Pressurized Hydrocarbon Liquids Study Calibration Report

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Nomenclature / Glossary

a(y)	Limit of the range of uncertainty due to random errors about a single measurement y
b(y)	Limit of the range of uncertainty due to systematic errors about a single measurement y
c(y)	Limit of the range of uncertainty due to combined random and systematic errors about a single parameters y
e	Estimate of systematic error
n	Number of repeated measurements.
t	Value of Student's t-distribution
$t_{95,\ n-1}$	The value of the t-distribution for (n-1) degrees of freedom and for a two-sided probability of 95 percent
v	Variance, σ^2
w	Range of a set of data
$\bar{x}$	Observed mean value of a set of data
x	Observed value of a variable
$\bar{y}$	Observed mean value corrected for bias
y	Observed value of a variable corrected for bias
μ	Mean of Gaussian normal distribution
σ	Standard deviation of a Gaussian normal distribution
Φ	Degrees of freedom
BFSL	Best fit straight line
CM	Coriolis meter
DC	Direct current
FSO	Full scale output
PIT	Pressure indicating transducer
PRV	Pressure relief valve

RTD	Resistance temperature detectors
V	Volts
VDC	Volts (direct current)
VOC	Volatile organic carbons

BF	Buoyancy factor
BLM	Bureau of Land Management
BPV	Base prover volume
BVC	Buoyancy vapor correction
CPL	Correction for the effect of pressure on liquid
CPL_m	Correction factor for the effect of pressure on a liquid passing through a meter (during a proof)
CPL_{MM}	Pressure correction factor of the master meter
CPL_{MUT}	Pressure correction factor of the meter under test
CPL_p	Correction factor for the effect of pressure on a liquid in a prover
CPS_p	Correction factor for the effect of pressure on steel on a liquid in a prover
CTL	Correction for the effect of temperature on liquid
CTL_m	Correction factor for the effect of temperature on a liquid passing through a meter (during a proof)
CTL_{MM}	Temperature correction factor of the master meter
CTL_{MUT}	Temperature correction factor of the meter under test
CTL_p	Correction factor for the effect of temperature on a liquid in a prover
CTS_p	Correction factor for the effect of temperature on steel on a liquid in a prover
DG	Coriolis drive gain
DMF	Density meter factor
DSF	Dynamic start/finish
GVF	Gas void fraction
IPC	Immersed pipe correction

ISV_{MM}	Indicated standard volume of the master meter	
ISV_{MUT}	Indicated standard volume of the meter under test	
IV_{MM}	Indicated volume of the master meter	
IV_{MUT}	Indicated volume of the meter under test	
MF_{DG}	Meter factor adjusted for high drive gain	
MF_{MM}	Meter factor of the master meter	
MF_{P}	Meter factor due to proving	
MM	Master meter	
MUT	Meter under test	
NIST	National Institute of Standards and Technology	
NKF	Nominal K-factor	
RM	Reference meter	
SSF	Static start/finish	
SVP	Small volume piston	
TSM	Transfer standard method	
UUT	Unit under test	
V_{60}	Volume at base conditions	
VCF	Volume correction factor	
$V_{t,P}$	Volume at alternate conditions	
ρ_{gas}	Density of the gas	(kg/m^3)
ρ_{liquid}	Density of the "bubble-free", standard density (via API 11.1)	(kg/m^3)
ρ_{mix}	Density of the two-phase flow	(kg/m^3)
CAL-V	Calibration validation (in-situ calibration)	
C_p	Gas heat capacity at constant pressure	($J/g*^0C$)
CSV	Current sense voltage	
DUT	Device under test	

FT3	Fox thermal meter model 3	
I	current supplied to the heated element	(Ampere)
k_{act}	Gas thermal conductivity of the actual gas composition	(W/m/K)
k_{cal}	Gas thermal conductivity of the calibrated gas composition	(W/m/K)
M	Mass flow rate	(g/s)
MSCFD	Thousands of standard cubic feet per day	
n	Constant	(unitless)
Pr_{act}	Prandtl number of the actual gas composition	(unitless)
Pr_{cal}	Prandtl number of the calibrated gas composition	(unitless)
v_{act}	Gas velocity of the actual gas composition	(m/s)
v_{cal}	Gas velocity of the calibrated gas composition	(m/s)
R_1	The electrical resistance of the heated RTD element	(ohms)
μ_{act}	Gas dynamic viscosity of the actual gas composition	(Pa*s)
μ_{cal}	Gas dynamic viscosity of the calibrated gas composition	(Pa*s)
ΔT	Temperature difference between the heated and reference RTDs	(^{0}C)
A_{75mm}	Cross sectional area of a pipe with diameter of 75mm	(m^2)
$A_{77.93mm}$	Cross sectional area of the in-situ pipe	(m^2)
PF_{75mm}	Position factor based on a pipe diameter of 75mm ($v_{average}$ / v_{local} = 0.796)	(-)
$PF_{77.93mm}$	Position factor based on a pipe diameter of 75mm ($v_{average}$ / v_{local} = 0.802)	(-)
Q_{actual}	Actual gas flowrate through the pipeline	(m^3/h)
$Q_{measured}$	Measured flow rate	(m^3/h)
QMS	Quality Management Systems	
r	Distance of each cup from the rotational axis	(m)
U	Velocity of the measured gas	(m/s)
v	Gas correction value due to compositional change	(m/s)
$v_{0,real}$	Actual smallest starting value	(m/s)

$v_{0,spec}$	Specified smallest starting value	(m/s)
v_{actual}	Actual local velocity	(m/s)
v_{cal}	Gas velocity measured by the vane anemometer during the calibration	(m/s)
$v_{measured}$	Local velocity measured by the vane anemometer	(m/s)
v_{ref}	Reference gas velocity from the vane anemometer calibration	(m/s)
ρ_{real}	Actual gas density	(kg/m^3)
ω	Rotational speed of the vane wheel	(rad/s)
Q_v	Standard volume flow rate	(sft^3/hr)
C_d	Orifice plate discharge coefficient	(-)
E_v	Velocity approach factor	(-)
Y_1	Upstream gas expansion factor	(-)
d	is the orifice bore diameter	(in)
G_r	Real gas relative density	(-)
Z_s	Compressibility factor of gas at standard conditions	(-)
Z_{f1}	Compressibility factor of the upstream gas at flowing conditions	(-)
PCCU	Portable configuration and calibration unit (software)	
P_{f1}	Upstream pressure	(psia)
T_f	Absolute temperature of gas at flowing conditions	(degree Rankine)
h_w	Differential pressure	(inches of water at 60^{o}F)
β	Ratio of the orifice bore diameter to the pipe diameter	(-)
κ	Isentropic exponent of the gas = C_p/C_v	(-)
MW_{gas}	Molecular weight of the measured gas	(lb/lb-mol)
MW_{air}	Molecular weight of air	(lb/lb-mol)
$Z_{b,air}$	Compressibility factor of air at 14.73 psia and 60^{o}F	(-)
$Z_{b,gas}$	Compressibility factor of the measured gas at 14.73 psia and 60^{o}F	(-)
DLS	Digital liquid sensor	

EEPROM	Electrically erasable programmable read-only memory	
EFM	Electronic flow measurement	
PLC	Programmable logic controller	
RTU	Remote terminal unit	
ADC	Analog-to-digital converter	
High_ADC	ADC reading at the top of the range (used during calibration of PITs and RTDs)	
Low	Calculated pressure at the bottom of the range (used during calibration of PITs and RTDs)	
Low_ADC RTDs)	ADC reading at the bottom of the range (used during calibration of PITs and	
Range	Total range of the analog device (used during calibration of PITs and RTDs)	
Raw_ADC	Current reading of the ADC (used during calibration of PITs and RTDs)	
TTL	Transistor-to-transistor logic	
Modbus	Method used to for transmitting information over serial lines between electronic devices	
R	Electrical resistance	(ohms)
ρ	Resistivity of the resistor material	(ohms*m)
l	Length of the pressure sensor	(m)
A	Cross sectional area of the pressure sensor	(m^2)
A	Constant (Callendar-Van Dusen equation)	(-)
B	Constant (Callendar-Van Dusen equation)	(-)
C	Constant (Callendar-Van Dusen equation)	(-)
CVD	Callendar-Van Dusen	
I_{EX}	Known current passed through the RTD	(ampere)
R_0	Resistance of the RTD at 0^{o}C	(ohms)
R_{100}	Resistance of the RTD at 100^{o}C	(ohms)
R_T	Resistance of the RTD at temperature “T”	(ohms)

T	Recording temperature	(^oC)
V_0	Measured RTD voltage	(VDC)
α	Temperature coefficient	(-)
β	Constant	(-)
δ	Constant	(-)

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1.0 Introduction

1.1 Purpose

The purpose of the pressurized hydrocarbon (HC) liquids sampling and analysis (PHLSA) study is described in paragraph 37 of the Consent Decree:

"The purpose of the study is to isolate individual variables of the sampling and analytical methods typically used to obtain information regarding the flash potential and makeup of pressurized hydrocarbon liquids and to identify protocols for determining how these samples can be reliably obtained, handled, and analyzed to produce accurate analytical results for practical application in modeling flashing losses."

