PHLSA Study Final Report
Appendix IV

Process Instrumentation Measurement Data, and Storage Tank Mass Balance and Flash Gas-to-Oil (FGOR) Calculations for the Summer and Winter Three-Pressure Testing

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IV.1 Introduction

This appendix presents the process instrumentation measurement data, and storage tank mass balance and FGOR calculations for the summer and winter three-pressure testing (Task 9 in the project work plan, Appendix I). Section IV.2 provides an overview of the data flow from the 3-pressure testing through final calculations of FGOR and the storage tank mass balance for each well cycle. Section IV.3 introduces the instrumentation used to measure the process pressures, temperatures, and flowrates at the O&G production site, and the equations used to calculate the FGOR and the storage tank mass balance values are presented in Section IV.4. Section IV.5 summarizes the measured FGOR and the storage tank mass balance values for each well cycle. Section IV.6 is an index for sub-Appendix IV.1 and sub-Appendix IV.2, which are electronic files containing the calculation spreadsheets. Sub-Appendix IV.3 is the calibration report for the measurement instruments.

For the summer 3-pressure testing:

- Testing was conducted during three high-pressure separator (i.e., target operating pressure ~ 260 psig) well cycles: S-HP1, S-HP2, and S-HP3.
- Testing was conducted during five mid-pressure separator (i.e., target operating pressure ~ 225 psig) well cycles: S-MP1, S-MP2, S-MP3, S-MP4, and S-MP5.
- Testing was conducted during three low-pressure separator (i.e., target operating pressure ~ 175 psig) well cycles: S-LP1, S-LP2, and S-LP3.

For the winter 3-pressure testing:

- Testing was conducted during three high-pressure separator (i.e., target operating pressure ~ 260 psig) well cycles: W-HP1, W-HP3, and W-HP4.
- Testing was conducted during three mid-pressure separator (i.e., target operating pressure ~ 225 psig) well cycles: W-MP1, W-MP2, and W-MP3.
- Testing was conducted during three low-pressure separator (i.e., target operating pressure ~ 175 psig) well cycles: W-LP1, W-LP2, and W-LP3.

IV.2 Overview of Data Flow and Calculations

Figure Section IV.2-1 shows the data flow and analysis for the three-pressure testing, and includes the following primary steps.

1. During each 3-pressure test well cycle, instrumentation measurements of process parameters were recorded by a data logger at 1.17 second intervals and process samples (e.g., pressurized condensate, tank-to-burner pipeline gas) were collected. Refer to Section 3.2.9 of the Final Report for the three-pressure testing matrix.
2. The data logger records were transferred a spreadsheet that calculated well cycle average and totals for measured parameters.
3. Coriolis meter measurements of produced oil volumes were reviewed with the manufacturer for possible adjustment for high drive gain. High drive gain is an indicator of two-phase flow that can bias oil flow rate measurements. Note that oil volume adjustments were small, one percent or less.
4. Storage tank-to-burner gas flowrates measured by two Fox thermal mass flowmeters (identified as instruments "Fox 1 flow" and "Fox 2 flow" in the tables and figures that follow) were adjusted using a heat transfer model because the process gases had compositions that differed from the instrument calibration gases. This model is based on correlations for heat transfer from a heated cylinder in a gas cross flow, and considers the density, viscosity, thermal conductivity and Prandtl number of the gas. The spreadsheets listed in Table IV.6-3 perform these calculations in two steps. For example, the "Fox Flowmeter 21773_Fox 1_Summer pre-test Cal Data" spreadsheet calculates a Reynolds number exponent "n" for the heat transfer model from calibration data provided by the manufacturer. The "Fox Meters Summer Tank Gas Composition Adjustment Factors" spreadsheet then calculates a composition adjustment factor to adjust measured flowrates for each well cycle using the heat transfer model, the "n" exponent, and the relative compositions of the well cycle process gas and the flow meter calibration gas. This issue is discussed in greater detail in Sections IV.3.1 and IV.6.
5. Process samples collected for each well cycle are sent to the laboratory for analysis. The lab results are in Appendix III and samples are identified by the Certificate of Analysis number in each spreadsheet.
6. Spreadsheets listed in Table IV.6-1 are used to calculate well cycle average and totals for measured process parameters.
7. The output from the spreadsheets listed in Table IV.6-1 and the lab results are inputs to the Spreadsheets listed in Table IV.6-2 which calculates well cycle storage tank mass balance and FGOR values.

The well cycle ID number and the Certificate of Analysis number for the lab results are used to track data through the data flow process outlined in Figure IV.2-1.

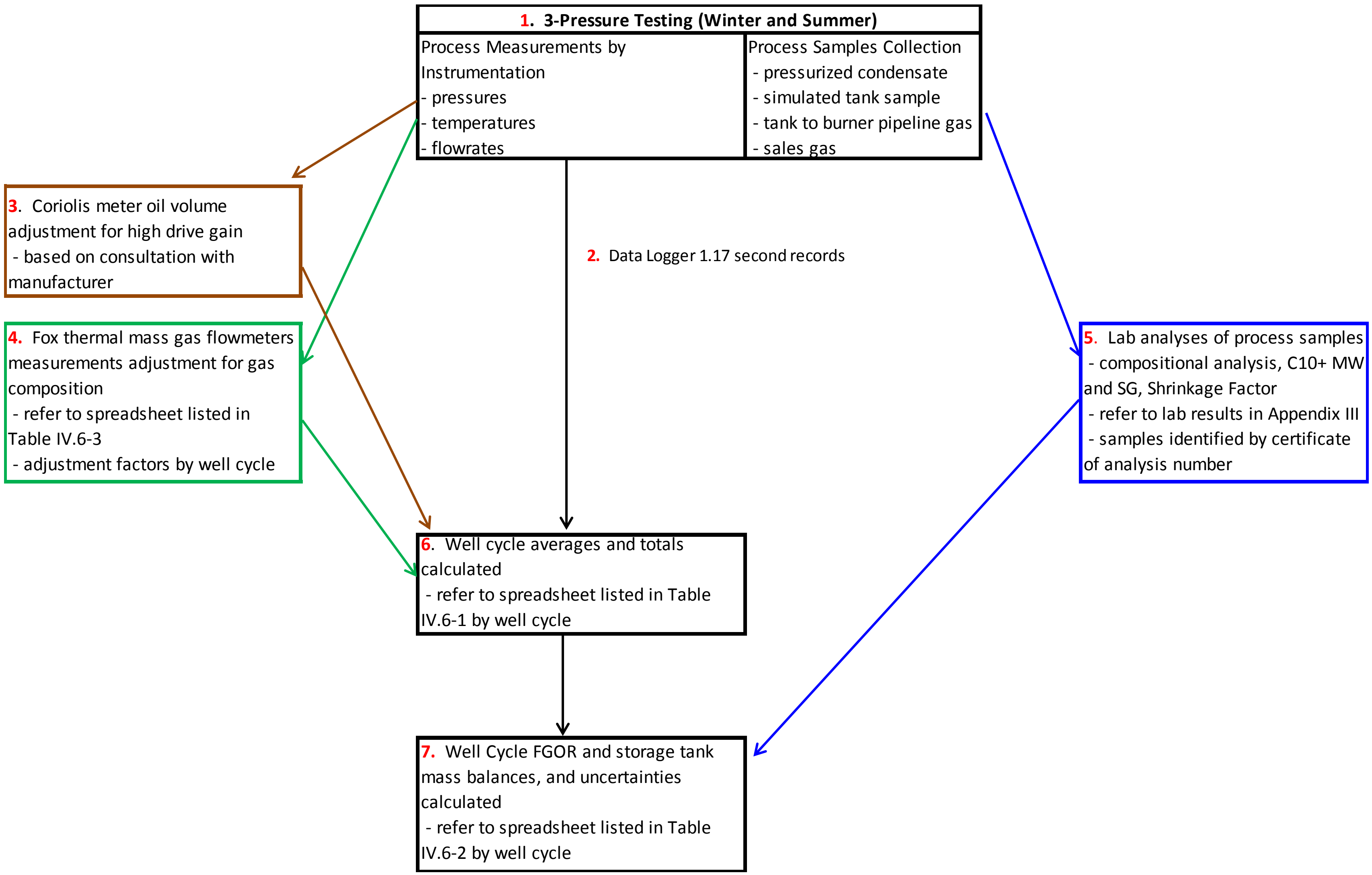

Figure IV.2-1. Three-pressure testing data flow process overview

IV.3 Process Instrumentation Measurements

The winter and summer three-pressure testing was conducted at the testing location is typical of a traditional vertical well production facility. This facility primarily consists of a well, three-phase separator, condensate storage tank, and a VOC burner to combust tank gas emissions. Section 2.1 in the report discusses the process flows and equipment operation. Figure IV.3-1 is a basic schematic of this location, and shows the primary process measurements during the three pressure testing used to measure the storage tank mass balance and FGOR for each well cycle. Table IV.3-1 provides more detail about these instruments. Figures IV.3-2 and IV.3-3 show the all the installed instruments for the summer testing and the winter testing, respectively, and Table IV.3-2 provides more detail about these instruments. Figures IV.3-4 to IV.3-8 are photos of key process equipment, instrumentation, and sample collection locations.

Table IV3-1. Instrumentation for Primary Process Measurements

Parameter	Instrument Type	Instrument ID	Engineering Units
P_{sep} – separator pressure	Pressure transducer	PIT 1	psig
T_{sep} – separator liquids temperature	Resistance Temperature Detector	RTD 1	°F
L_{oil} – pre-flash oil production	Coriolis meter	CM Flow	bbl/day[A]
P_{tank} – tank headspace gas pressure	Pressure transducer	PIT 2	oz/in^2
$T_{tank\ gas}$ – tank headspace gas temperature	Resistance Temperature Detector	RTD 3	°F
$H_{tank\ liquid}$ – tank liquid level	Tank liquid level sensor	LL1	inches
$T_{tank\ bottom}$ – tank liquids temperature 1 foot above tank bottom	Resistance Temperature Detector	RTD 8	°F
Q_{FG} – tank to burner pipeline gas flow	Thermal mass gas flow meter	Fox 1 flow	MCFD[A]
Q_{FG} – tank to burner pipeline gas flow	Thermal mass gas flow meter	Fox 2 flow	MCFD[A]
Q_{FG} – tank to burner pipeline gas flow	Vane anemometer	Vane anemometer	m^3/hr
T_{FG} – tank to burner pipeline gas temperature	Resistance Temperature Detector	RTD 6	°F

A. Instrument measures instantaneous flow rate and has a totalizer function

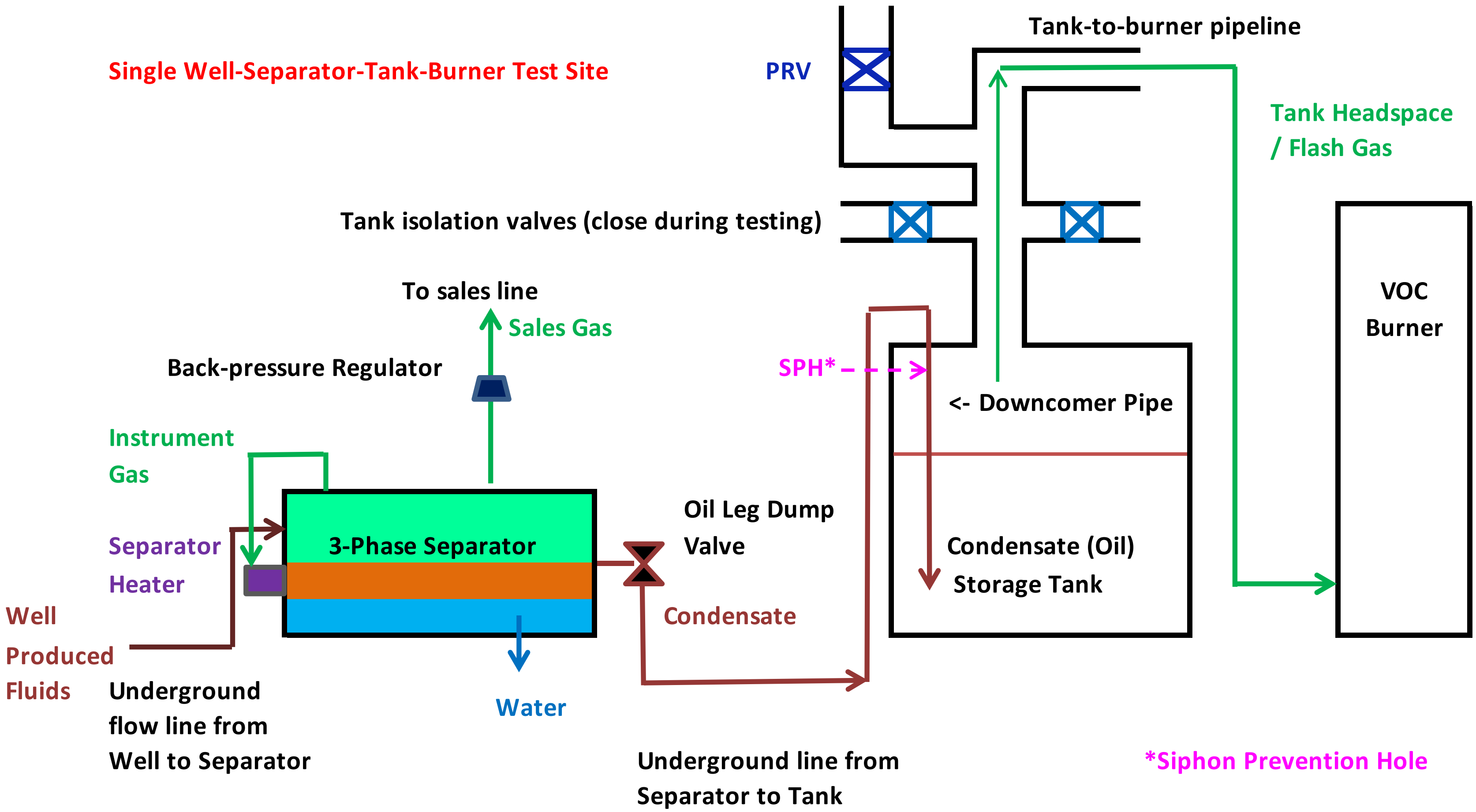

Figure IV3-1. Process schematic and primary process measurements instrumentation used to determine storage tank mass balance and FGOR during the three pressure testing.

