atmospheric pressure. All dry gas field meters are calibrated before initial use. Once the meter is placed in operation, its calibration is checked after each test series or bimonthly, whichever is less. Dry gas meters are calibrated against a NIST reference meter or orifice.

Field top loading balances are calibrated annually (or more frequently as needed) using NIST traceable mass standards. Field balance calibration is checked daily prior to usage using a field mass standard. Analytical balances are annually calibrated by a third party per manufacturer instructions using NIST traceable standards. Analytical balance calibration is checked with Class S-1 analytical weights prior to daily usage.

6.3 DATA VALIDATION

The data presented in final reports are reviewed three times. First, the analyst reviews and certifies that the raw data complies with technical controls, documentation requirements, and standard group procedures. Second, the Senior Project Manager reviews and certifies that data packages comply to specifications for sample holding conditions, chain-of-custody, data documentation, and the final report is free of transcription errors. Third, a QA review is performed by additional senior personnel. This review thoroughly examines the entire completed data report. Once the review process is completed, the report is approved by ERM senior personnel and issued. All raw laboratory data and final reports are stored for a minimum of 5 years.

Appendix A

Data Summary and Calculations

Appendix B

ERM Field Data

Appendix C

Laboratory Data

Appendix D

Equipment Calibrations