Based on this purpose, an accurate analytical results used for practical application in modeling flashing losses is of great interest. In other words, a true characterization of all of the independent variables required to estimate flashing losses is needed to achieve the specified purpose. To do so, the Bernhardt test site was instrumented with over 30 measurement devices that encapsulate what is believed to provide an accurate representation of the pertinent process as a function of space and time.

1.2 Organization

This report depicts several chapters and sections:

Chapter 2: provides background information on statistical terms and nomenclature that will be used throughout this report. Calculation of the relevant statistical parameters will be demonstrated.

Chapter 3: provides a detailed outlook of the majority of instrumentations used in the test site. Each section will depict a different measurement device or sensor.

Chapter 4: provides a detailed description of the pressure transducers used in the test site. Each section will depict a different measurement device.

Chapter 5: provides a detailed description of the resistance temperature detectors used in the test site. Each section will depict a different measurement device.

References: a bibliographic list of sources used in this report.

Appendices: supporting documentation relating to chapters 2 through 5 will be shown.

2.0 Background

2.1 Statistical terms and nomenclature

This report will use the statistical terms defined by the third edition (2008) of the "International vocabulary of metrology – Basic and general concepts and associated terms (VIM)" [1].

2.1.1 Quantities and units

Quantity:	Property of a phenomenon, body, or substance, where the property has a magnitude that can be expressed as a number and a reference.
Kind:	Aspect common to mutually comparable quantities.
Quantity value:	Number and reference together expressing magnitude of a quantity

2.1.2 Measurement

Measurement:	Process of experimentally obtaining one of more quantity values that can reasonably be attributed to a quantity.
Metrology:	Science of measurement and its application.
Measurand:	Quantity intended to be measured.
Measurement result:	Set of quantity values being attributed to a measurand together with any other available relevant information.
Measurement quantity value:	Quantity value representing a measurement result.
Measurement accuracy:	Closeness of agreement between indications of measured quantity values obtained by replicate measurements on the same or similar objects under specified conditions.
Measurement trueness:	Closeness of agreement between the average of an infinite number of replicate measured quantity values and a reference quantity value.
Measurement precision:	Closeness of agreement between indications of measured quantity values obtained by replicate measurements on the same or similar objects under specified conditions.
Measurement error:	Measured quantity value minus a reference value.

Systematic measurement error:	Component of measurement error that in replicate measurements remains constant or varies in a predictable manner.
Measurement bias:	Estimate of a systematic measurement error.
Random measurement error:	Component of measurement error that in replicate measurements varies in an unpredictable manner.
Measurement uncertainty (MU):	Non-negative parameter characterizing the dispersion of the quantity values being attributed to a measurand, based on the information used.
Standard MU:	Measurement uncertainty expressed as a standard deviation.
Combined standard MU:	Standard measurement uncertainty that is obtained using the individual standard measurement uncertainties associated with the input quantities in a measurement model.
Input quantity:	Quantity that must be measured, or a quantity, that value of which can be otherwise obtained, in order to calculate a measured quantity value of a measurand.
Output quantity:	Quantity, the measured value of which is calculated using the values of input quantities.

2.1.3 Devices for measurement

Measuring instrument:	Device used for making measurements, alone or in conjunction with one of more supplementary devices.
Measuring system:	Set of one or more measuring instruments and often other devices, including any reagent and supply, assembled and adapted to give information used to generate measured quantity values within specified intervals for quantities of specified kinds.
Reference quantity value:	Quantity value used a basis for comparison with values of quantities of the same kind.
Measuring transducer:	Device, used in measurement, that provides an output quantity having a specified relation to the input quantity.

Sensor:	Element of a measuring system that is directly affected by a phenomenon, body, or substance carrying a quantity to be measured.
Detector:	Device or substance that indicates the presence of a phenomenon, body, or substance when a threshold value of an associated quantity is exceeded.

2.1.4 Properties of measuring devices

Indication:	Quantity value provided by a measuring instrument or a measuring system.
Instrumental bias:	Average of replicate indications minus a reference quantity value.
Instrumental drift:	Continuous or incremental change over time in indication, due to changes in metrological properties of a measuring instrument.
Calibration diagram:	Graphical expression of the relation of indication and corresponding measurement result.
Calibration curve:	Expression of the relation between indication and corresponding measured quantity value

2.2 Calculation of statistical parameters

The following calculations and statistical definitions are obtained from API Chapter 13.1 – "Statistical Aspects of Measuring and Sampling" [2].

Standard deviation of a Gaussian distribution:

$$\sigma(y) = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(y_i - \overline{y}_i\right)^2} \qquad (2\text{-}1)$$

Variance:

$$V(y) = \sigma^2(y) \qquad (2\text{-}2)$$

Uncertainty due to random error:

$$a(y) = \left(t_{95,n-1}\right) * \sigma(y) \qquad (2\text{-}3)$$

Uncertainty due to systematic error:

$$b(y) = 0.95\left|\frac{(e_1 - e_2)}{2}\right| \tag{2-4}$$

Combined uncertainty due to (2-3) and (2-4):

$$c(\overline{y}) = \sqrt{a^2(\overline{y}) + b^2(\overline{y})} \tag{2-5}$$

The equations listed above may not encapsulate all the statistical parameters necessary for the calculation of uncertainty for each of the meters to be discussed in the next chapter. Hence, in the case of an uncertainty calculation different than that listed in this sub-section, it will be shown under each meter, individually.

3.0 Summary of Instrument Measurement Uncertainty Estimates

3.1 <u>Summary of Bernhardt Site Instruments</u>

The test site includes over 30 instrumentation installed on different process units (e.g. separator, tank, VOC burner etc.) and piping. All instruments transmit to an automation stand / data-logger via Wi-Fi, and are downloaded manually in a csv file. Throughout the study there have been three different instrument configurations: (1) winter; (2) summer and (3) post-summer, as shown below.