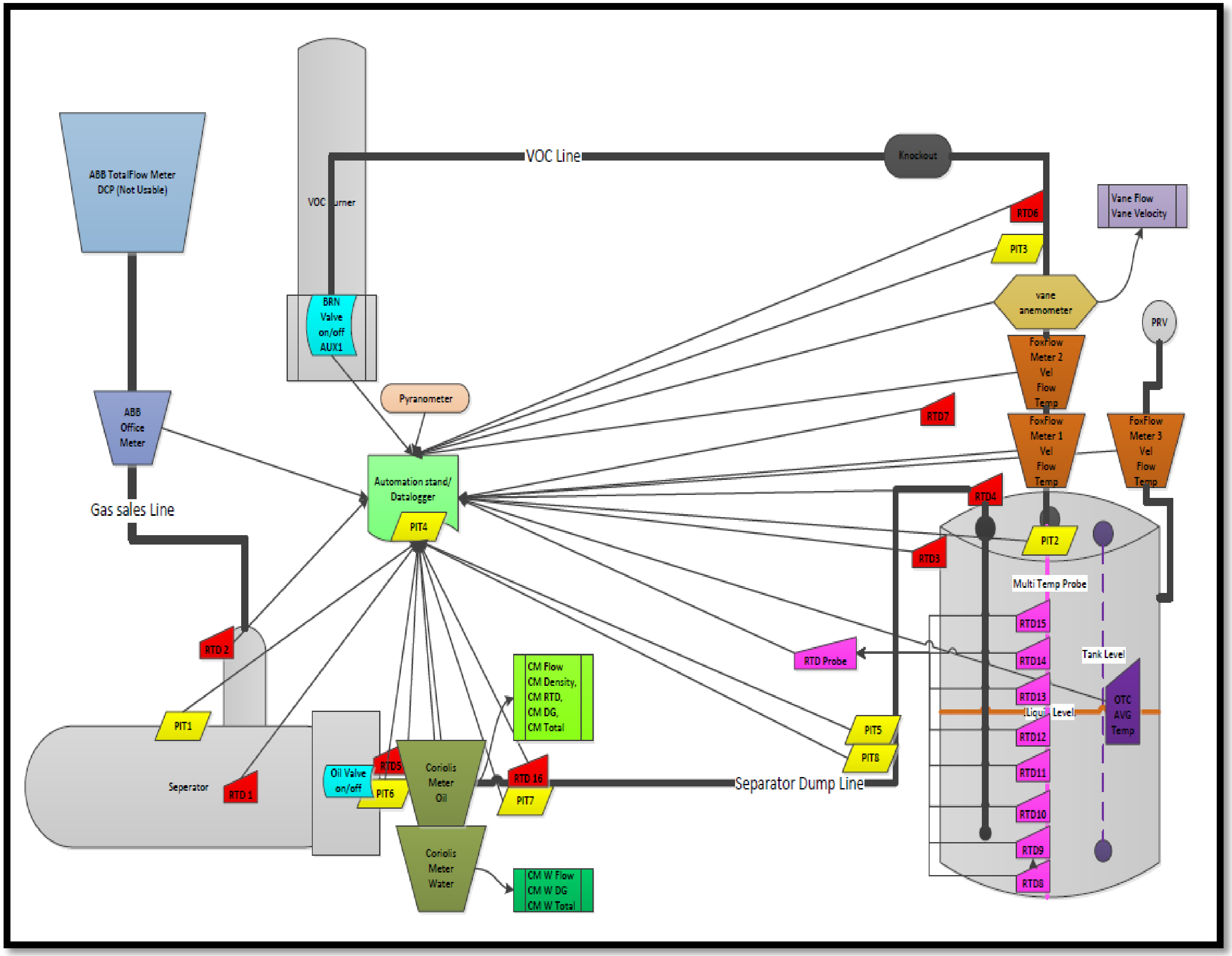

Figure IV.3-2. Summer 3-pressure testing instruments.

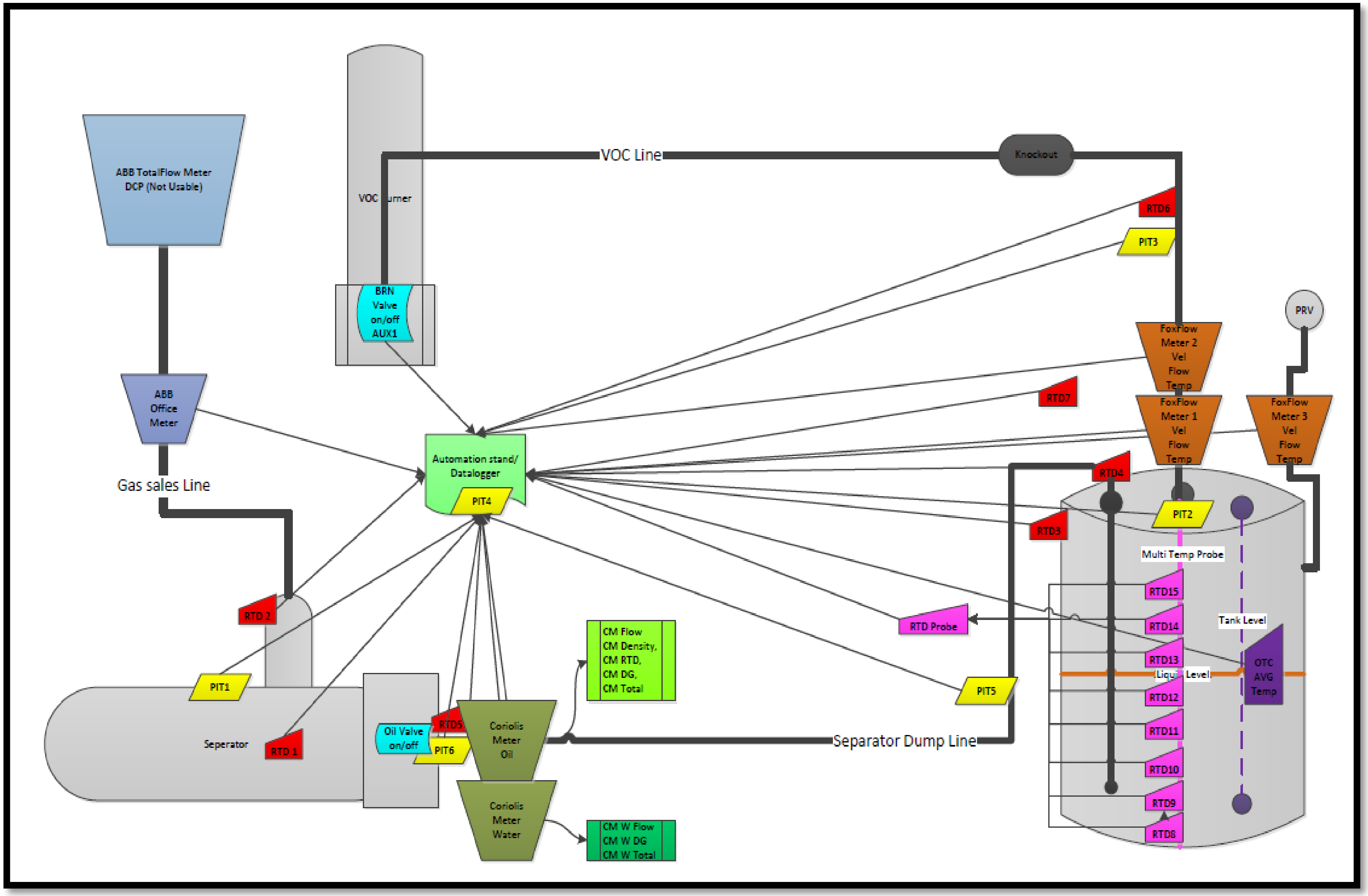

Figure IV.3-3. Winter 3-pressure testing instruments.

Figure IV.3-4. Test separator with back-pressure control regulator (red device at top of picture).

Figure IV.3-5. Condensate Storage Tanks with three gas flowmeters in insulated and heat-traced tank-to-burner pipeline. Gas sample collection port above knockout drum.

Figure IV.3-6. Coriolis oil flow meter.

Figure IV.3-7. Pressurized condensate sample ports and oil box sight glass (upper right corner).

Figure IV.3-8. VOC burners.

Table IV3-2. Instrumentation for Process Measurements

Parameter	Data-logger ID	Manu-facturer	Model	Serial Number	Input	Output	Location	Instrument	Range	Accuracy	Calibration Method	Cal Record Exist?	Source of Instrument Calibration	Data Collection Frequency[B]	Units
Ambient pressure (P_{amb})	PIT 4	Dylix Corporation	GXR2-PP010-A03-B07-C01-D07	140548697	8-38 vdc	1-5 vdc	Automation Stand	Pressure transducer	0-1 psig (0-16 oz)	± 2% of measured value	3 Point linear	Yes	Alex Casetta	1 second	PSIG
Ambient temperature ($T_{ambient}$)	RTD 7	Thermocouple Technology	WA715612	4815	12 vdc	1-5 vdc	Vicinity of tank, upwind	RTD	-25 – 175ºF	± 2 ºF	3 Point linear		Alex Casetta	1 second	ºF
Separator Oil Temperature ($T_{sep\ oil}$)	RTD 1	Thermocouple Technology	XDA	1300014631	12 vdc	1-5 vdc	Separator oil layer	RTD	0 – 250ºF	± 2 ºF	3 Point linear		Alex Casetta	1 second	ºF
Separator Gas Temperature ($T_{sep\ gas}$)	RTD 2	Thermocouple Technology	XDA	1300012874	12 vdc	1-5 vdc	Separator gas headspace	RTD	0 – 250ºF	± 2 ºF	3 Point linear		Alex Casetta	1 second	ºF
Separator Pressure (P_{sep})	PIT 1	Foxboro	IGP10-V22E1F	12031714	9-30 vdc	1-5 vdc	Separator headspace	Pressure transducer	0-500 psi	± 2% of measured value	3 Point linear		Alex Casetta	1 second	PSIG
Vane Meter Velocity	Vane_Velocity	Hontzsch	UFA-Ex-d-ZS25-E-10A	mn20 12122	20-27 vdc	4-20 mA	In tank VOC burner line downcomer upstream of knockout[C]	Vane anemometer	0.1 – 70 m/s	< 1.5%	Hontzch	Yes	Hontzch	1 second	m/s
Separator produced gas flowrate ($Q_{sales\ gas}$)	ABB Flow	ABB Total Flow	XFC G4 - Model X6413Y	T121881581	< 15 vdc	1-5 vdc	Separator gas leg	XFC G4 6413	0-250 DP 0-500 SP	0.05% URL	3 Point linear	Yes	Certified Crystal	1 second	Std MCF per day
Separator-to-oil tank pipe gas/liquids pressure Hi ($P_{dump\ flow}$)	PIT 8	Barksdale	435H5-04-W72		12-28 vdc	4-20 mA	Where the sep-to-oil tank pipeline comes to the surface, base of upcomer	Pressure transmitter	0 – 100 psig	± 0.25% of measured value (at Full-Scale at 75F)	3 Point linear		Alex Casetta	1 second	PSIG
Separator oil flowrate to tank (Q_{oil})	CM Flow	Emerson	R100SB21NW BAEZZZZ	14430099	17.3 vdc	1-5 vdc	Separator oil leg upstream of dump valve	Coriolis meter	0-6576 bbl/d	± 0.5% of rate	At Factory	Yes	Emerson	1 second	Barrels Per Day
Separator oil to tank density (ρ_{oil})	CM Density	Emerson	R100SB21NW BAEZZZZ	14430099	17.3 vdc	1-5 vdc	Separator oil leg upstream of dump valve	Coriolis meter	0-3.0	± 0.01 g/cm^3	At Factory	Yes	Emerson	1 second	SGU
Separator oil to tank temperature ($T_{CM\ oil}$)	CM RTD	Emerson	R100SB21NW BAEZZZZ	14430099	17.3 vdc	1-5 vdc	Separator oil leg upstream of dump valve	Coriolis meter	(-)40 – 140ºF	± 1 ºC ± 0.5% of reading	At Factory	Yes	Emerson	1 second	ºF