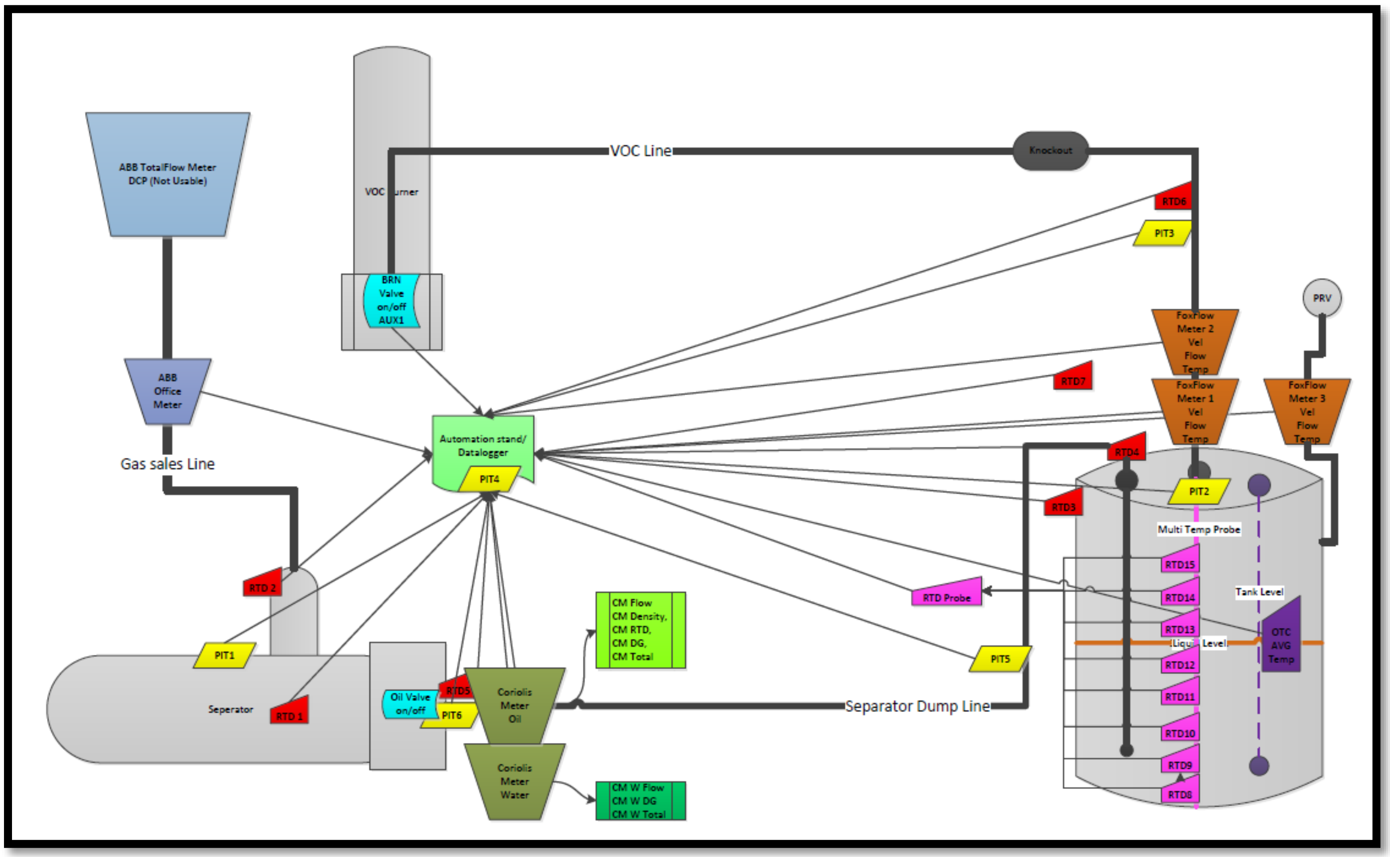

Figure 3-1. Instrumentation map of the test site as of the winter sampling week

Following the winter-phase testing, it was suggested that the addition of several more instrumentations would improve the understanding of both the separator and the tank. Thus, additional pressure transducer and thermocouple were added downstream of the Coriolis meters (PIT7 and RTD 16, respectively). Also, since the reading of PIT5 may have been underestimated (due to the fact that its range was well below the actual pressure measured), it was decided to add a new 0-100 psig pressure transmitter (PIT8). Additionally, a sun radiation meter was added to correlate breathing loss with the sun's radiation. Finally, and perhaps most importantly, the vane anemometer has been added to the tank-to-burner pipe to set as another flowrate verification for the flash gas.

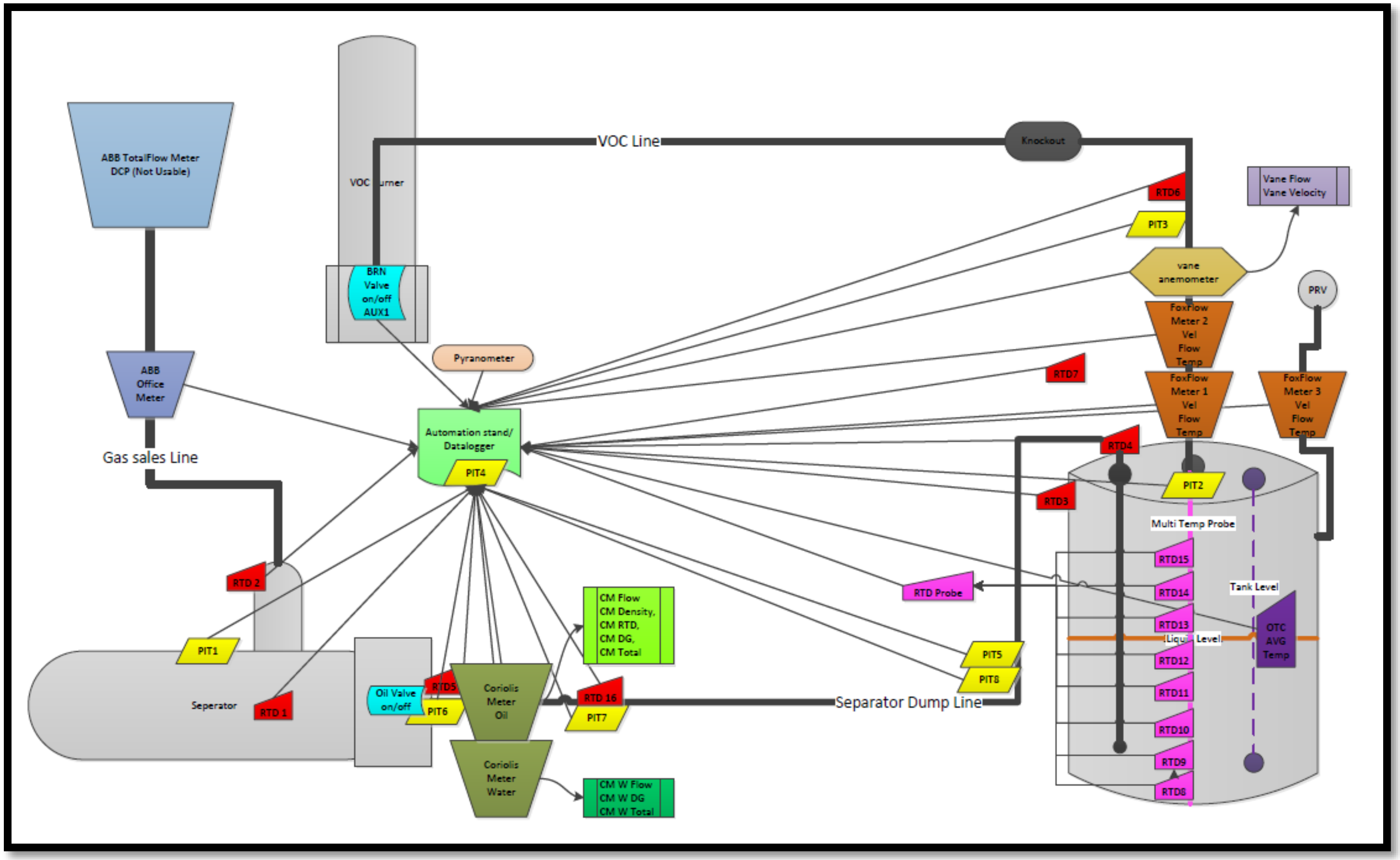

Figure 3-2. Instrumentation map of the test site as of the summer sampling week

At the conclusion of the summer phase testing it was discovered that a hole exists in the so-called ‘down-comer’ (last segment of the separator-to-tank pipe) whose target is to avoid of a case of a separator overflow during upset conditions (since a negative pressure is applied and consequently oil flows from the tank back to the separator). In order to estimate the two-phase flow outside of the small orifice, the closet pressure reading was at the top of the pipe prior to entering the tank. Therefore, RTD4 was placed by PIT9 and a series of post-summer experiments were conducted in mid-August to help determining the oil fraction leaving through the small orifice.

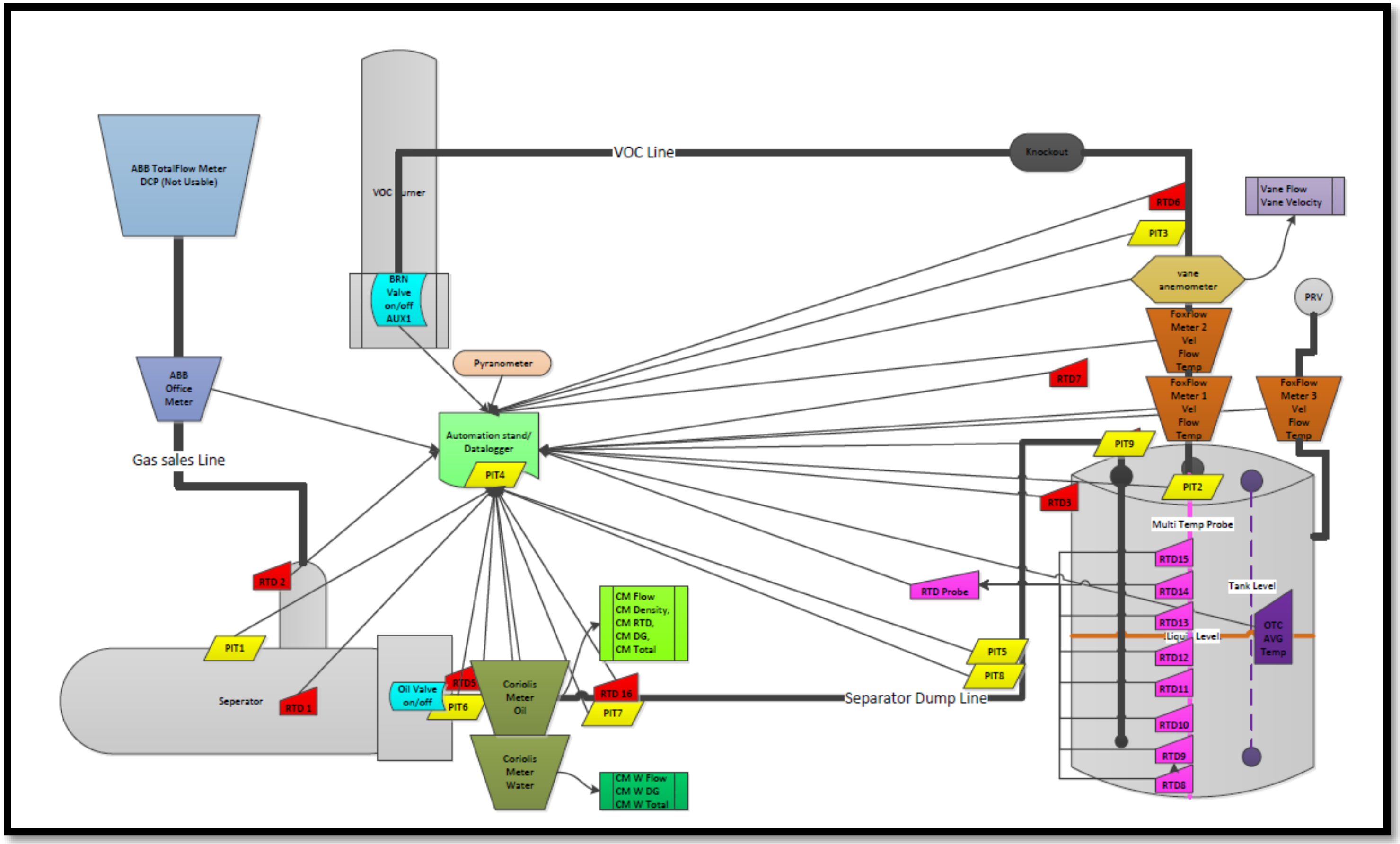

Figure 3-3. Instrumentation map of the test site as of the post-summer sampling week

The following tables summarize the instrumentation by process unit and shows all meters includes the measured parameter, engineering units, range and accuracy.