Parameter	Data-logger ID	Manu-facturer	Model	Serial Number	Input	Output	Location	Instrument	Range	Accuracy	Calibration Method	Cal Record Exist?	Source of Instrument Calibration	Data Collection Frequency[B]	Units
Coriolis meter drive gain	CM DG	Emerson	R100SB21NW BAEZZZZ	14430099	17.3 vdc	1-5 vdc	Separator oil leg upstream of dump valve	Coriolis meter	0-100%	N/A	At Factory	Yes	Emerson	1 second	Percen t
Solar Radiation reading	Solar_Ra d	Hukseflux	SR05-DA2	2059	12 vdc	4-20 mA	7 m south of storage tanks	SR05 pyranometer	0-1600	N/A	At Factory	Yes	Hukseflux	1 second	W/m^2
Separator-to-oil tank pipe gas/liquids pressure Post dump valve	PIT 7	Barksdale	435H5-04-W72		12-28 vdc	4-20 mA	Where the sep-to-oil tank pipeline leaves the dump valve	Pressure transmitter	0 – 100 psig	± 0.25% of measured value (at Full-Scale at 75F)	3 Point linear		Alex Casetta	1 second	PSIG
Separator Dump leg, Just after dump valve	RTD 16	Thermocouple Technology	1080AA (ENCL)	WA715611	12 vdc	1-5 vdc	Separator Dump leg, Just after dump valve	RTD	-25 – 175ºF	± 2ºF	3 Point linear		Alex Casetta	1 second	ºF
Separator water flowrate to tank (Q_{water})	CM W Flow	Emerson	F100SB21CQB AEZZZZ	14267449	17.3 vdc	1-5 vdc	Separator water leg upstream of dump valve	Coriolis meter	0-6576 bbl/d	± 0.28% of rate	At Factory	Yes	Emerson	1 second	Barrel s Per Day
Coriolis meter Water drive gain	CM DG	Emerson	F100SB21CQB AEZZZZ	14267449	17.3 vdc	1-5 vdc	Separator Water leg upstream of dump valve	Coriolis meter	0-100%	N/A	At Factory	Yes	Emerson	1 second	Percen t
Oil dump valve on/off position & dump time/ duration (τ_{dump}, I_{dump})	O Dump Po	N/A	N/A	N/A			Oil dump valve	Valve position indicator	0 or 1	NA	N/A	N/A	N/A	1 second	0,1,2,3
Separator-to-oil tank pipe gas/liquids temperature ($T_{dump\ flow}$)	RTD 4	Thermocouple Technology	XDA			1-5 vdc	Separator-to-oil tank pipe, just prior to entering the tank on the horizontal section	RTD	0 – 250ºF	± 2ºF	3 Point linear		Alex Casetta	1 second	ºF
Separator-to-oil tank pipe gas/liquids temperature ($P_{dump\ flow}$)	PIT 5	Ashcroft	A2XBM0415C 21.5#G	1512391	10-30 vdc	1-5 vdc	Where the sep-to-oil tank pipeline comes to the surface, base of upcomer	Pressure transducer	0-1.5 psig (0-24 oz)	± 2% of measured value	3 Point linear	Yes	Alex Casetta	1 second	PSIG
Separator-to-oil tank pipe gas/liquids pressure Lo ($P_{dump\ flow}$)	PIT 9				10-30 vdc	1-5 vdc	Separator-to-oil tank pipe, just prior to entering the tank on the horizontal section	Pressure transducer	0-1.5 psig (0-24 oz)	± 2% of measured value	3 Point linear		Alex Casetta	1 second	PSIG

Parameter	Data-logger ID	Manu-facturer	Model	Serial Number	Input	Output	Location	Instrument	Range	Accuracy	Calibration Method	Cal Record Exist?	Source of Instrument Calibration	Data Collection Frequency[B]	Units
Oil tank headspace gas temperature ($T_{tank\ gas}$)	RTD 3	Thermocouple Technology	XDA	1300014737	12 vdc	1-5 vdc	In tank, at top of tank, centerline	RTD	-25 – 175ºF	± 2ºF	3 Point linear		Alex Casetta	1 second	ºF
Oil tank gas/liquids temperature ($T_{tank\ 1}$)	RTD 15	Electrolab	DLS 2100	16LS111530 483	5.6-12.9 vdc	1-5 vdc	In tank, cernterline,152" above tank bottom	RTD	(-)40 – 185ºF	± 1.5ºF	At Factory	Offest = -0.4ºF	Electrolab	1 second	ºF
Oil tank gas/liquids temperature ($T_{tank\ 2}$)	RTD 14	Electrolab	DLS 2100	16LS111530 483	5.6-12.9 vdc	1-5 vdc	In tank, centerline, 135" above tank bottom	RTD	(-)40 – 185ºF	± 1.5ºF	At Factory	Offest = 1.5ºF	Electrolab	1 second	ºF
Oil tank gas/liquids temperature ($T_{tank\ 3}$)	RTD 13	Electrolab	DLS 2100	16LS111530 483	5.6-12.9 vdc	1-5 vdc	In tank, centerline, 112" above tank bottom	RTD	(-)40 – 185ºF	± 1.5ºF	At Factory	Offest = 2ºF	Electrolab	1 second	ºF
Oil tank gas/ liquids temperature ($T_{tank\ 4}$)	RTD 12	Electrolab	DLS 2100	16LS111530 483	5.6-12.9 vdc	1-5 vdc	In tank, centerline, 92" above tank bottom	RTD	(-)40 – 185ºF	± 1.5ºF	At Factory	Offest = 0.5ºF	Electrolab	1 second	ºF
Oil tank gas/liquids temperature ($T_{tank\ 5}$)	RTD 11	Electrolab	DLS 2100	16LS111530 483	5.6-12.9 vdc	1-5 vdc	In tank, centerline, 72" above tank bottom	RTD	(-)40 – 185ºF	± 1.5ºF	At Factory	Offest = 1.5ºF	Electrolab	1 second	ºF
Oil tank gas/liquid temperature ($T_{tank\ 6}$)	RTD 10	Electrolab	DLS 2100	16LS111530 483	5.6-12.9 vdc	1-5 vdc	In tank, centerline, 52" above tank bottom	RTD	(-)40 – 185ºF	± 1.5ºF	At Factory	Offest = 0.5ºF	Electrolab	1 second	ºF
Oil tank gas/liquids temperature ($T_{tank\ 7}$)	RTD 9	Electrolab	DLS 2100	16LS111530 483	5.6-12.9 vdc	1-5 vdc	In tank, centerline, 32" above tank bottom	RTD	(-)40 – 185ºF	± 1.5ºF	At Factory	Offest = 0.5ºF	Electrolab	1 second	ºF
Oil tank gas/liquids temperature ($T_{tank\ 8}$)	RTD 8	Electrolab	DLS 2100	16LS111530 483	5.6-12.9 vdc	1-5 vdc	In tank, centerline, 14" above tank bottom[A]	RTD	(-)40 – 185ºF	± 1.5ºF	At Factory	Offest = 0ºF	Electrolab	1 second	ºF
Oil tank liquid level ($H_{tank\ liquids}$)	LL1	Electrolab	DLS 2100	16LS111530 483	5.6-12.9 vdc	1-5 vdc	Oil tank liquid surface	Tank level sensor	0 – 180 Inches	0.125 inch	Closed Contact Single Offset	Yes	Alex Casetta	1 second	Inches
Oil tank headspace gas pressure ($P_{tank\ gas}$)	PIT 2	Ashcroft	A2XBM0415C 21.5#G	1512394	10-30 vdc	1-5 vdc	Bulk tank headspace pressure (gauge pressure)	Pressure transducer	0-1.5 psig (0-24 oz)	± 2% of measured value	3 Point linear	Yes	Alex Casetta	1 second	PSIG

Parameter	Data-logger ID	Manu-facturer	Model	Serial Number	Input	Output	Location	Instrument	Range	Accuracy	Calibration Method	Cal Record Exist?	Source of Instrument Calibration	Data Collection Frequency[B]	Units
Oil tank VOC burner line gas temperature ($T_{VOC\ pipe}$)	RTD 6	Thermosync	ATP-1000	15111370	9-30 vdc	1-5 vdc	In tank VOC burner line downcomer upstream of flowmeter(s)	RTD	-25 – 175ºF	± 2ºF	3 Point linear		Alex Casetta	1 second	ºF
Oil tank VOC burner line gas pressure ($P_{VOC\ pipe}$)	PIT 3	American Sensor Technology	AST44LPP0000 2P3L1000-SS	1415630 140509	10-28 vdc	1-5 vdc	In tank VOC burner line downcomer upstream of flowmeter(s) (gauge P)	Pressure transducer	0-2 psig (0-32 oz)	< ± 0.5% of measured value for 0-1 psig	3 Point linear	Yes	Alex Casetta	1 second	PSIG
Oil tank VOC burner line gas velocity	Fox1 Velocity	Fox Thermal Instruments	FT3	21773	21.6-26.4 vdc	1-5 vdc	In tank VOC burner line downcomer upsteam of knockout[C]	Thermal flowmeter	TBD	TBD	At Factory	Yes	Fox Flow Labs	1 second	normal meters per hour (nmph)
Oil tank VOC burner line gas flowrate ($Q_{tank\ gas\ 1}$)	Fox1 Flow	Fox Thermal Instruments	FT3	21773	21.6-26.4 vdc	1-5 vdc	In tank VOC burner line downcomer upsteam of knockout[C]	Thermal flowmeter	0 - 500 MCF Two Curves	1% Reading + .2 % Full Scale	At Factory	Yes	Fox Flow Labs	1 second	Standard MCF per day
Oil tank VOC burner line gas temp	Fox1 Temp	Fox Thermal Instruments	FT3	21773	21.6-26.4 vdc	1-5 vdc	In tank VOC burner line downcomer upsteam of knockout[C]	Thermal flowmeter	Minus 40 to 240	1.80%	At Factory	Yes	Fox Flow Labs	1 second	ºF
Oil tank VOC burner line gas flowrate ($Q_{tank\ gas\ 2}$)	Vane Anemometer	Hontzsch	UFA-Ex-d-ZS25-E-10A	mn20 12122	20-27 vdc	4-20 mA	In tank VOC burner line downcomer upsteam of knockout[C]	Vane anemometer	0-253.2 m3/h	< 1.5%	Hontzch	Yes	Hontzch	1 second	actual m^3/hr
Oil tank VOC burner line gas Velocity	Fox2 Velocity	Fox Thermal Instruments	FT3	21776	21.6-26.4 vdc	1-5 vdc	In tank VOC burner line downcomer upsteam of knockout[C]	Thermal flowmeter	TBD	TBD	At Factory	Yes	Fox Flow Labs	1 second	normal meters per hour (nmph)
Oil tank VOC burner line gas Flowrate ($Q_{tank\ gas}$)	Fox2 Flow	Fox Thermal Instruments	FT3	21776	21.6-26.4 vdc	1-5 vdc	In tank VOC burner line downcomer upsteam of knockout[C]	Thermal flowmeter	0 - 500 MCF Two Curves	1% Reading + .2 % Full Scale	At Factory	Yes	Fox Flow Labs	1 second	Standard MCF per day
Oil tank VOC burner line gas Temp	Fox2 Temp	Fox Thermal Instruments	FT3	21776	21.6-26.4 vdc	1-5 vdc	In tank VOC burner line downcomer upsteam of knockout[C]	Thermal flowmeter	Minus 40 to 240	1.80%	At Factory	Yes	Fox Flow Labs	1 second	ºF

Parameter	Data-logger ID	Manu-facturer	Model	Serial Number	Input	Output	Location	Instrument	Range	Accuracy	Calibration Method	Cal Record Exist?	Source of Instrument Calibration	Data Collection Frequency[B]	Units
Separator Dump Temp, Just prior to Coriolis meter.	RTD 5	ABB Total Flow	TTF300L1C2H BSK2	3K62000015 3491	< 30 vdc	4-20 mA	Separator Dump leg, Just prior to Coriolis meter.	RTD	0 – 200°F	± 2°F	3 Point linear		Alex Casetta	1 second	°F
Separator Dump Pressure, Just prior to Coriolis meter.	PIT 6	Ashcroft	A2XBM0415C 2500#G - XCY	1512140	10-30 vdc	1-5 vdc	Separator Dump leg, Just prior to Coriolis meter.	Pressure transducer	0-500 psig	± 2% of measured value	3 Point linear		Alex Casetta	1 second	PSIG
Oil tank PRV vent gas flowrate ($Q_{PRV\ gas}$)	Fox3 Velocity	Fox Thermal Instruments	FT3	21775	21.6-26.4 vdc	1-5 vdc	In tank PRV vent line upstream of the PRV[C]	Thermal flowmeter	TBD	TBD	At Factory	Yes	Fox Flow Labs	1 second	normal meters per hour (nmph)
Oil tank PRV vent gas flowrate ($Q_{PRV\ gas}$)	Fox3 Flow	Fox Thermal Instruments	FT3	21775	21.6-26.4 vdc	1-5 vdc	In tank PRV vent line upstream of the PRV[C]	Thermal flowmeter	0 - 500 MCF Two Curves	1% Reading + .2 % Full Scale	At Factory	Yes	Fox Flow Labs	1 second	Standard MCF per day
Oil tank PRV vent gas flowrate ($Q_{PRV\ gas}$)	Fox3 Temp	Fox Thermal Instruments	FT3	21775	21.6-26.4 vdc	1-5 vdc	In tank PRV vent line upstream of the PRV[C]	Thermal flowmeter	Minus 40 to 240	1.80%	At Factory	Yes	Fox Flow Labs	1 second	°F
VOC valve on/off position & dump time/ duration (τ_{dump}, I_{dump})	BRNvalve/ AUX1	NA	NA	NA			Valve position sensor on the VOC valve	Valve position indicator	0 or 1	NA	NA	NA	Alex Casetta	2 second	0,1
CM Totalizer	AUX 2						CM Totalizer						Alex Casetta	1 Second	
CM_W_Totalizer	AUX 3						CM_W_Totalizer						Alex Casetta	1 Second	
Fox 1 Totalizer	AUX 4						Fox 1 Totalizer						Alex Casetta	1 Second	
Fox 2 Totalizer	AUX 5						Fox 2 Totalizer						Alex Casetta	1 Second	

IV.3.1 Storage Tank-to-Burner Pipeline Gas Flow Rate Measurement

The storage tank-to-burner pipeline gas flow rate rapidly changes at the start of each separator liquids dump (and flash gas release) and after the end of the dump, and such rapidly changing flow rates are difficult to measure. The gas flow measurement was further complicated because the gas composition and temperature (which impact instrument response and accuracy) differed for each well cycle, and differed from the calibration gas composition and temperature. Two thermal mass gas flow meters (Fox Flow 1 and Fox Flow 2 in Figures IV3-1, IV3-2, and IV3-1) were installed in series in the tank-to-burner pipeline. A third flow meter, a vane anemometer (also shown in the figures), which has a different measurement principle, was installed for the summer testing as discussed below.