Table 3-1: Pressure Transducer on the High-Pressure Separator

Parameter	Data logger ID	Location	Instrument	Range	Accuracy	Data Collection Frequency
Separator Pressure	PIT 1	Separator headspace	Pressure transducer	0–500 psig	± 2% of measured value	1 second
Separator Dump Pressure	PIT 6	Upstream of Coriolis meter	Pressure transducer	0–500 psig	± 2% of measured value	1 second
Separator-to-oil tank pipe gas / liquids pressure Post dump valve	PIT 7	Downstream of dump valve	Pressure transmitter	0–100 psig	± 0.25% of measured value at FSO at 75ºF	1 second

Table 3-2: RTDs on the High-Pressure Separator

Parameter	Data logger ID	Location	Instrument	Range	Accuracy	Data Collection Frequency
Separator Oil Temperature	RTD 1	Separator oil layer	RTD	0–200ºF	± 2ºF	1 second
Separator Gas Temperature	RTD2	Separator gas headspace	RTD	0–200ºF	± 2ºF	1 second
Separator Dump Temperature	RTD5	Upstream of Coriolis meter	RTD	0–200ºF	± 2ºF	1 second
Separator Dump leg	RTD16	Downstream of dump valve	RTD	0–200ºF	± 2ºF	1 second

Table 3-3: Flow Rate Measurement (including Coriolis meter) on the High-Pressure Separator

Parameter	Data logger ID	Location	Instrument	Range	Accuracy	Data Collection Frequency
Separator produced gas flowrate	ABB Flow	Separator gas leg	XFC G4 6413Y	0–250 MSCFD DP[a] 0–500 MSCFD SP[b]	0.05%	1 second
Separator oil flowrate to tank [R100-series]	CM Flow	Upstream of oil dump valve	Coriolis meter	0–6576 Std. bbl/d	± 0.5% of rate	1 second
Separator oil to tank density	CM Density	Upstream of oil dump valve	Coriolis meter	0–3.0 SGU	± 10 kg/m^3	1 second
Separator oil to tank temperature	CM RTD	Upstream of oil dump valve	Coriolis meter	(-)40–140 ºF	± 1 ºC ± 0.5% of reading	1 second
Coriolis meter drive gain	CM DG	Upstream of oil dump valve	Coriolis meter	0–100%	N/A[c]	1 second
Separator water flowrate to tank [F100-series]	CM W Flow	Upstream of water dump valve	Coriolis meter	0–6576 Std. bbl/d	± 0.28% of rate	1 second
Coriolis meter Water drive gain	CM DG	Upstream of water dump valve	Coriolis meter	0–100%	N/A[c]	1 second

[a] Differential pressure (pressure difference through the orifice plate.

[b] Static pressure (total pressure in the line).

[c] The drive gain is not typically used as a process measurement parameter, more of a diagnostic to determine what is going on in the process.

Table 3-4: Instruments on the Separator-to-Tank Pipe Segment and Tank Headspace

Parameter	Data logger ID	Location	Instrument	Range	Accuracy	Data Collection Frequency
Separator-to-oil tank pipe gas/liquids pressure Lo	PIT 5	Where the sep-to-oil tank pipeline comes to the surface, base of upcomer	Pressure transducer	0–1.5 psig	± 2% of measured value	1 second
Separator-to-oil tank pipe gas/liquids pressure Hi	PIT 8	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 FSO at 75ºF	1 second
Top of riser pressure	PIT 9[d]	Just prior to entering the tank on the horizontal section	Pressure transducer	0–100 psig	± 2% of measured value	1 second
Oil tank headspace gas pressure	PIT 2	Bulk tank headspace pressure (gauge)	Pressure transducer	0–1.5 psig	± 2% of measured value	1 second
Oil tank headspace gas temperature	RTD3	In tank, at top of tank, centerline	Thermocouple	(-)25–175 ºF	± 2 ºF	1 second
Separator-to-oil tank pipe gas/liquids temperature	RTD 4[c]	Just prior to entering the tank on the horizontal section	Thermocouple	0–250 ºF	± 2 ºF	1 second

[d] On 08/10/2016, PIT 9 was replaced by RTD 4 to obtain more information regarding the dump pressure near the tank.

Table 3-5: RTDs on the Tank

Parameter	Data logger ID	Location	Instrument	Range	Accuracy	Data Collection Frequency
Oil tank gas/liquids temperature	RTD 8	In tank, cernterline, 14” above tank bottom	RTD	(-)40–185 ºF	± 1.5 ºF	1 second
Oil tank gas/liquids temperature	RTD 9	In tank, cernterline, 32” above tank bottom	RTD	(-)40–185 ºF	± 1.5 ºF	1 second
Oil tank gas/liquids temperature	RTD 10	In tank, cernterline, 52” above tank bottom	RTD	(-)40–185 ºF	± 1.5 ºF	1 second
Oil tank gas/liquids temperature	RTD 11	In tank, cernterline, 72” above tank bottom	RTD	(-)40–185 ºF	± 1.5 ºF	1 second
Oil tank gas/liquids temperature	RTD 12	In tank, cernterline, 92” above tank bottom	RTD	(-)40–185 ºF	± 1.5 ºF	1 second
Oil tank gas/liquids temperature	RTD 13	In tank, cernterline, 112” above tank bottom	RTD	(-)40–185 ºF	± 1.5 ºF	1 second
Oil tank gas/liquids temperature	RTD 14	In tank, cernterline, 135” above tank bottom	RTD	(-)40–185 ºF	± 1.5 ºF	1 second
Oil tank gas/liquids temperature	RTD 15	In tank, cernterline, 152” above tank bottom	RTD	(-)40–185 ºF	± 1.5 ºF	1 second

Table 3-6: Temperature and Pressure Monitors on the Tank-to-Burner Pipe Segment

Parameter	Data logger ID	Location	Instrument	Range	Accuracy	Data Collection Frequency
Oil tank VOC burner line gas temperature	RTD 6	In tank VOC burner line downcomer upstream of flowmeters	RTD	(-)30–150 ºF	± 2 ºF	1 second
Oil tank VOC burner line gas pressure	PIT 3	In tank VOC burner line downcomer upstream of flowmeters	Pressure transducer	0–1.5 psig	± 2% of measure d value	1 second

Table 3-7: Flow Rate Measurement on the Tank-to-Burner Pipe Segment

Parameter	Data logger ID	Location	Instrument	Range	Accuracy	Data Collection Frequency
Oil tank VOC burner line gas flowrate	Fox1 Flow	In tank VOC burner line downcomer upsteam of knockout pot	Thermal flowmeter	0–500 MSCFD Two[e] curves	1% Reading + 0.2 % Full Scale	1 second
Oil tank VOC burner line gas flowrate	Fox2 Flow	In tank VOC burner line downcomer upsteam of knockout pot	Thermal flowmeter	0–500 MSCFD Three[f] curves	1% Reading + 0.2 % Full Scale	1 second
Oil tank PRV vent gas flowrate	Fox3 Flow	In tank PRV vent line upstream of the PRV	Thermal flowmeter	0–500 MSCFD Two[d] curves	1% Reading + 0.2 % Full Scale	1 second
Oil tank VOC burner line gas flowrate	Vane anemo-meter	In tank VOC burner line downcomer upsteam of knockout	Vane anemo-meter	0–253.2 actual m^3/hr	< 1.5%	1 second

[e] Calibration was performed using gas compositions at two temperatures (40^{o}F and 90^{o}F)

[f] Calibration was performed using gas compositions at three temperatures (40^{o}F, 65^{o}F and 90^{o}F)

Table 3-8: Miscellaneous Instruments

Parameter	Data logger ID	Location	Instrument	Range	Accuracy	Data Collection Frequency
Solar Radiation meter	Solar_Rad	7 m south of storage tanks	SR05 pyranometer	0–1600 W/m^2		1 second
Oil tank liquid level	LL1	Oil tank liquid surface	Tank level sensor	0–180 inch	± 0.125 inch	1 second
Ambient pressure	PIT 4	In tank VOC burner line downcomer upstream of flowmeters	Pressure transducer	0–1.5 psig	± 2% of measure d value	1 second
Oil dump valve on/off position & dump time/ duration	O_ Dump _Po	Oil dump valve	Valve position indicator	0–3[g]	N/A	1 second
VOC valve on/off position & dump time/ duration	BRN_ valve	Valve position sensor on the VOC valve	Valve position indicator	0 or 1	N/A	1 second

[g] Units depends on valve position (0 = off, 1 = dumping, 2 = in cycle, 3 = in cycle & dumping)

3.2 Coriolis Meter

3.2.1 Description and principle of operation

Coriolis mass flowmeters measure the force resulting from the acceleration caused by mass moving toward (or away from) a center of rotation. The meter utilizes a vibrating tube in which Coriolis acceleration of a fluid in a flow loop can be created and measured. The measuring tubes are forced to oscillate such that a sine wave is produced. At zero flow, the two tubes vibrate in phase with each other. When flow is introduced, the Coriolis forces cause the tubes to twist, which results in a phase shift. The time difference between the waves is measured and is directly proportional to the mass flow rate [3].