Thermal mass flowmeters measure gas mass flow using a heated element that losses heat to flowing gas, and the gas mass flowrate is correlated to the electrical power required to maintain a constant heated element temperature. The response of these instruments is impacted by the pipeline gas composition and associated heat transfer properties (e.g., density, viscosity, thermal conductivity). When the process gas composition deviates from the calibration gas composition, the measurement accuracy is reduced. Vane anemometers measure volumetric flow rate and are less impacted by gas composition. Corrections were needed to account for differences from calibration conditions. Discussion in Section IV.6 and spreadsheets listed in Table IV-6.3 present the methodologies used to adjust the measured flowrates for all three flowmeters based on process conditions versus calibration conditions. Three flow meters were employed with the idea that agreement or differences between the redundant meters would provide insight into the accuracy of these measurements.

Figure IV.3-9 provides a comparison of the tank-to-burner gas flowmeters measurement during the summer three-pressure testing. These data include composition adjusted flows for the two Fox thermal mass meters and the vane anemometer, and the good agreement between the three measurements for most of the well cycles (e.g., all three measurements within 4% of the average for 8 of the 10 well cycles) provides some confidence in the measurements.

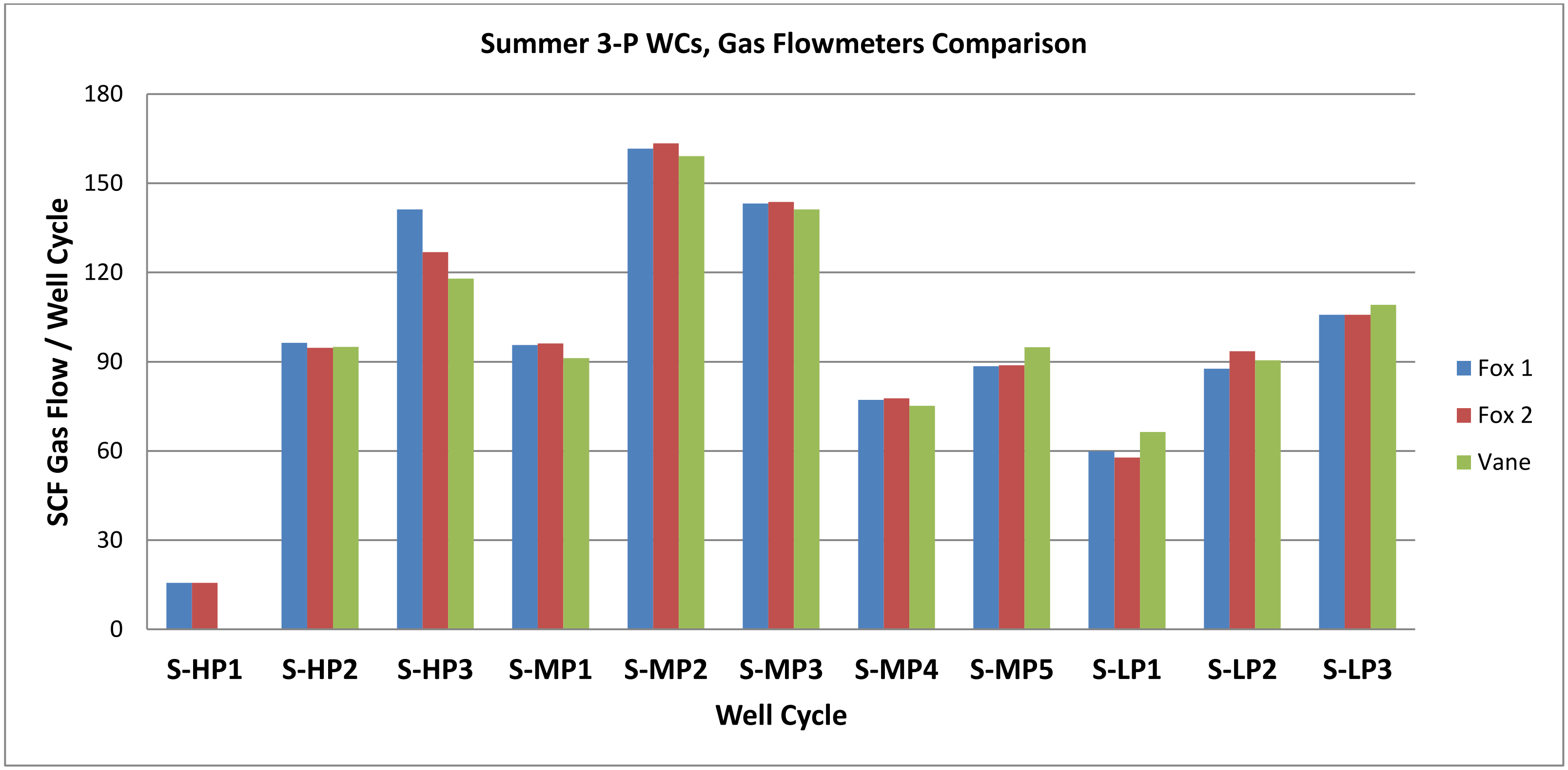

Figure IV.3-9. Comparison of tank-to-burner gas flowmeter measurements during the summer three-pressure testing.

IV.4 FGOR and Storage Tank Mass Balance Calculations Approach

IV.4-1 FGOR Calculations

Equation IV.4-1 is used to calculate the measured FGOR for a well cycle at standard temperature and pressure (STP).

$$FGOR = \frac{Vol_{FG}}{Vol_{post-flash\,oil}} = \frac{V_{Tank-Burner} + \Delta V_{Tank\,Headspace\,Gas} - BL}{L_{pre-flash\,oil} * Shrinkage\ Factor} \qquad \text{Eqn. IV.4-1}$$

Where:

FGOR = flash gas-to-oil ratio for a well cycle (standard cubic feet of flash gas/barrel post-flash condensate/oil) (scf/bbl)

Vol_{FG} = volume of flash gas generated during a well cycle (scf)

$Vol_{post\text{-}flash\ oil}$ = volume of post-flash oil produced during a well cycle (bbl)

$V_{Tank\text{-}Burner}$ = volume of gas that flowed from the tank to the burner during the well cycle (scf)

- Measured by a thermal mass flow meter [Instrument = Fox 1 flow and Fox 2 flow] or a vane anemometer (refer to Eqn. IV.4-2)

$\Delta V_{Tank\ Headspace\ Gas}$ = change in the volume of gas (at standard temperature and pressure (STP)) in the tank headspace and tank-to-VOC burner pipeline during the well cycle (scf)

- Calculated from ideal gas law and pre- and post-well cycle headspace gas Volume (V), Temperature (T) and Pressure (P). Refer to Equation IV.4-3

BL = breathing losses from the tank during the well cycle (scf)

- Calculated from ideal gas law and pre- and post-“breathing cycle” headspace gas V, T & P. Refer to Equation IV.4-4

$L_{pre\text{-}flash\ oil}$ = volume of pre-flash oil that flowed from separator to tank during well cycle

- Measured by Coriolis meter (bbl at STP). Refer to Equation IV.4-5

Shrinkage Factor $= \frac{Volume\ of\ post-flash\ Oil}{Volume\ of\ pre-flash\ Oil}$

- Determined from Lab analysis of pressurized condensate sample

Equation IV.4-2 calculates the volume of gas that flowed from tank to burner during the well cycle at standard conditions, as measured by the vane anemometer:

$$Vane\ Anemometer_{STP} = Vane\ Anemometer * \frac{P_M * T_S}{Z * P_S * T_M} \qquad \text{Eqn. IV.4-3}$$

Vane Anemometer$_{STP}$ = volume measured by vane anemometer adjusted to standard temperature of 60ºF and standard pressure of 14.73 pounds per square inch absolute (psia)

Vane Anemometer = volume measured by vane anemometer (actual cubic feet (acf)) [Instrument = vane anemometer]

P_M = measured storage tank to VOC burner line gas pressure (pounds per square inch gauge (psig)) [Instrument = PIT 3] + ambient pressure (psia) [Instrument = PIT 4]

T_S = standard temperature = 60ºF = 288.706K

Z = compressibility factor for the tank-to-burner pipeline gas

P_S = standard pressure of 14.73 psia (101,560 pascals (Pa)) (standard pressure for process simulation software/equation of state (PSM/EOS) calculations)

T_M = measured storage tank to VOC burner line gas temperature (K) [Instrument = RTD 6]

If the storage tank over-pressures and vents through the PRV, then would need to add PRV vent flow [Instrument = Fox3 Flow]; however, this volume was negligible for all of the tests.

Equation IV.4-3 calculates $\Delta V_{Tank\ Headspace\ Gas}$ (scf) from the change in the moles of gas from the Start to the End of the well cycle using the ideal gas law and standard temperature and pressure:

$$\Delta V_{Tank\,HeadspaceGas} = \left(n_{HSGasE} - n_{HSGasS}\right) * \frac{R * T_S * 35.3147}{P_S} \qquad \text{Eqn. IV.4-3}$$

n_{HSGasE} = number of moles of tank headspace gas at the End of the well cycle (moles). Refer to Equation IV.4-3.1

n_{HSGasS} = number of moles of tank headspace gas at the Start of the well cycle (moles). Refer to Equation IV.4-3.2

R = 8.31446 = ideal gas constant

35.3147 = cubic feet per cubic meter

Equation IV.4-3.1 calculates the moles of tank headspace gas at the End of the well cycle using the ideal gas law and actual temperature and pressure (n):

$$n_{HSGasE} = \frac{P_{TankE} * 6894.76 * \frac{V_{HSE}}{35.3147}}{R * T_{HSE}}$$ Eqn. IV.4-3.1

P_{TankE} = tank headspace gas pressure at the End of the well cycle (psig) [Instrument = PIT 2] + Ambient Pressure (psia) [Instrument = PIT 4]

6,894.76 = Pa per psi

V_{HSE} = tank headspace volume (=volume of gas in the tank + the volume of the tank-to-VOC burner pipeline + the volume of the separator to tank pipeline downstream of the accumulated liquid) at the End of the well cycle (cf) [Instrument = LL1]

T_{HSE} = temperature of the tank headspace gas at the End of the well cycle (K) = average of Oil tank headspace gas temperature [Instrument = RTD 3] and Oil tank VOC burner line gas temperature [Instrument = RTD 6]

Equation IV.4-3.2 calculates the moles of tank headspace gas at the Start of the well cycle using the ideal gas law and actual temperature and pressure (n):

$$n_{HSGasS} = \frac{P_{TankS} * 6894.76 * \frac{V_{HSS}}{35.3147}}{R * T_{HSS}}$$ Eqn. IV.4-3.2

P_{TankS} = tank headspace gas pressure at the Start of the well cycle (psig) [Instrument = PIT 2] + Ambient Pressure (psia) [Instrument = PIT 4]

V_{HSS} = tank headspace volume (=volume of gas in the tank + the volume of the tank-to-VOC burner pipeline + the volume of the separator to tank pipeline downstream of the accumulated liquid) at the Start of the well cycle (cf) [Instrument = LL1]

T_{HSS} - temperature of the tank headspace gas at the Start of the well cycle (K) = average of Oil tank headspace gas temperature [Instrument = RTD 3] and Oil tank VOC burner line gas temperature [Instrument = RTD 6]

Equation IV.4-4 calculates the "BL rate" from the change in the tank headspace gas temperature and pressure during "breathing cycles" using the ideal gas law, and the BL cycle duration:

NOTE - "Breathing cycle" duration for BL calculations is from time of low pressure to time of high pressure.