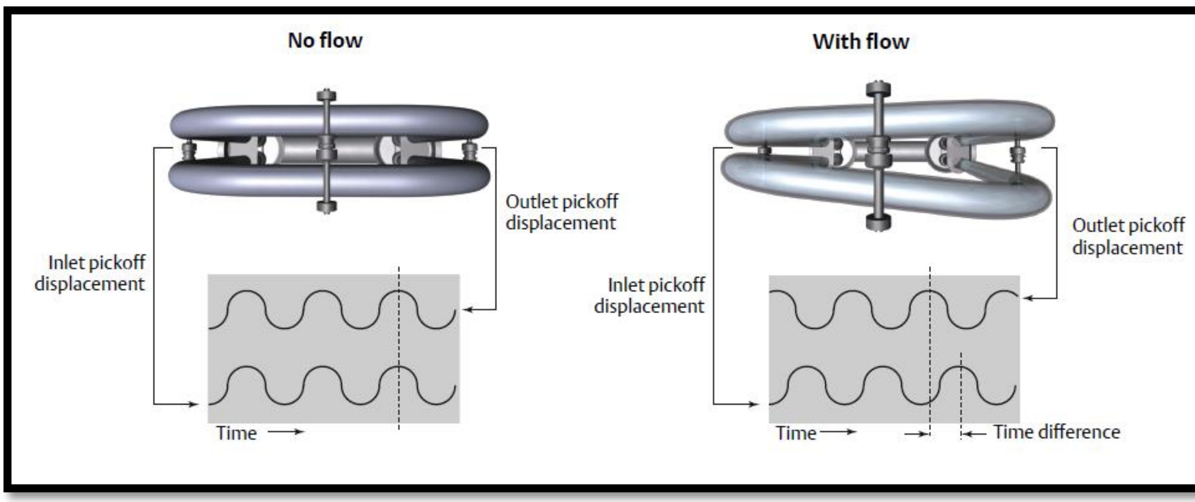

Figure 3-4. Comparison of zero flow and full flow in Coriolis tubes [3]

3.2.2 Output specifications

There are two models of Coriolis meters used in the test site: (1) R100 (oil leg) and (2) F100 (water leg). Both Coriolis meters have the same output specifications listed in Table 3-9:

Table 4-5: Output Specifications of Coriolis Meter

Specification	
Analog input flow	17.3 VDC
Analog output flow	1–5 VDC
Calibration code	Z
Temperature range	(-)40–140^{o}F
Accuracy class	±0.5% of rate

In order to translate the measurement data (e.g. tubes vibration frequency, mass flow rate of the fluid traveling through the tubes etc.) into meaningful insight, a transmitter wired to the

Coriolis meter is needed. The in-situ transmitter used is Micro Motion Model 5700 with the input/output characteristics shown in Table 3-10 below:

Table 3-10: Model 5700 Transmitter Specifications

Specification	
Internal voltage	24 VDC (nom)
External voltage	30 VDC (max)
Scalable range	4–20 mA
Downscale fault	Configurable from 1.0 – 3.6 mA, default value = 2.0 mA
Upscale fault	Configurable from 21.0 – 23.0 mA, default value = 22.0 mA
Linearity	0.015% Span, Span = 16 mA

The transmitter provides users with an access to detailed measurement history ("Coriolis logs") up to 30 days from the measurement itself. The logs can be downloaded to a csv file by the user.

3.2.3 Summary of calibration/proving procedures

By default, the Coriolis meter measures the mass flow rate of the desired fluid going through its tubes. However, volume of the fluid will change with varying temperature, due to thermal expansion; and pressure, due to fluid compression. Custody transfer measurement typically requires the meter accuracy to be proved in the field against a known volume reference. Thus, this sub-section differentiates between the *calibration* and the *proving* of the Coriolis meter.

Calibration is typically performed in a laboratory at several different flow rates, densities, or temperatures (using water as a medium) so that the meter's calibration factor is determined based on ISO/IEC 17025 standard. Each certified calibration facility performs liquid mass flow, density, and volume flow calibrations with mass flow uncertainties as low as 0.03% or less.

The Coriolis meters maintain two typical calibration stands: (1) Transfer Standard Method (TSM) and (2) gravimetric flow. Typically, two calibration techniques are used: (1) static start/finish and (2) dynamic start/finish. A short description of each calibration stand is shown below [4].

<u>Static start/finish (SSF)</u>

SSF is a gravimetric calibration method where the calibration batch begins and ends at no flow condition. The reference used in this method is a weigh scale. The test fluid is water which is collected in a tank. The tank is placed on a scale so that the mass of the water is determined. The mass indication of the scale is corrected with the Buoyancy Factor (BF) and an Immersed

Pipe Correction (IPC). BF is influenced by values taken during the use of the scale, Buoyancy Vapor Correction (BVC). Fluid pressure and temperature are measured both upstream and downstream of the unit under test (UUT). Additionally, ambient pressure, temperature and humidity are measured during each test.

Dynamic start/finish (DSF)

DSF is a gravimetric calibration method where the calibration batch begins and ends at stead-state flow. The calibration is performed in closed conduits and it uses water as a test fluid. The water passes through the unit under test (UUT) and the reference meter (RM). The reference meters (also called Master meters) are known good meters initially calibrated on an ISO 17025 accredited Primary gravimetric flow stand and TSM traceability is maintained annually by using Global Reference Meters. The mass total from the UUT is compared to the mass total from the RM via pulse counters. Fluid temperature and pressure is measured upstream and downstream of the UUT.

Proving

In addition to the factory-based calibration, a series of meter proving tests (under normal operating conditions in the field) were conducted to the Coriolis meters at the test site. Flowmeters are proven by comparing the indicated flow measurement (volume or mass) to a reference flow volume or mass. The results of the proving generate a Meter Factor (MF_P), a number near 1.000 that adjusts the flow calibration factor so that the unit under test matches the reference.

The test consisted of connecting a Coriolis master meter (MM) in series with the meter under test (MUT) and comparing the MUT to a known NIST-traceable volume by master meter according to standards set forth in API MPMS Ch. 4.5. The proving was performed with a non-hazardous, non-combustible petroleum distillate to minimize the potential for multi-phase flow during the proving period. The petroleum distillate was a 42°API gravity oil surrogate which was pumped in upstream from the isolated MUT, through both the MUT and the MM, and then returned to the distillate tank (Figure 3-5). The pressure and flow rate were controlled through the pumping trailer and were set to mimic normal operational conditions of the MUT.

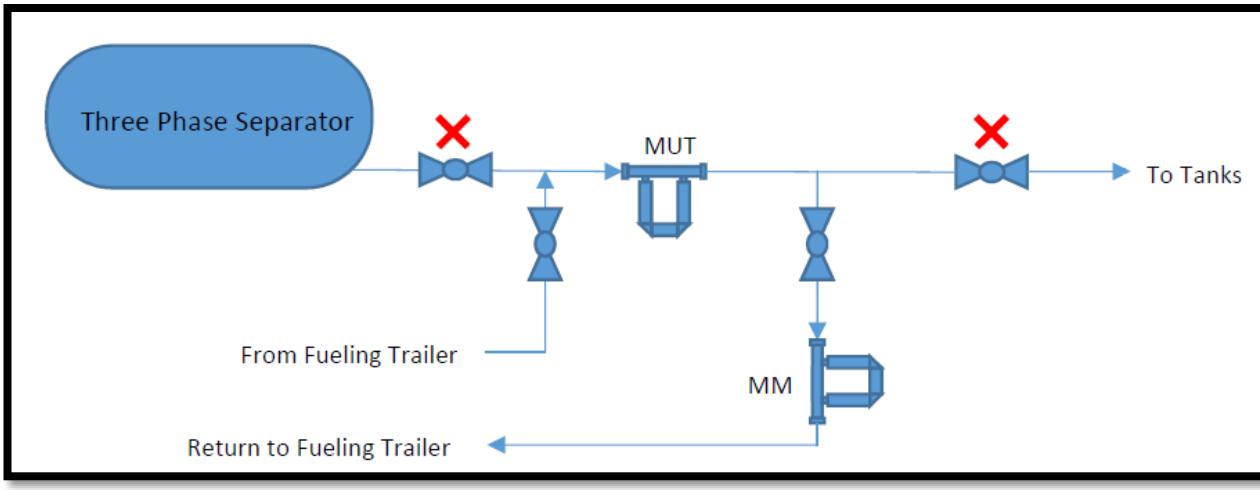

Figure 3-5. In-field testing setup (red arrows indicate closed valves)

3.2.4 Summary of calibration results

Multiple calibration and proving tests were conducted on the two meters used in the test-site, namely:

- Calibration report for F-100 Coriolis meter (water-leg)
- Calibration report for R-100 Coriolis meter (oil-leg)
- Meter proving prior to winter phase sampling week
- Meter proving prior to summer phase sampling week
- Meter proving following summer phase sampling week

As discussed above, the most representative parameter for a meter's accuracy is the meter factor. While this parameter is more common in proving terminology, the calibration lab also reports this factor, though with different definition: the ratio of the "Referenced Total" and the "Meter Total", as reported by the calibration lab. Table 3-11 below illustrates the calibration results for both Coriolis meters used in the test site (for oil and water flow rate measurement).

Table 3-11: Summary of Coriolis Calibration and Proving Tests

Test type	Coriolis Model	Date	SG of Medium	Flow % (of max)	Meter Factor
Calibration (water-leg)	F-100	07/29/2014	1.00	5.00	0.999
				25.0	0.999
				50.0	0.999
Calibration (oil-leg)	R-100	12/13/2011	1.00	50.0	Not Reported

An in-field, in-situ meter proving test was conducted on 3/4/16, 7/21/16 and 8/4/2016 to determine the meter factor or correction for installation and operational affects as well as random error. Since the meter factor calculation in the proving process is more complex than that of the calibration value determined by the lab, the following section addresses the method used to evaluate that parameter.

<u>Meter Factor Determination by Master Meter Method</u>

The meter-under-test ("MUT" in Figure 3-5) was proved against a master meter ("MM" in Figure 3-5) according to API MPMS Ch.4.5 using a transfer of meter factor approach from the MM to the MUT. The meter factor was determined by comparing collected pulses, which corresponds to Indicated Volume (IV), on both meters simultaneously. The average of 5 of these collected pulses test-runs determines the average IV that both the MUT and MM detected during the test period. The IV on both meters is then corrected for any temperature (correction for the temperature of liquid or CTL) or pressure (correction for the pressure of liquid or CPL) effects to arrive at an Indicated Standard Volume (ISV). Finally, a master meter factor is applied according to the following equation (3-1):

$$MF_P = \frac{ISV_{MM}}{ISV_{MUT}} = \frac{MF_{MM}*IV_{MM}*CTL_{MM}*CPL_{MM}}{IV_{MUT}*CTL_{MUT}*CPL_{MUT}} \tag{3-1}$$

Where:

MF_P is the Coriolis meter factor due to proving
ISV_{MM} is the indicated standard volume of the master meter
ISV_{MUT} is the indicated standard volume of the meter under test
MF_{MM} is the meter factor of the master meter
IV_{MM} is the indicated volume of the master meter
IV_{MUT} is the indicated volume of the meter under test
CTL_{MM} is the temperature correction factor of the master meter
CTL_{MUT} is the temperature correction factor of the meter under test
CPL_{MM} is the pressure correction factor of the master meter
CPL_{MUT} is the pressure correction factor of the meter under test

A different approach determine the meter factor based on direct meter pulses (to obtain volumetric flow) is reported in API 13.3.B.1.3, as shown in equation (3-2) [6]:

$$MF_P = BPV * CTS_p * CPS_p * \frac{NKF}{Pulses} * \frac{CTL_p}{CTL_m} * \frac{CPL_p}{CPL_m} \tag{3-2}$$

Where:

BPV is the base prover volume
CTS_p is the correction factor for the effect of temperature on steel on a liquid in a prover
CPS_p is the correction factor for the effect of pressure on steel on a liquid in a prover
NKF is the nominal K-factor
CTL_p is the correction factor for the effect of temperature on a liquid in a prover
CTL_m is the correction factor for the effect of temperature on a liquid passing through a meter (during a proof)
CPL_p is the correction factor for the effect of pressure on a liquid in a prover
CPL_m is the correction factor for the effect of pressure on a liquid passing through a meter (during a proof)

Measurement Uncertainty of Secondary Test Measure (Master Meter)

The master meter method described in API MPMS Ch.4.5 is a secondary test measure method as contrasted to measurement against a fixed volume displacement prover as described in API MPMS Ch.4.2. As such, the master meter method has an additional random measurement uncertainty above the random uncertainty contained within a primary test measure (prover).

The master meter used in this test was proved at multiple flow rates against a Small Volume Piston Prover (SVP) to determine a curve of meter factor versus flow rate (Figure 3-6). Once the proving flow rate was determined, a MM meter factor was interpolated from Figure 3-6 to determine the applicable MM meter factor to be applied in equation (3-1).

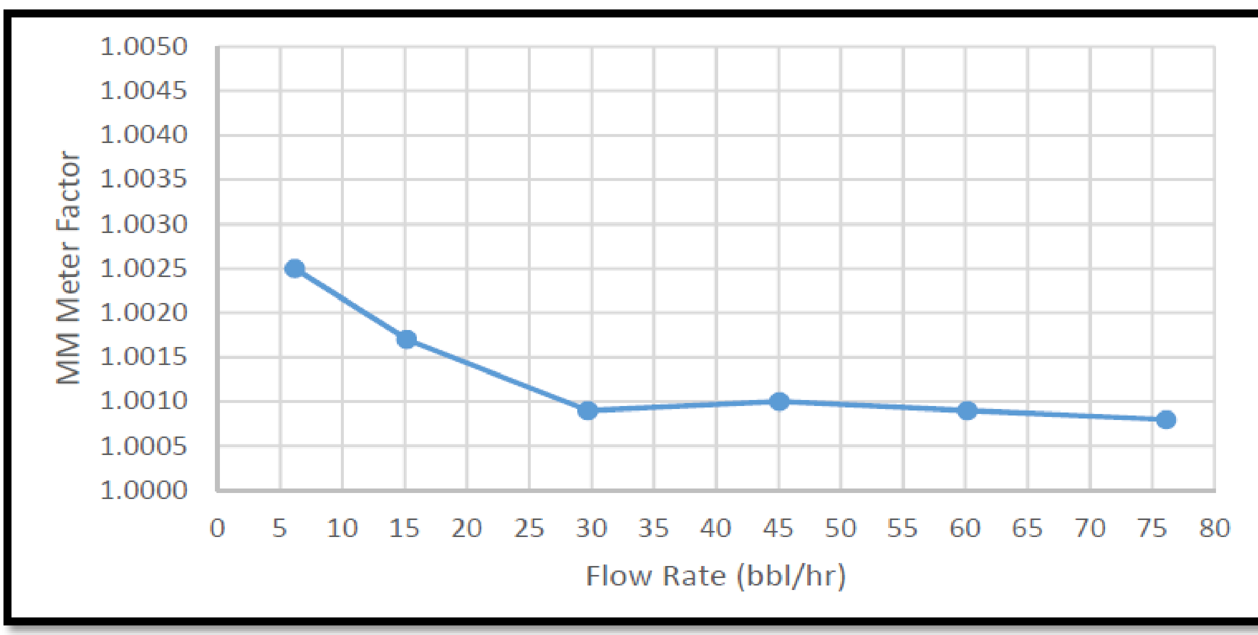

Figure 3-6. Master meter MF versus flow rate

Each MM meter factor carries a random uncertainty according to API MPMS Ch.4.5 of 0.027% (MF_P ± 0.00027) or better using the repeatability criteria of proving against a SVP of 5 test runs that repeat within a tolerance range of 0.05%. A simple linear interpolation was used to quantify the MM meter factor between flow rates. The maximum allowable meter factor shift between two adjacent proving flow rates for the master meter is set at 10/10000th or density meter factor (DMF) |DMF| ≤ 0.001. While this linear interpolation will increase the potential uncertainty of the MM meter factor, the potential for uncertainty has been limited to ±0.077% as a worst case and can generally be expected to be much less than this value, especially given the proximity of the MUT proving flow rate to one of the MM proving flow rates.

Additional sources of measurement uncertainty are encapsulated within the uncertainty of the meter factor itself where they are used in the determination of the meter factor. These uncertainties are the uncertainty of temperature and pressure. Being a secondary test measure, the MM meter factor also carries the uncertainty of the base prover volume or BPV of the SVP with which the MM was proved. This allowable uncertainty is standardized in API MPMS Ch.4.9 and set at 0.027%. The uncertainty of the SVP used in proving the master meter is roughly an order of magnitude better than the standard and is listed in the water draw calibration of the SVP.