Figure IV-1 shows tank gas headspace pressure (y-axis) change with time (x-axis). The tank gas pressure increases due to heating, and when the pressure reaches ~ 5 oz/in^2 the VOC burner starts and burns gas until the pressure is reduced to ~ 2 oz/in^2

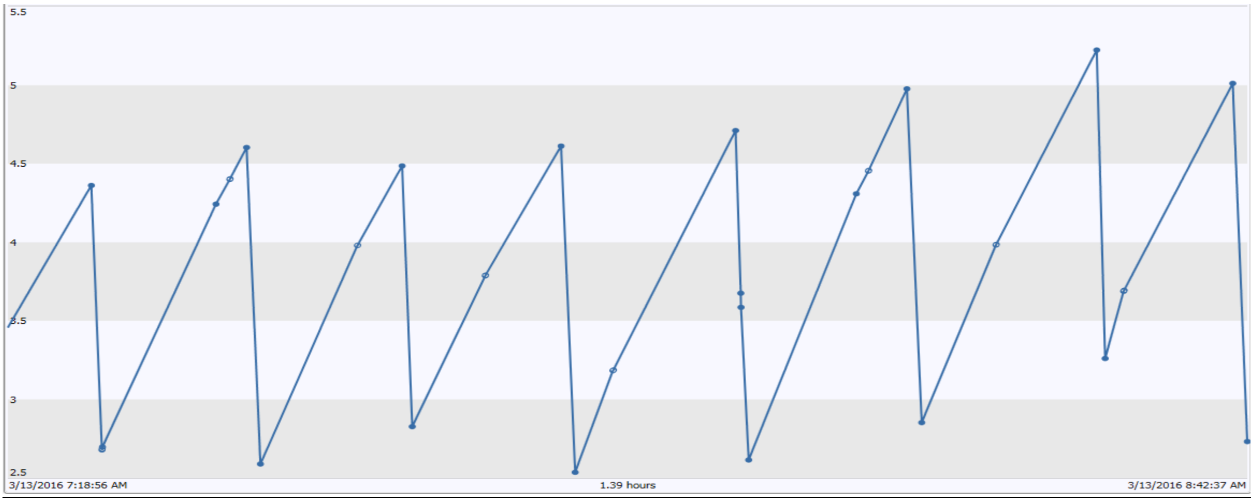

Figure IV.4-1. Oil tank gas headspace pressure change with time.

$$BL = \left[\frac{(n_{HSGasBLCE} - n_{HSGasBLCS}) * \dfrac{R * T_S * 35.3147}{P_S}}{BLC_{duration}} \right] * WC_{duration}$$ Eqn. IV.4-4

Equation IV4-4 calculates the "BL rate" (scf/min) from the change in the moles of tank headspace gas from the Start to the End of the BL cycle using the ideal gas law, standard temperature and pressure, and the duration of the BL cycle. Multiple this rate (calculated in the [ ]) by the duration of the well cycle to estimate total breathing losses for the well cycle (i.e., BL).

$n_{HSGasBLCE}$ = number of moles of headspace gas at the End of the BL cycle (moles)

$n_{HSGasBLCS}$ = number of moles of headspace gas at the Start of the BL cycle (moles)

$BLC_{duration}$ = duration of the BL cycle (i.e., End time of the BL cycle – Start time of the BL cycle) (min)

$WC_{duration}$ = duration of the well cycle (i.e., End time of the well cycle – Start time of the well cycle) (min)

NOTE – more than one BL rate may be calculated and averaged for a well cycle if the BL rate varies.

Equation IV4-4.1 calculates the moles (n) of gas at the End of the BL cycle using the ideal gas law and actual temperature and pressure:

$$n_{HSGasBLCE} = \frac{P_{TankBLCE} * 6894.76 * \dfrac{V_{HSBLCE}}{35.3147}}{R * T_{HSBLCE}} \qquad \text{Eqn. IV.4-4.1}$$

$P_{TankBLCE}$ = tank headspace gas pressure at the End of the BL cycle (psig) [Instrument = PIT 2] + Ambient Pressure (psia) [Instrument = PIT 4]

V_{HSBLCE} = tank headspace volume (=volume of gas in the tank + the volume of the tank-to-VOC burner pipeline + the volume of the separator to tank pipeline downstream of the accumulated liquid) at the End of the BL cycle (cf) [Instrument = LL1]

T_{HSBLCE} = temperature of the tank headspace gas at the End of the BL cycle (K) = average of Oil tank headspace gas temperature [Instrument = RTD 3] and Oil tank VOC burner line gas temperature [Instrument = RTD 6]

Equation IV4-4.2 calculates the moles (n) of gas at the Start of the BL cycle using the ideal gas law and actual temperature and pressure:

$$n_{HSGasBLCS} = \frac{P_{TankBLCS} * 6894.76 * \dfrac{V_{HSBLCS}}{35.3147}}{R * T_{HSBLCS}} \qquad \text{Eqn. IV.4-4.2}$$

$P_{TankBLCS}$ = tank headspace gas pressure at the Start of the BL cycle (psig) [Instrument = PIT 2] + Ambient Pressure (psia) [Instrument = PIT 4]

V_{HSBLCS} = tank headspace volume (=volume of gas in the tank + the volume of the tank-to-VOC burner pipeline + the volume of the separator to tank pipeline downstream of the accumulated liquid) at the Start of the BL cycle (cf) [Instrument = LL1]

T_{HSBLCS} = temperature of the tank headspace gas at the Start of the BL cycle (K) = average of Oil tank headspace gas temperature [Instrument = RTD 3] and Oil tank VOC burner line gas temperature [Instrument = RTD 6]

Equation IV.4-5 calculates the volume of pre-flash oil that flowed from the separator to the tank during the well cycle at standard conditions:

$$L_{pre-flashoil} = L_{pre-flashoil_M} * \frac{\rho_M}{\rho_{STP}}$$ Eqn. IV.4-5

$L_{pre\text{-}flash\ oil}$ = volume of pre-flash oil that flowed from the separator to the tank during the well cycle at standard temperature and pressure (bbl)

$L_{pre\text{-}flash\ oilM}$ = measured volume of pre-flash oil that flowed from the separator to the tank during the well cycle (bbl) [Instrument = CM Totalizer]

ρ_M = measured density of pre-flash oil (kg/m^3) [Instrument = CM Density]

ρ_{STP} = density of pre-flash oil at 14.73 psi and 60ºF (kg/m^3)

Equation IV.4-6 calculates measured FGOR for individual FG hydrocarbons ($FGOR_i$) from the FGOR and the FG composition determined by the on-site GC:

$$FGOR_i = FGOR * FG_i$$ Eqn. IV.4-6

$FGOR_i$ = FGOR for hydrocarbon "i" for the well cycle (scf HC_i/bbl)

FGOR = FGOR for the well cycle (scf FG/bbl)

FG_i = mole fraction of hydrocarbon "i" in the flash gas for the well cycle (mole i/mole FG) [Instrument = on-site GC + tedlar bag sample and analysis for C6+ HC species]

IV.4-2 Storage Tank Mass Balance Calculations

Equation IV.4-7 is used to calculate the storage tank hydrocarbon mass balance for a well cycle:

$$ST_{MB} = \frac{Mass_{FG}}{\Delta Mass_{oil}} = \frac{Mass_{FG}}{Mass_{pre\text{-}flashoil} - Mass_{post\text{-}flashoil}}$$ Eqn. IV.4-7

Where:

ST_{MB} = storage tank HC mass balance for a well cycle

$Mass_{FG}$ = measured mass of flash gas generated during a well cycle (kg)

- Refer to Equation IV.4-8

$Mass_{post\text{-}flash\ oil}$ = measured mass of post-flash HC liquid produced during a well cycle (kg)

- Refer to Equation IV.4-9

$Mass_{pre\text{-}flash\ oil}$ = measured mass of pre-flash HC liquid produced during a well cycle (kg)

- Refer to Equation IV.4-10

$\Delta Mass_{oil}$ = $Mass_{pre\text{-}flash\ oil}$ - $Mass_{post\text{-}flash\ oil}$

Equation IV.4-8 is used to calculate the mass of flash as generated during a well cycle:

$$Mass_{FG} = FGOR * L_{pre-flashoil} * ShrinkageFactor * \frac{1}{35.3147} * \frac{P_s}{R * T_s} * MW_{FG} \quad \text{Eqn. IV.4-8}$$

MW_{FG} = molecular weight of the flash gas (g/gmole)

- Refer to SPL lab report (Appendix III)

Equation IV.4-9 is used to calculate the volume of pre-flash oil that flowed from the separator to the tank during the well cycle:

$$Mass_{pre-flashoil} = L_{pre-flashoil} * 0.159 * \rho_{pre-flash\,oil} \quad \text{Eqn. IV.4-9}$$

0.159 = m^3 per bbl

$\rho_{pre\text{-}flash\ oil}$ = density of pre-flash oil that flowed from the separator to the tank during the well cycle (kg/m^3) [Analysis = pressurized condensate sample]

Equation IV.4-10 is used to calculate the volume of post-flash oil that flowed from the separator to the tank during the well cycle:

$$Mass_{pre-flashoil} = L_{post-flashoil} \left(= L_{pre-flashoil} * Shrinkage\,Factor \right) * 0.159 * \rho_{post-flash\,oil} \quad \text{Eqn. IV.4-10}$$

$L_{post\text{-}flash\ oil}$ = volume of post-flash oil that flowed from the separator to the tank during the well cycle (bbl) [Analysis = lab weathered, at flash temperature, pressurized condensate sample]

$\rho_{post\text{-}flash\ oil}$ = density at flash temperature of post-flash oil that flowed from the separator to the tank during the well cycle (kg/m^3) [Analysis = lab weathered pressurized condensate sample]

Equation IV.4-11 calculates the storage tank mass balance for individual HCs expressed as the ratio of the mass of HC_i in the flash gas generated and the change in the mass of HC_i in the HC liquid (optimal for mass balance is 1.0):

$$ST_{MBCHi} = \frac{Mass_{FG} * FGMF_{HC\,i}}{Mass_{pre-flashoil} * Pre - Flash\,Oil\,MF_{HCi} - Mass_{post-flashoil} * Post - Flash\,Oil\,MF_{HCi}}$$

ST_{MBHCi} = storage tank mass balance for hydrocarbon “i“ (%)

$Mass_{FG}$ = mass of flash gas generated during a well cycle (kg)

$FGMF_{HCi}$ = mass fraction of hydrocarbon "i" in the flash gas during a well cycle (kg HCi/kg FG) [Analysis = on-site GC]

$Mass_{pre\text{-}flash\ oil}$ = mass of pre-flash HC liquid produced during a well cycle (kg)

Pre-Flash Oil MF_{HCi} = mass fraction of HC "i" in the pre-flash HC liquid produced during a well cycle (kg HCi/kg pre-flash HC liquid) [Analysis = GC of pressurized condensate sample]

$Mass_{post\text{-}flash\ oil}$ = mass of post-flash HC liquid produced during a well cycle (kg)

Post-Flash Oil MF_{HCi} = mass fraction of HC "i" in the post-flash HC liquid produced during a well cycle (kg HCi/kg post-flash HC liquid) [Analysis = GC analysis of weathered condensate]

IV.5 Summary of FGOR and Storage Tank Mass Balance Measurements

The following tables summarize the results of the measured storage tank mass balances and FGORs:

- Table IV-1. Summer Testing Process Data, FGOR, and Mass Balance (MB) Results by Well Cycle: CP Cylinder Sample Collection and GPA 2103M Analysis
- Table IV-2. Summer Testing Process Data, FGOR, and Mass Balance (MB) Results by Well Cycle: CV Cylinder Sample Collection and GPA 2103M Analysis
- Table IV-3. Summer Testing Process Data, FGOR, and Mass Balance (MB) Results by Well Cycle: CP Cylinder Sample Collection and GPA 2186M Analysis
- Table IV-4. Summer Testing Process Data, FGOR, and Mass Balance (MB) Results by Well Cycle: CV Cylinder Sample Collection and GPA 2186M Analysis
- Table IV-5. Winter Testing Process Data, FGOR, and Mass Balance (MB) Results by Well Cycle: CP Cylinder Sample Collection and GPA 2103M Analysis
- Table IV-6. Winter Testing Process Data, FGOR, and Mass Balance (MB) Results by Well Cycle: CV Cylinder Sample Collection and GPA 2103M Analysis
- Table IV-7. Winter Testing Process Data, FGOR, and Mass Balance (MB) Results by Well Cycle: CP Cylinder Sample Collection and GPA 2186M Analysis
- Table IV-8. Winter Testing Process Data, FGOR, and Mass Balance (MB) Results by Well Cycle: CV Cylinder Sample Collection and GPA 2186M Analysis

The summary data in these tables were extracted from the spreadsheets listed in Table IV.6-2.

These tables include, for each well cycle:

- Key process parameters separator pressure (P_{sep}), separator temperature (T_{sep}), storage tank headspace temperature ($T_{tank\ HS}$), and the tank liquids temperature one foot from the bottom in the vicinity of the down-comer exit ($T_{tank\ bottom}$).
- The FGOR measured during the well cycle (Eqn. IV.4-1).
- The storage tank mass balance measured during the well cycle (Eqn. IV.4-7).
  - The mass of tank-to-burner gas flow measured during the well cycle is an estimate of the mass of flash gas generated during the well cycle; however, it is believed to be biased slightly high. The <u>volume</u> of tank-to-burner gas flow measured during the well cycle is believed to be a good estimate of the <u>volume</u> of flash gas generated during the

well cycle; however, the tank-to-burner gas flow includes some heavier hydrocarbons that volatilize into the tank headspace as the tank absorbs solar radiation and breathing losses are generated. Thus, the tank-to-burner gas includes flash gas and breathing losses gas (i.e., the flash gas mixes with the existing tank headspace gas and some mix of the two flows to the VOC burner), and because the breathing losses gas likely has a larger fraction of heavy hydrocarbons (e.g., C4, C5) than the flash gas, the tank HC mass balance measurements likely have a slight high bias. For example, in Table IV-1 well cycle S-HP3 has a total HC mass balance closure of 98%, but the mass balance closures for the anticipated primary flash gas components – methane, ethane, and propane (i.e., C 1 – C3) – range from 65% to 80%, whereas as the mass balance closures for C4 and C5 are greater than 100%. This suggests some of the C1 – C3 HCs generated during the flashing are displacing heavier breathing losses HCs (that flow to the burner) and remaining in the tank headspace during the well cycle. In general, the tank C5 mass balance closures (i.e., Tank C5 MB) are much greater than the overall tank mass balance closures (i.e., Tank HC MB) suggesting most of the C5 is from tank breathing losses. The Tank C5 MBs generally have high uncertainties.

- FGOR at 100% MB is the ratio of the FGOR and tank HC mass balance measured during the well cycle, and provides an estimate of the FGOR would be if cold tank liquids were not "quenching" flash gas formation. For example, if the measured FGOR was 150 scf/bbl and the tank mass balance was 50%, then the estimated FGOR at 100% MB would be 300 scf/bbl. These estimates are likely biased low by the likely high bias in the storage tank mass balance (as discussed above), and these estimates generally have very high uncertainties.
- Tank mass balances for C1 to C5 hydrocarbons.

There are two considerations when reviewing the mass balance and measured FGOR results:

1.) The uncertainties reported in the tables are calculated from the uncertainties of the measured parameters, but do not consider if the all the measured parameters were 100% representative of process conditions during the well cycle; and

- Note that best efforts were made to collect representative (i.e., process average) samples and measure process parameters at average locations/conditions, and that any biases from "non-representative" samples and measurements are anticipated to be small but are not known. Consideration "2" lists some factors that could impact such potential biases.

2.) Many factors impact the storage tank mass balance closures, and these include:

- The data suggest that cold tank liquids suppress or quench flash gas generation during some well cycles, particularly early in the day (i.e., non-equilibrium tank conditions);
- Measurement inaccuracies. For example, tank-to-burner pipeline gas flow rate measurement challenges include rapidly changing flowrates (i.e., severe transients), low flow rates, gas composition effects, and a very low pressure drop that limits flow rate measurement options;
- Timing issues. P_{sep} during pressurized oil sample collection was typically a few psi less than P_{sep} during the well cycle (i.e., the oil that flowed to the tank was at a higher pressure than the oil sample);
    - For the summer testing, the sample collection pressures were 2 to 7 psi lower than the average separator pressure during the well cycle (9 of the 11 well cycles agreed within 5 psi) and the sample collection temperatures were from 2°F higher to 8°F lower than the average separator temperature during the well cycle (9 of the 11 well cycles agreed within 3°F).
    - T_{sep} is measured in the bulk oil in the separator and the sample collection temperature is measured in the oil box to Coriolis meter pipeline, and there is opportunity for oil to cool slightly during flow between the two locations.
    - A separator pressure drop of 3 -5 psi was typically observed during a well cycle.
- The assumption that the separator liquid is in equilibrium with the gas at the separator temperature and pressure during the well cycle may not be valid;
- Potential for residual oil in the separator to have a different composition than oil produced from the well during the well cycle;
- The tank-burner pipeline gas sample (used as flash gas in mass balance calculations) differs from actual flash gas (i.e., as discussed above, gas samples includes flash gas and heavier HCs from breathing losses. In addition, the tank gas is likely stratified and air gets pulled into the tank at night);
    - Single point in time measurements of flash gas;
- Variable oil accumulation (i.e., pre- and post-well cycle) in the separator-to-tank under-ground pipeline impacts the assumption that the volume of oil measured by the Coriolis meter during the well cycle (and adjusted for post-flash shrinkage) is the same volume that flowed to the tank;

- Temperature and pressure of the lab weathered pressurized condensate sample (relative to actual tank/flash conditions), and relative duration of condensate weathering;
  - Tank fluids could be slow to reach equilibrium.
- Tank liquids recent temperature history;
- Estimation of breathing losses; and
- Other factors.

IV.5.1 Summary of Key Notes and Observations Associated with the FGOR and Storage Tank Mass Balance Measurements

The following are some key notes and observations associated with the FGOR and storage tank mass balance measurements:

- Before the winter testing and before the summer testing the thief hatch, PRV, and other tank connections were checked for leaks.
- During the winter testing, the Fox thermal mass meters totalizers were updating at 15 cf increments, which was a large fraction of the total flow for some of the well cycles. Therefore, the instantaneous flowmeter measurements were integrated for the duration of the well cycle. The totalizer increment was adjusted to 1 cubic foot prior to the summer testing.
- Winter testing LP#3. The separator oil temperature dropped from 95.8 to 76.2°F during the well cycle. The separator gas temperature dropped also, and these temperature drops suggest the oil entering the separator was much colder than and different than the residual oil. Thus, the oil flowing to the tank and collected as a sample may not have been at equilibrium if for no other reason than incomplete mixing.
- The separator dump valve trim size was reduced between the winter testing (0.5" trim) and the summer testing (3/8" trim).
- The separator heater did not operator during the summer testing.
- A practice of emptying the oil box before well cycle and at the end of each well cycle was adopted such the volume of oil produced during the well cycle passed through the Coriolis meter.
- A compressor was operated during the low pressure tests and some mid-pressure tests to control the separator pressure. Starting up the compressor typically caused the separator

pressure to fluctuate for a few minutes, but there was no evidence that this impacted pressurized condensate results.

- API 11.1 was used to adjust measured oil volumes to standard temperature and pressure.
- After well cycle S-HP1 it was determined that the vane anemometer had a resistor installed for communication and that this resistor dampened the output. The resistor was removed and the vane anemometer measurements for this well cycle were discarded.

Table IV-1. Summer Testing Process Data, FGOR, and Mass Balance (MB) Results by Well Cycle: CP Cylinder Sample Collection and GPA 2103M Analysis

Summer Testing, CP Cylinder Samples, GPA 2103M Analysis

Well Cycle	P_{sep} (psig)	T_{sep} (°F)	$T_{tank\ HS}$ (°F)	$T_{tank\ bottom}$ (°F)	FGOR (scf/bbl)	Tank HC MB (FG/ΔL)[A]	FGOR at 100% MB (scf/bbl)[B]	Tank C1 MB (FG/ΔL)	Tank C2 MB (FG/ΔL)	Tank C3 MB (FG/ΔL)	Tank C4 MB (FG/ΔL)	Tank C5 MB (FG/ΔL)
	Average During Well Cycle				Measured Value (95% Level of Confidence)							
S-HP1	265	63	72	77	78 (+/- 9.0)	19% (+/- 3.6%)	410 (+/- 87)	14% (+/- 1.7%)	14% (+/- 1.7%)	17% (+/- 2%)	23% (+/- 2.3%)	77% (+/- 27%)
S-HP2	264	78	100	80	184 (+/- 8)	61% (+/- 12%)	300 (+/- 58)	32% (+/- 2.0%)	34% (+/- 1.7%)	43% (+/- 2.2%)	60% (+/- 3%)	190% (+/- 61%)
S-HP3	265	86	100	83	328 (+/- 74)	98% (+/- 28%)	330 (+/- 120)	69% (+/- 16%)	65% (+/-15%)	80% (+/- 18%)	110% (+/- 20%)	290% (+/- 87%)
S-MP1	229	66	75	78	172 (+/- 14)	58% (+/- 13%)	300 (+/- 70)	53% (+/- 5.0%)	41% (+/- 3.5%)	47% (+/- 4.1%)	67% (+/- 5.2%)	160% (+/- 47%)
S-MP2	228	70	89	79	256 (+/- 13)	83% (+/- 17%)	310 (+/- 70)	77% (+/- 5.2%)	57% (+/- 3.3%)	66% (+/- 3.8%)	91% (+/- 5.1%)	180% (+/- 37%)
S-MP3	234	84	90	80	327 (+/- 14)	105% (+/- 23%)	310 (+/- 64)	96% (+/- 6.0%)	74% (+/- 3.7%)	84% (+/- 4.2%)	120% (+/- 6.0%)	260% (+/- 62%)
S-MP4	229	62	71	75	156 (+/- 8.4)	47% (+/- 10%)	330 (+/- 68)	50% (+/- 3.4%)	36% (+/- 2.1%)	39% (+/- 2.2%)	55% (+/- 3.4%)	160% (+/- 55%)
S-MP5	231	72	87	76	228 (+/- 26)	71% (+/- 16%)	320 (+/- 80)	70% (+/- 8.4%)	51% (+/- 5.8%)	53% (+/- 6.1%)	71% (+/- 6.7%)	150% (+/- 34%)
S-LP1	178	67	72	75	149 (+/- 28)	49% (+/- 14%)	300 (+/- 100)	63% (+/- 12%)	43% (+/- 8.0%)	39% (+/- 7.4%)	49% (+/- 7.5%)	150% (+/- 53%)
S-LP2	175	70	89	76	193 (+/- 18)	71% (+/- 19%)	270 (+/- 77)	88% (+/- 9.1%)	59% (+/- 5.7%)	53% (+/- 5.2%)	64% (+/- 5.2%)	140% (+/- 33%)
S-LP3	178	80	96	78	277 (+/- 17)	121% (+/- 35%)	230 (+/- 67)	110% (+/- 7.8%)	84% (+/- 5.4%)	84% (+/- 5.6%)	110% (+/- 7.0%)	300% (+/- 96%)

A. FG/ΔL = mass of tank-to-burner gas flow measured during Well Cycle / change in mass of liquid during Well Cycle (= pre-flash - post-flash liquid mass)

B. FGOR at 100% MB = FGOR / Tank HC MB

Table IV-2. Summer Testing Process Data, FGOR, and Mass Balance (MB) Results by Well Cycle: CV Cylinder Sample Collection and GPA 2103M Analysis

Summer Testing, CV Cylinder Samples, GPA 2103M Analysis

Well Cycle	P_{sep} (psig)	T_{sep} (°F)	$T_{tank\ HS}$ (°F)	$T_{tank\ bottom}$ (°F)	FGOR (scf/bbl)	Tank HC MB (FG/ΔL)[A]	FGOR at 100% MB (scf/bbl)[B]	Tank C1 MB (FG/ΔL)	Tank C2 MB (FG/ΔL)	Tank C3 MB (FG/ΔL)	Tank C4 MB (FG/ΔL)	Tank C5 MB (FG/ΔL)
	Average During Well Cycle				Measured Value (95% Level of Confidence)							
S-HP1	265	63	72	77	78 (+/- 9.0)	18% (+/- 3.2%)	430 (+/- 90)	16% (+/- 2.0%)	16% (+/- 1.8%)	18% (+/- 2.1%)	27% (+/- 2.6%)	-4,000% (+/- 32,000%)
S-HP2	264	78	100	80	184 (+/- 8)	59% (+/- 11%)	310 (+/- 60)	47% (+/- 2.8%)	36% (+/- 1.7%)	42% (+/- 2.1%)	58% (+/- 2.9%)	140% (+/- 31%)
S-HP3	265	86	100	83	328 (+/- 74)	97% (+/- 27%)	340 (+/- 120)	84% (+/- 19%)	65% (+/-15%)	80% (+/- 18%)	110% (+/- 20%)	360% (+/- 120%)
S-MP1	229	66	75	78	172 (+/- 14)	58% (+/- 14%)	300 (+/- 80)	60% (+/- 5.6%)	41% (+/- 3.5%)	47% (+/- 4.1%)	68% (+/- 5.2%)	170% (+/- 50%)
S-MP2	228	70	89	79	256 (+/- 13)	83% (+/- 18%)	310 (+/- 60)	79% (+/- 5.3%)	57% (+/- 3.2%)	66% (+/- 3.8%)	92% (+/- 5.4%)	190% (+/- 43%)
S-MP3	234	84	90	80	327 (+/- 14)	105% (+/- 23%)	310 (+/- 60)	110% (+/- 6.7%)	75% (+/- 3.8%)	85% (+/- 4.2%)	120% (+/- 6.4%)	280% (+/- 72%)
S-MP4	229	62	71	75	156 (+/- 8.4)	44% (+/- 9.2%)	350 (+/- 70)	59% (+/- 4.1%)	39% (+/- 2.2%)	43% (+/- 2.6%)	67% (+/- 4.5%)	550% (+/- 600%)
S-MP5	231	72	87	76	228 (+/- 26)	74% (+/- 18%)	310 (+/- 80)	74% (+/- 8.9%)	52% (+/- 6.0%)	54% (+/- 6.2%)	73% (+/- 6.9%)	190% (+/- 50%)
S-LP1	178	67	72	75	149 (+/- 28)	49% (+/- 14%)	300 (+/- 100)	73% (+/- 14%)	44% (+/- 8.4%)	40% (+/- 7.7%)	51% (+/- 7.7%)	170% (+/- 73%)
S-LP2	175	70	89	76	193 (+/- 18)	70% (+/- 19%)	270 (+/- 70)	99% (+/- 10%)	60% (+/- 5.8%)	53% (+/- 5.2%)	61% (+/- 5.0%)	110% (+/- 21%)
S-LP3	179	80	96	78	277 (+/- 17)	123% (+/- 36%)	230 (+/- 60)	110% (+/- 8.2%)	85% (+/- 5.5%)	84% (+/- 5.5%)	110% (+/- 7.0%)	300% (+/- 96%)

A. FG/ΔL = mass of tank-to-burner gas flow measured during Well Cycle / change in mass of liquid during Well Cycle (= pre-flash - post-flash liquid mass)

B. FGOR at 100% MB = FGOR / Tank HC MB

Table IV-3. Summer Testing Process Data, FGOR, and Mass Balance (MB) Results by Well Cycle: CP Cylinder Sample Collection and GPA 2186M Analysis