Results of the Master Meter Proving

A before and after proving of the MUT was performed and the stability of the MUT during the well testing period was assessed. The MUT meter factor before and after along with associated proving uncertainties is listed in Table 3-12 below.

Table 3-12: Coriolis's Meter Factor Summary

Date Performed	Proving Flow Rate (bbl/hr)	MUT Meter Factor	Meter Factor Uncertainty %
3/4/2016	10	1.0008	0.022
7/21/2016	8	0.9979	0.018
8/4/2016	8	0.9995	0.022
8/4/2016	25	1.0001	0.009
8/4/2016	47	1.0003	0.022

The proving results show that the MUT is functioning with relatively little installation and operational errors. For comparison, a meter factor of exactly 1.0000 according to equation (3-1) above indicates an exact agreement with the NIST standards of measure. The Bureau of Land Management (BLM) standard criteria for custody transfer is a meter factor that is within the range of 0.9900 and 1.0100, has an uncertainty of 0.027% or better, and shows no more than ±0.0025 deviation between two proving tests. While API has no set standards for these criteria, these values have been widely accepted by the industry to be acceptable custody transfer criteria.

By these criteria, the MUT meter factors show good agreement from before and after the well testing period at the flow rate of interest (8 bbl/hr). Additionally, the MUT meter factors indicate good zero stability of the meter when viewed over a wide range of flow rates. Coriolis meters in general have a low flow turndown limit where accuracy of measurement tends to suffer. For this particular make and model of Coriolis meter, the stated low flow turndown is set at ~12.6 bbl/hr. Given the range of flow rates tested, minimal drift of accuracy is seen even below this manufacturer-stated limit.

Adjustment for high drive gain

The Coriolis's drive gain (abbreviated DG) is a measure of the power usage required to maintain the tube vibration at the specified frequency, and is expressed in a percentage of available power. A typical value for the DG is below 15% (e.g. no more than 15% of the power is required to maintain the tube at the specified frequency). The DG serves as an indicator to spot whether an entrained gas is present in the production flow, therefore any DG values higher than 15% have to be adjusted accordingly.

In order to correct the volume flow for bubbles (i.e. two-phase flow in the oil), the Gas Void Fraction (GVF) for all densities needs to be calculated based on equation (3-3a):

$$GVF = \frac{\rho_{mix} - \rho_{liquid}}{\rho_{gas} - \rho_{liquid}} \quad (3\text{-}3a)$$

Where:

GVF is the gas void fraction (unitless)
ρ_{mix} is the density of the two-phase flow (kg/m^3)
ρ_{liquid} is the density of the "bubble-free", standard density (kg/m^3)
ρ_{gas} is the density of the gas (kg/m^3)

Since $\rho_{liquid} >> \rho_{gas}$, equation (3-3a) can be rearranged to equation (3-3b):

$$GVF = \frac{\rho_{liquid} - \rho_{mix}}{\rho_{liquid}} \quad (3\text{-}3b)$$

The GVF calculated in equation (3-3b) indicates whether the standard volume measurement is too high (if GVF > 0) or too low (if GVF < 0), so that the new meter factor adjusted for DG is:

$$MF_{DG} = 1 - GVF \quad (3\text{-}4)$$

Where:

MF_{DG} is the adjusted meter factor for high drive gain readings.

Volumetric adjustment to standard conditions

The Coriolis readings (e.g. flow rate or total flow) are depicted in line conditions, without any correction applied from the manufacturer (i.e. MF_P = 1 when the meter leaves the factor). Given that the test site is located near Greeley (CO), the ambient pressure is approximately 12.3 psia. Since the density (and therefore volume) of hydrocarbons is sensitive to temperate and pressure, a volume correction factor (VCF) is used to correct observed volumes to equivalent volumes at standard temperature and pressure (60^{o}F and 14.7 psia), which serve as a way to use volumetric measures equitably in general commerce.

The most common and widely recognized standard that establish such a correction to crude oils and other relevant oil products (e.g. liquid refined products, lubricating oils etc.) is API 11.1 [5] ("Manual of Petroleum Measurement Standards – Temperature and Pressure Volume Correction Factors for Generalized Crude Oils, Refined Products, and Lubricating Oils"), which is applicable for crude oils with density ranging from 610.6 kg/m^3 to 1163.5 kg/m^3.

As stated above, the correction factor should consist of a temperature and pressure portions to correct hydrocarbon liquids to standard conditions. The temperature portion of this correction is referred as the "Correction for the effect of Temperature on Liquid" (CTL) and the pressure portion is referred as the Correction for the effect of Pressure on Liquid (CPL), both of which are defined in API 11.1. However, this correction is relatively small for liquids compared to gases (< 1%).

The actual Coriolis flow is adjusted to standard conditions based on the following conversion illustrated in equation (3-5):

$$V_{60} = V_{t,P} * MF_P * C_{TL} * C_{PL} * MF_{DG} \quad (3\text{-}5)$$

Where:

V_{60} is the volume at standard conditions (60^{o}F and 14.7 psia)
$V_{t,P}$ is the volume measured at alternate conditions
MF_P is the Coriolis meter factor due to proving
C_{TL} is the correction for the effect of temperature on liquid
C_{PL} is the correction for the effect of pressure on liquid

3.2.5 List of related files / documentation

- Calibration record of F-100 meter by Micro Motion, Inc.
- Calibration record of R-100 meter by Micro Motion, Inc.
- Micro Motion Calibration Procedure (Emerson Process Management).

- Calibration and Measurement Capability of Transfer Standard Method Flow Meter Calibration Stands (Emerson Process Management).
- Proving records (including master meter) for winter phase testing by Volumetrics.
- Proving records (including master meter) for summer phase testing (pre and post) by Volumetrics.
- Proving records for master meter (HANK)
- Gravimetric waterdraw certificate.

3.3 Thermal Mass Flow Rate (Fox Thermal FT3 Model)

3.3.1 Description and principle of operation

Thermal mass meters measure gas flow based upon the concept of convective heat transfer (since gases absorb heat). Figure 3-7 is a schematic of the Fox meter. A heated resistance temperature detector (RTD) placed in an air or gas stream transfers heat to the gas in proportion to the mass flow rate of the gas. A second RTD acts as a reference sensor and determines the gas temperature.

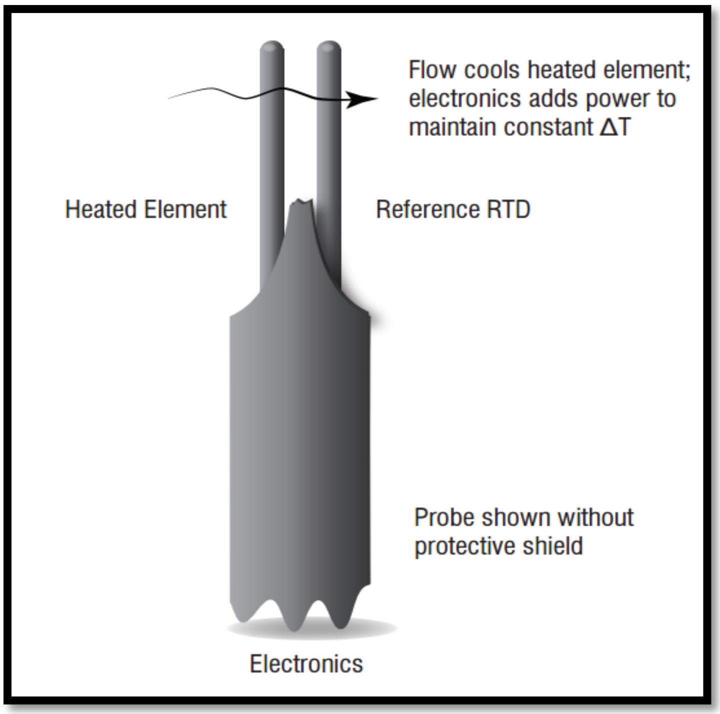

Figure 3-7. Concept of thermal mass flow meters [7]

The electrical power required to maintain a constant temperature differential between the two detectors is proportional to the gas mass flow rate [7], as shown in equation (3-6a).

$$W = I^2 R_1 \tag{3-6a}$$

Where:

W is the electrical power supplied to the heated RTD element (Watts)
I is the current supplied to the heated RTD element (ampere)
R_1 is the electrical resistance of the heated RTD element (ohms)

This electrical power is measured and converted to a gas flow rate using the relationship developed by Thomas (1911) [8], as shown in equation (3-6b):

$$M = \frac{W}{C_p \Delta T} \quad (3\text{-}6b)$$

Where:

M is the mass flow rate in g/s
C_p is the heat capacity of the gas at constant pressure J/g*^{0}C
ΔT is the temperature difference between the heated and reference RTD elements in ^{0}C

3.3.2 Output specifications

Once the flow rate has been determined based on the electrical power required to maintain a constant temperature differential between the sensors, the microprocessor (which controls the sensor and determines the resulting electrical characteristics) linearize the signal to deliver a linear 4 to 20mA signal. The following is provided from the manufacturer:

- Two isolated 4 to 20mA outputs (output one is for flow rate and output two is programmable for flow rate or temperature).
- For input voltage, 24 VDC is recommended, however ±10% of the base value is satisfactory.