Summer Testing, CP Cylinder Samples, GPA 2186M Analysis

Well Cycle	P_{sep} (psig)	T_{sep} (°F)	$T_{tank\ HS}$ (°F)	$T_{tank\ bottom}$ (°F)	FGOR (scf/bbl)	Tank HC MB (FG/ΔL)[A]	FGOR at 100% MB (scf/bbl)[B]	Tank C1 MB (FG/ΔL)	Tank C2 MB (FG/ΔL)	Tank C3 MB (FG/ΔL)	Tank C4 MB (FG/ΔL)	Tank C5 MB (FG/ΔL)
	Average During Well Cycle				Measured Value (95% Level of Confidence)							
S-HP1	265	63	72	77	78 (+/- 9.0)	21% (+/- 4.4%)	380 (+/- 90)	15% (+/- 1.8%)	15% (+/- 1.8%)	21% (+/- 2.1%)	23% (+/- 2.2%)	130% (+/- 85%)
S-HP2	264	78	100	80	184 (+/- 8)	66% (+/- 15%)	280 (+/- 60)	35% (+/- 2.2%)	35% (+/- 2.0%)	44% (+/- 2.3%)	60% (+/- 3.4%)	240% (+/- 110%)
S-HP3	265	86	100	83	328 (+/- 74)	107% (+/- 33%)	310 (+/- 120)	74% (+/- 17%)	68% (+/-15%)	82% (+/- 18%)	110% (+/- 20%)	350% (+/- 130%)
S-MP1	229	66	75	78	172 (+/- 14)	65% (+/- 18%)	270 (+/- 80)	54% (+/- 5.2%)	41% (+/- 3.8%)	47% (+/- 4.2%)	65% (+/- 5.4%)	180% (+/- 65%)
S-MP2	228	70	89	79	256 (+/- 13)	92% (+/- 25%)	280 (+/- 70)	79% (+/- 5.8%)	58% (+/- 3.8%)	67% (+/- 4.2%)	90% (+/- 5.8%)	210% (+/- 60%)
S-MP3	234	84	90	80	327 (+/- 14)	120% (+/- 31%)	280 (+/- 70)	94% (+/- 6.2%)	75% (+/- 4.5%)	87% (+/- 5.0%)	120% (+/- 7.0%)	300% (+/- 93%)
S-MP4	229	62	71	75	156 (+/- 8.4)	53% (+/- 14%)	290 (+/- 80)	54% (+/- 4.0%)	36% (+/- 2.5%)	40% (+/- 2.6%)	53% (+/- 3.8%)	170% (+/- 70%)
S-MP5	231	72	87	76	228 (+/- 26)	79% (+/- 23%)	290 (+/- 90)	73% (+/- 9%)	51% (+/- 6.0%)	53% (+/- 6.3%)	68% (+/- 6.8%)	170% (+/- 52%)
S-LP1	178	67	72	75	149 (+/- 28)	54% (+/- 17%)	280 (+/- 100)	65% (+/- 12%)	43% (+/- 9.3%)	40% (+/- 7.6%)	47% (+/- 7.2%)	210% (+/- 120%)
S-LP2	175	70	89	76	193 (+/- 18)	84% (+/- 29%)	230 (+/- 80)	86% (+/- 9%)	57% (+/- 5.8%)	52% (+/- 5.2%)	60% (+/- 5.2%)	240% (+/- 31%)
S-LP3	179	80	96	78	277 (+/- 17)	142% (+/- 52%)	200 (+/- 70)	110% (+/- 8.3%)	84% (+/- 6.2%)	86% (+/- 6.0%)	110% (+/- 7.6%)	390% (+/- 190%)

A. FG/ΔL = mass of tank-to-burner gas flow measured during Well Cycle / change in mass of liquid during Well Cycle (= pre-flash - post-flash liquid mass)

B. FGOR at 100% MB = FGOR / Tank HC MB

Table IV-4. Summer Testing Process Data, FGOR, and Mass Balance (MB) Results by Well Cycle: CV Cylinder Sample Collection and GPA 2186M Analysis

Summer Testing, CV Cylinder Samples, GPA 2186M Analysis

Well Cycle	P_{sep} (psig)	T_{sep} (°F)	$T_{tank\ HS}$ (°F)	$T_{tank\ bottom}$ (°F)	FGOR (scf/bbl)	Tank HC MB (FG/ΔL)[A]	FGOR at 100% MB (scf/bbl)[B]	Tank C1 MB (FG/ΔL)	Tank C2 MB (FG/ΔL)	Tank C3 MB (FG/ΔL)	Tank C4 MB (FG/ΔL)	Tank C5 MB (FG/ΔL)
	Average During Well Cycle				Measured Value (95% Level of Confidence)							
S-HP1	265	63	72	77	78 (+/- 9.0)	19% (+/- 3.9%)	400 (+/- 90)	17% (+/- 2.2%)	16% (+/- 2.0%)	19% (+/- 2.2%)	26% (+/- 2.6%)	-390% (+/- 750%)
S-HP2	264	78	100	80	184 (+/- 8)	66% (+/- 15%)	280 (+/- 60)	38% (+/- 2.5%)	34% (+/- 2.0%)	42% (+/- 2.2%)	58% (+/- 3.2%)	210% (+/- 81%)
S-HP3	265	86	100	83	328 (+/- 74)	101% (+/- 31%)	330 (+/- 120)	120% (+/- 28%)	74% (+/-17%)	83% (+/- 19%)	110% (+/- 20%)	290% (+/- 90%)
S-MP1	229	66	75	78	172 (+/- 14)	64% (+/- 18%)	270 (+/- 70)	63% (+/- 6.0%)	41% (+/- 3.8%)	47% (+/- 4.2%)	65% (+/- 5.4%)	170% (+/- 58%)
S-MP2	228	70	89	79	256 (+/- 13)	91% (+/- 24%)	280 (+/- 70)	86% (+/- 6.0%)	59% (+/- 4.0%)	67% (+/- 4.3%)	91% (+/- 5.8%)	210% (+/- 59%)
S-MP3	234	84	90	80	327 (+/- 14)	120% (+/- 31%)	280 (+/- 70)	120% (+/- 7.6%)	77% (+/- 4.6%)	86% (+/- 5.0%)	110% (+/- 7.0%)	310% (+/- 100%)
S-MP4	229	62	71	75	156 (+/- 8.4)	52% (+/- 14%)	300 (+/- 70)	58% (+/- 4.2%)	37% (+/- 2.6%)	41% (+/- 2.7%)	60% (+/- 4.5%)	270% (+/- 180%)
S-MP5	231	72	87	76	228 (+/- 26)	79% (+/- 23%)	290 (+/- 809)	74% (+/- 9.1%)	52% (+/- 6.2%)	54% (+/- 6.4%)	69% (+/- 6.8%)	180% (+/- 52%)
S-LP1	178	67	72	75	149 (+/- 28)	52% (+/- 16%)	290 (+/- 100)	78% (+/- 15%)	45% (+/- 8.6%)	41% (+/- 7.8%)	50% (+/- 7.7%)	250% (+/- 170%)
S-LP2	175	70	89	76	193 (+/- 18)	83% (+/- 28%)	230 (+/- 80)	99% (+/- 10%)	59% (+/- 6.1%)	52% (+/- 5.2%)	60% (+/- 5.2%)	110% (+/- 25%)
S-LP3	179	80	96	78	277 (+/- 17)	142% (+/- 52%)	200 (+/- 70)	110% (+/- 8.8%)	85% (+/- 6.2%)	84% (+/- 6.0%)	110% (+/- 7.6%)	340% (+/- 150%)

A. FG/ΔL = mass of tank-to-burner gas flow measured during Well Cycle / change in mass of liquid during Well Cycle (= pre-flash - post-flash liquid mass)

B. FGOR at 100% MB = FGOR / Tank HC MB

Table IV-5. Winter Testing Process Data, FGOR, and Mass Balance (MB) Results by Well Cycle: CP Cylinder Sample Collection and GPA 2103M Analysis

Winter 3-pressure Testing, CP Cylinder Samples, GPA 2103M Analysis

Well Cycle	P_{sep} (psig)	T_{sep} (°F)	$T_{tank\ HS}$ (°F)	$T_{tank\ bottom}$ (°F)	FGOR (scf/bbl)	Tank HC MB (FG/ΔL)[A]	FGOR at 100% MB (scf/bbl)[B]	Tank C1 MB (FG/ΔL)	Tank C2 MB (FG/ΔL)	Tank C3 MB (FG/ΔL)	Tank C4 MB (FG/ΔL)	Tank C5 MB (FG/ΔL)
	Average During Well Cycle				Measured Value (95% Level of Confidence)							
W-HP1	262	85	66	46	120 (+/- 61)	67% (+/- 46%)	180 (+/- 140)	40% (+/- 20%)	50% (+/- 25%)	48% (+/- 24%)	38% (+/- 14%)	73% (+/- 33%)
W-HP3	246	59	49	47	114 (+/- 70)	34% (+/- 22%)	330 (+/- 290)	39% (+/- 24%)	38% (+/- 23%)	35% (+/- 21%)	31% (+/- 14%)	-250% (+/- 350%)
W-HP4	263	58	70	45	174 (+/- 75)	47% (+/- 22%)	370 (+/- 230)	46% (+/- 20%)	46% (+/- 20%)	46% (+/- 20%)	33% (+/- 10%)	40% (+/- 13%)
W-MP1	235	81	57	45	115 (+/- 64)	39% (+/- 24%)	290 (+/- 240)	50% (+/- 28%)	41% (+/- 23%)	35% (+/- 19%)	26% (+/- 11%)	55% (+/- 27%)
W-MP2	227	92	74	44	140 (+/- 53)	77% (+/- 44%)	180 (+/- 120)	62% (+/- 22%)	57% (+/- 22%)	52% (+/- 20%)	33% (+/- 10%)	30% (+/- 8.6%)
W-MP3	229	85	57	46	169 (+/- 75)	72% (+/- 44%)	230 (+/- 160)	77% (+/- 34%)	75% (+/- 33%)	71% (+/- 31%)	55% (+/- 18%)	130% (+/- 69%)
W-LP1	178	87	85	45	122 (+/- 42)	83% (+/- 52%)	150 (+/- 100)	71% (+/- 25%)	65% (+/- 22%)	63% (+/- 22%)	51% (+/- 14%)	150% (+/- 88%)
W-LP2	179	90	79	46	167 (+/- 44)	91% (+/- 42%)	180 (+/- 100)	94% (+/- 25%)	94% (+/- 25%)	92% (+/- 25%)	70% (+/- 14%)	150% (+/- 62%)
W-LP3	180	85	60	47	61 (+/- 51)	33% (+/- 31%)	180 (+/- 230)	35% (+/- 30%)	35% (+/- 30%)	31% (+/- 26%)	24% (+/- 15%)	60% (+/- 46%)

A. FG/ΔL = mass of tank-to-burner gas flow measured during Well Cycle / change in mass of liquid during Well Cycle (= pre-flash - post-flash liquid mass)

B. FGOR at 100% MB = FGOR / Tank HC MB

Table IV-6. Winter Testing Process Data, FGOR, and Mass Balance (MB) Results by Well Cycle: CV Cylinder Sample Collection and GPA 2103M Analysis

Winter 3-pressure Testing, CV Cylinder Samples, GPA 2103M Analysis

Well Cycle	P_{sep} (psig)	T_{sep} (°F)	$T_{tank\ HS}$ (°F)	$T_{tank\ bottom}$ (°F)	FGOR (scf/bbl)	Tank HC MB (FG/ΔL)[A]	FGOR at 100% MB (scf/bbl)[B]	Tank C1 MB (FG/ΔL)	Tank C2 MB (FG/ΔL)	Tank C3 MB (FG/ΔL)	Tank C4 MB (FG/ΔL)	Tank C5 MB (FG/ΔL)
	Average During Well Cycle				Measured Value (95% Level of Confidence)							
W-HP1	262	85	66	46	120 (+/- 62)	66% (+/- 46%)	180 (+/- 150)	41% (+/- 21%)	50% (+/- 26%)	48% (+/- 25%)	37% (+/- 14%)	64% (+/- 28%)
W-HP3	246	59	49	47	114 (+/- 70)	33% (+/- 21%)	350 (+/- 310)	40% (+/- 24%)	39% (+/- 24%)	35% (+/- 22%)	32% (+/- 15%)	-99% (+/- 67%)
W-HP4	263	58	70	45	174 (+/- 75)	46% (+/- 22%)	380 (+/- 240)	46% (+/- 20%)	46% (+/- 20%)	46% (+/- 20%)	33% (+/- 11%)	40% (+/- 14%)
W-MP1	235	81	57	45	115 (+/- 65)	39% (+/- 25%)	290 (+/- 240)	50% (+/- 28%)	42% (+/- 24%)	35% (+/- 20%)	27% (+/- 11%)	55% (+/- 28%)
W-MP2	227	92	74	44	140 (+/- 54)							
W-MP3	229	85	57	46	169 (+/- 76)	71% (+/- 41%)	240 (+/- 160)	78% (+/- 35%)	76% (+/- 34%)	71% (+/- 32%)	57% (+/- 19%)	200% (+/- 140%)
W-LP1	178	87	85	45	122 (+/- 43)	82% (+/- 52%)	150 (+/- 100)	74% (+/- 26%)	66% (+/- 23%)	64% (+/- 22%)	52% (+/- 14%)	150% (+/- 91%)
W-LP2	179	90	79	46	167 (+/- 44)							
W-LP3	180	85	60	47	61 (+/- 52)	33% (+/- 32%)	180 (+/- 230)	37% (+/- 31%)	35% (+/- 30%)	31% (+/- 26%)	24% (+/- 15%)	64% (+/- 53%)

A. FG/ΔL = mass of tank-to-burner gas flow measured during Well Cycle / change in mass of liquid during Well Cycle (= pre-flash - post-flash liquid mass)

B. FGOR at 100% MB = FGOR / Tank HC MB

Table IV-7. Winter Testing Process Data, FGOR, and Mass Balance (MB) Results by Well Cycle: CP Cylinder Sample Collection and GPA 2186M Analysis

Winter 3-pressure Testing, CP Cylinder Samples, GPA 2186M Analysis

Well Cycle	P_{sep} (psig)	T_{sep} (°F)	$T_{tank\ HS}$ (°F)	$T_{tank\ bottom}$ (°F)	FGOR (scf/bbl)	Tank HC MB (FG/ΔL)[A]	FGOR at 100% MB (scf/bbl)[B]	Tank C1 MB (FG/ΔL)	Tank C2 MB (FG/ΔL)	Tank C3 MB (FG/ΔL)	Tank C4 MB (FG/ΔL)	Tank C5 MB (FG/ΔL)
	Average During Well Cycle				Measured Value (95% Level of Confidence)							
W-HP1	262	85	66	46	120 (+/- 62)	97% (+/- 870%)	120 (+/- 120)	40% (+/- 21%)	50% (+/- 26%)	48% (+/- 25%)	37% (+/- 14%)	86% (+/- 45%)
W-HP3	246	59	49	47	114 (+/- 71)	38% (+/- 26%)	300 (+/- 270)	38% (+/- 24%)	38% (+/- 24%)	35% (+/- 22%)	31% (+/- 14%)	-120% (+/- 100%)
W-HP4	263	58	70	45	174 (+/- 76)	49% (+/- 24%)	360 (+/- 230)	45% (+/- 20%)	47% (+/- 20%)	48% (+/- 20%)	35% (+/- 11%)	58% (+/- 22%)
W-MP1	235	81	57	45	115 (+/- 65)	44% (+/- 30%)	260 (+/- 220)	50% (+/- 28%)	42% (+/- 24%)	36% (+/- 20%)	27% (+/- 11%)	95% (+/- 68%)
W-MP2	227	92	74	44	140 (+/- 54)	100% (+/- 72%)	140 (+/- 100)	60% (+/- 23%)	57% (+/- 22%)	53% (+/- 21%)	33% (+/- 9%)	32% (+/- 10%)
W-MP3	229	85	57	46	169 (+/- 76)	90% (+/- 59%)	190 (+/- 140)	76% (+/- 34%)	75% (+/- 34%)	72% (+/- 32%)	54% (+/- 18%)	180% (+/- 130%)
W-LP1	178	87	85	45	122 (+/- 43)	110% (+/- 96%)	110 (+/- 110)	72% (+/- 25%)	65% (+/- 23%)	65% (+/- 23%)	51% (+/- 14%)	290% (+/- 350%)
W-LP2	179	90	79	46	167 (+/- 45)	125% (+/- 87%)	130 (+/- 130)	96% (+/- 26%)	94% (+/- 25%)	94% (+/- 25%)	69% (+/- 15%)	190% (+/- 120%)
W-LP3	180	85	60	47	61 (+/- 52)	41% (+/- 42%)	150 (+/- 190)	37% (+/- 31%)	35% (+/- 30%)	32% (+/- 27%)	24% (+/- 15%)	120% (+/- 160%)

A. FG/ΔL = mass of tank-to-burner gas flow measured during Well Cycle / change in mass of liquid during Well Cycle (= pre-flash - post-flash liquid mass)

B. FGOR at 100% MB = FGOR / Tank HC MB

Table IV-8. Winter Testing Process Data, FGOR, and Mass Balance (MB) Results by Well Cycle: CV Cylinder Sample Collection and GPA 2186M Analysis

Winter 3-pressure Testing, CV Cylinder Samples, GPA 2186M Analysis

Well Cycle	P_{sep} (psig)	T_{sep} (°F)	$T_{tank\ HS}$ (°F)	$T_{tank\ bottom}$ (°F)	FGOR (scf/bbl)	Tank HC MB (FG/ΔL)[A]	FGOR at 100% MB (scf/bbl)[B]	Tank C1 MB (FG/ΔL)	Tank C2 MB (FG/ΔL)	Tank C3 MB (FG/ΔL)	Tank C4 MB (FG/ΔL)	Tank C5 MB (FG/ΔL)
	Average During Well Cycle				Measured Value (95% Level of Confidence)							
W-HP1	262	85	66	46	120 (+/- 62)	94% (+/- 83%)	130 (+/- 130)	39% (+/- 20%)	50% (+/- 26%)	49% (+/- 26%)	38% (+/- 15%)	120% (+/- 67%)
W-HP3	246	59	49	47	114 (+/- 71)	37% (+/- 25%)	310 (+/- 280)	39% (+/- 24%)	39% (+/- 24%)	36% (+/- 22%)	33% (+/- 15%)	-54% (+/- 29%)
W-HP4	263	58	70	45	174 (+/- 75)	48% (+/- 24%)	360 (+/- 230)	46% (+/- 20%)	47% (+/- 20%)	48% (+/- 21%)	35% (+/- 11%)	59% (+/- 23%)
W-MP1	235	81	57	45	115 (+/- 65)	44% (+/- 30%)	260 (+/- 220)	49% (+/- 28%)	42% (+/- 24%)	36% (+/- 21%)	27% (+/- 11%)	120% (+/- 100%)
W-MP2	227	92	74	44	140 (+/- 53)							
W-MP3	229	85	57	46	169 (+/- 76)	89% (+/- 59%)	190 (+/- 140)	76% (+/- 34%)	76% (+/- 34%)	73% (+/- 33%)	55% (+/- 18%)	160% (+/- 110%)
W-LP1	178	87	85	45	122 (+/- 43)	110% (+/- 95%)	110 (+/- 110)	72% (+/- 25%)	66% (+/- 23%)	65% (+/- 23%)	52% (+/- 14%)	250% (+/- 260%)
W-LP2	179	90	79	46	167 (+/- 45)	120% (+/- 79%)	140 (+/- 100)	97% (+/- 26%)	96% (+/- 26%)	96% (+/- 26%)	72% (+/- 14%)	930% (+/- 1,300%)
W-LP3	180	85	60	47	61 (+/- 52)	40% (+/- 42%)	150 (+/- 190)	37% (+/- 31%)	35% (+/- 30%)	32% (+/- 27%)	24% (+/- 16%)	160% (+/- 250%)

A. FG/ΔL = mass of tank-to-burner gas flow measured during Well Cycle / change in mass of liquid during Well Cycle (= pre-flash - post-flash liquid mass)

B. FGOR at 100% MB = FGOR / Tank HC MB

IV.6 Overview of Sub-Appendices

Table IV.6-1 lists the spreadsheets with the process instrumentation data records and summary calculations for the winter and summer 3-pressure testing for the indicated well cycle. Summary calculations include well cycle averages and totals for measured process parameters (e.g., total flash gas generation volume, well cycle average separator temperature and pressure). Indicated adjustments to measured tank-to-burner gas flowrates are calculated. These spreadsheets are included in sub-Appendix IV.1.

The output from the spreadsheets listed in Table IV.6-1 and the analytical lab results were inputs to the spreadsheets listed in Table IV.6-2 which calculate well cycle storage tank mass balance and FGOR values, and associated uncertainties. These spreadsheets are included in sub-Appendix IV.2.

Flowrates measured by the Fox thermal mass flowmeters of gases with compositions that differ from the calibration gases were adjusted using a heat transfer model. This model is based on correlations for heat transfer from a heated cylinder in a gas cross flow, and considers the density, viscosity, thermal conductivity and Prandtl number of the gas. The spreadsheets listed in Table IV.6-3 perform these calculations in two steps. For example, the "Fox Flowmeter 21773_Fox 1_Summer pre-test Cal Data_060117_Rev 1" spreadsheet calculates a Reynolds number exponent "n" for the heat transfer model from calibration data provided by the manufacturer. The "Fox Meters Summer Tank Gas Composition Adjustment Factors_060117" spreadsheet then calculates a composition adjustment factor to adjust measured flowrates for each well cycle using the heat transfer model, the "n" exponent, and the relative compositions and properties of the well cycle process gas and the flow meter calibration gas.

Spreadsheets include either a "Read Me First" or "Instructions and Data Entry" worksheet that describes the spreadsheet function and lists and describes all the worksheets in the spreadsheet. The worksheets include documentation of the calculations.

Table IV.6-1. 3-Pressure Testing Process Instrumentation Data and Calculation Spreadsheets in Sub-Appendix IV.1

Well Cycle	Spreadsheet Name
Summer Three-Pressure Tests	
S-HP1	S-HP1 Process Data.xlsx
S-HP2	S-HP2 Process Data.xlsx
S-HP3	S-HP3 Process Data.xlsx
S-MP1	S-MP1 Process Data.xlsx
S-MP2	S-MP2 Process Data.xlsx
S-MP3	S-MP3 Process Data.xlsx
S-MP4	S-MP4 Process Data.xlsx
S-MP5	S-MP5 Process Data.xlsx
S-LP1	S-LP1 Process Data.xlsx
S-LP2	S-LP2 Process Data.xlsx
S-LP3	S-LP3 Process Data.xlsx
Winter Three-Pressure Tests	
W-HP1	W-HP1 Process Data.xlsx
W-HP3	W-HP3 Process Data.xlsx
W-HP4	W-HP4 Process Data.xlsx
W-MP1	W-MP1 Process Data.xlsx
W-MP2	W-MP2 Process Data.xlsx
W-MP3	W-MP3 Process Data.xlsx
W-LP1	W-LP1 Process Data.xlsx
W-LP2	W-LP2 Process Data.xlsx
W-LP3	W-LP3 Process Data.xlsx

Table IV.6-2. 3-Pressure Testing Storage Tank Mass Balance and FOGR Calculation Spreadsheets in Sub-Appendix IV.2

Well Cycle	Spreadsheet Name
Summer Three-Pressure Tests	
S-HP1	S-HP1 MB_FGOR Uncertainty_2103.xlsx
S-HP1	S-HP1 MB_FGOR Uncertainty_2186.xlsx
S-HP2	S-HP2 MB_FGOR Uncertainty_2103.xlsx
S-HP2	S-HP2 MB_FGOR Uncertainty_2186.xlsx
S-HP3	S-HP3 MB_FGOR Uncertainty_2103.xlsx
S-HP3	S-HP3 MB_FGOR Uncertainty_2186.xlsx
S-MP1	S-MP1 MB_FGOR Uncertainty_2103.xlsx
S-MP1	S-MP1 MB_FGOR Uncertainty_2186.xlsx
S-MP2	S-MP2 MB_FGOR Uncertainty_2103.xlsx
S-MP2	S-MP2 MB_FGOR Uncertainty_2186.xlsx
S-MP3	S-MP3 MB_FGOR Uncertainty_2103.xlsx
S-MP3	S-MP3 MB_FGOR Uncertainty_2186.xlsx
S-MP4	S-MP4 MB_FGOR Uncertainty_2103.xlsx
S-MP4	S-MP4 MB_FGOR Uncertainty_2186.xlsx
S-MP5	S-MP5 MB_FGOR Uncertainty_2103.xlsx
S-MP5	S-MP5 MB_FGOR Uncertainty_2186.xlsx
S-LP1	S-LP1 MB_FGOR Uncertainty_2103.xlsx
S-LP1	S-LP1 MB_FGOR Uncertainty_2186.xlsx
S-LP2	S-LP2 MB_FGOR Uncertainty_2103.xlsx
S-LP2	S-LP2 MB_FGOR Uncertainty_2186.xlsx
S-LP3	S-LP3 MB_FGOR Uncertainty_2103.xlsx
S-LP3	S-LP3 MB_FGOR Uncertainty_2186.xlsx
Winter Three-Pressure Tests	
W-HP1	W-HP1 MB_FGOR Uncertainty_2103.xlsx
W-HP1	W-HP1 MB_FGOR Uncertainty_2186.xlsx
W-HP3	W-HP3 MB_FGOR Uncertainty_2103.xlsx
W-HP3	W-HP3 MB_FGOR Uncertainty_2186.xlsx
W-HP4	W-HP4 MB_FGOR Uncertainty_2103.xlsx
W-HP4	W-HP4 MB_FGOR Uncertainty_2186.xlsx
W-MP1	W-MP1 MB_FGOR Uncertainty_2103.xlsx
W-MP1	W-MP1 MB_FGOR Uncertainty_2186.xlsx
W-MP2	W-MP2 MB_FGOR Uncertainty_2103.xlsx
W-MP2	W-MP2 MB_FGOR Uncertainty_2186.xlsx
W-MP3	W-MP3 MB_FGOR Uncertainty_2103.xlsx

Well Cycle	Spreadsheet Name
W-MP3	W-MP3 MB_FGOR Uncertainty_2186.xlsx
W-LP1	W-LP1 MB_FGOR Uncertainty_2103.xlsx
W-LP1	W-LP1 MB_FGOR Uncertainty_2186.xlsx
W-LP2	W-LP2 MB_FGOR Uncertainty_2103.xlsx
W-LP2	W-LP2 MB_FGOR Uncertainty_2186.xlsx
W-LP3	W-LP3 MB_FGOR Uncertainty_2103.xlsx
W-LP3	W-LP3 MB_FGOR Uncertainty_2186.xlsx

Table IV.6-3. Fox Thermal Mass Gas Flowmeters Composition Adjustment Spreadsheets in Sub-Appendix IV.3

Well Cycle	Spreadsheet Name
Summer Three-Pressure Tests	
All	Fox Flowmeter 21773_Fox 1_Summer pre-test Cal Data.xlsx
All	Fox Flowmeter 21776_Fox 2_Summer pre-test Cal Data.xlsx
All	Fox Meters Summer Tank Gas Composition Adjustment Factors.xlsx
Winter Three-Pressure Tests	
All	Fox Flowmeter 21773_Fox 1_Winter pre-test Cal Data.xlsx
All	Fox Flowmeter 21776_Fox 2_Winter pre-test Cal Data.xlsx
All	Fox Meters Winter Tank Gas Composition Adjustment Factors.xlsx