3.2.3 Summary of calibration procedures

The thermal mass meters used in the test site were model FT3 manufactured by Fox Thermal Instruments, Inc. For the FT3 meters, a factory calibration and an in-pipe calibration validation, also abbreviated CAL-V, are conducted:

- Factory calibration – occurs in the calibration laboratory and uses calibration standards traceable to NIST.
- CAL-V calibration – allows the operator to validate the meter's calibration accuracy under actual flow conditions by testing the functionality of the sensor and associated signal processing circuitry.

For the factory calibration procedure, the process begins with a detailed customer application data review and sign-off by lab personnel. The following steps are then completed [9]:

a. Select lab, lab piping and accessories to replicate actual installation.
b. Install the flowmeter (Device Under Test or DUT), pressurize and leak test the calibration system.
c. Charge calibration tunnel with calibration gas or gas mixture (the customer provides two gas compositions with similar components to simulate the 'process' gas because the gas heat transfer properties (primarily thermal conductivity, density, and viscosity) impact the heat transfer and the sensor response).
d. Perform preliminary test of calibration standard and data acquisition system.

e. Perform zero stability tests and take zero calibration point.
f. Collect approximately 12 calibration flow range data points and an over range point.
g. Download collected calibration data to DUT.
h. Perform final calibration verification over the entire flow range to ensure calibration parameters have been properly downloaded and that the DUT is performing within the published accuracy specification.
i. Download all flow meter calibration data and settings to master and back-up calibration databases.
j. Prepare calibration QC documents to record all raw data, parameters and settings and store in master and back-up calibration databases.
k. Prepare customer calibration certificate to include raw sensor voltages, flow velocities and flow rates in customer-specified units, standard asset number, reference standard data, gas/gas mixture, and calibration technician signature.

For the testing at the Bernhardt site, three gas compositions[A] were used to factory calibrate the Fox FT3 meters. These compositions were based on process simulation modelling of equilibrium tank headspace gas compositions for three temperatures: 40°F (gas curve 1, Winter operation simulation), 65°F (gas curve 3, Spring/Fall operation simulation) and 90°F (gas curve 2, Summer operation simulation). These compositions are shown in Table 3-13:

Table 3-13. Flash Gas Compositions (in mol%) For Fox FT3 Factory Calibrations

Component	Gas Curve 1	Gas Curve 2	Gas Curve 3[A]
Methane	32.43	20.89	26.26
Ethane	25.81	18.16	22.05
Propane	18.17	16.53	18.19
Butanes	12.40	17.99	15.96
Pentanes	6.51	15.50	10.64
Hexanes	N/A	N/A	1.45
Carbon dioxide	1.98	1.32	1.63

[A]Gas curve 3 was used in FT3 S/N 21776 to see whether the calibration output was linear.

The calibration for each meter consists of 20 data points with output signal varying from 4 mA (= 0 MSCFD) to 20 mA (= 500 MSCFD). Using proprietary software designed by Fox Thermal Instruments, a trained calibration technician using automatic data collection equipment collects flow data through the customers flow range. In a Fox Thermal Flowmeter the sensor, the DC voltage signal is referred to as Current Sense Voltage (abbreviated CSV). Velocity at standard conditions is referred to as velocity. Under normal[1] operation, the flowmeters microprocessor reads CSV and calculates the mass velocity from the calibration table stored in the meter's memory. Mass flow rate is calculated by multiplying the mass velocity times the cross sectional area of the customers pipe[2] [13].

The second calibration procedure performed in-situ under actual pipe conditions is the CAL-V calibration. During CAL-V mode (Figure 3-8a), the microprocessor controls the sensor and determines the resulting electrical characteristics, whereas during factory mode (Figure 3-8b) the signal processing electronics control the sensor.

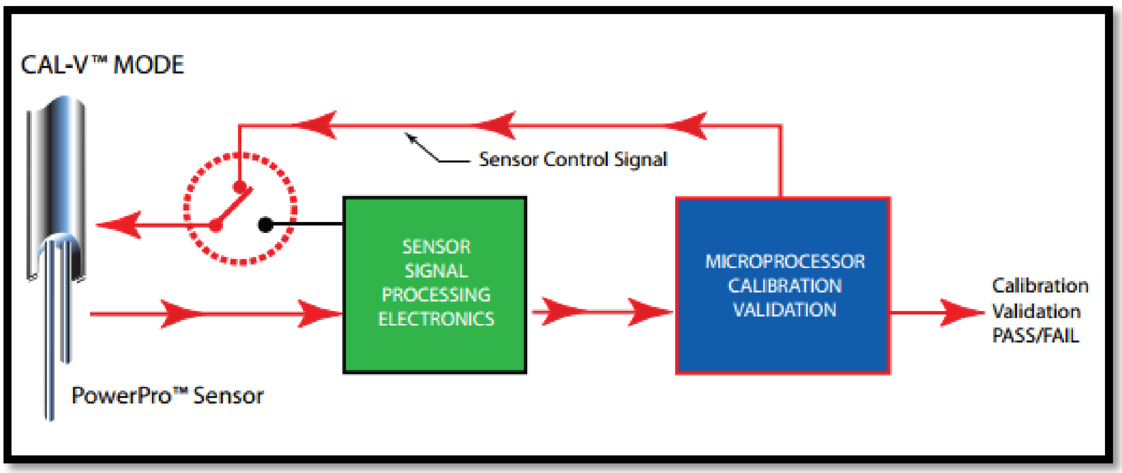

Figure 3-8a. Circuitry of CAL-V measurement mode of FT3 model [10]

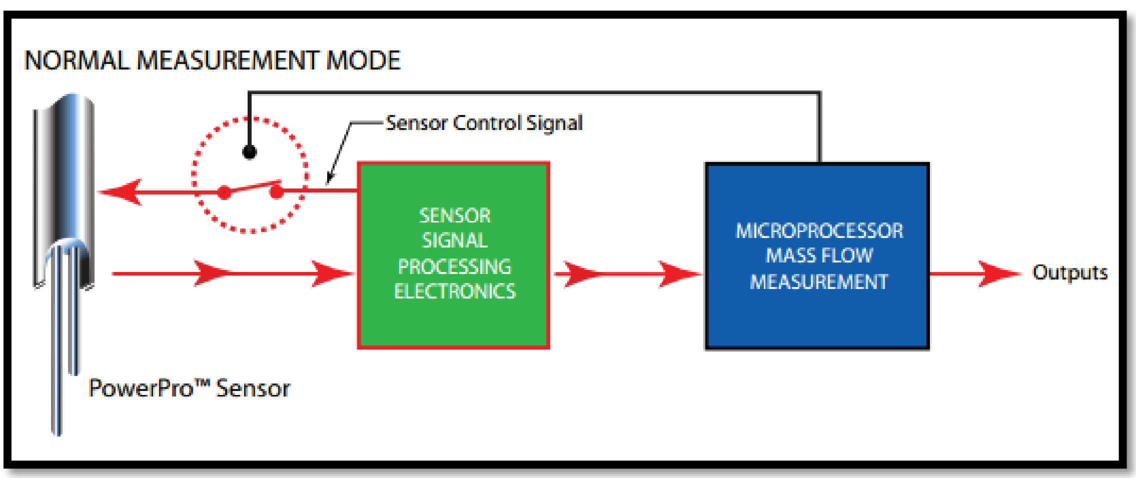

Figure 3-8b. Circuitry of normal measurement mode of FT3 model [10]

The in-situ calibration results are compared with the factory-based calibration. The CAL-V test provides three output parameters shown on the calibration validation certification:

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[1] Normal refers to a reference condition at 0°C and 760 mmHg.
[2] The factory based calibration was conducted on a 3-inch pipe diameter (ID = 3.068 inch).

1. **CAL-V Result:** A "Pass" or "Fail" result shown on the screen. If the CAL-V diagnostic finds the sensor too far out of range compared to the factory calibration baseline, that's a "Fail" result. If the diagnostic finds the meter within tolerances, it's a "Pass".
2. **CAL-V Value:** This is the baseline value from the most recent factory calibration of the meter. It is a measure of the ratio in resistance (in ohms) between the meter's two sensors at the CAL-V diagnostic's test voltage.
3. **CAL-V Verify**: This is the percentage difference between the factory baseline resistance ratio and the in-the-moment resistance ratio. If this value is too large, i.e. an absolute value greater than 2.5%, the CAL-V Result will be "Fail." If the absolute value of the Verify value is 2.5% or less, it's a "Pass."

3.2.4 Summary of calibration results

Unlike the proving process for the Coriolis meter, there is no independent check for the FT3 meters.

Table 3-14 below summarizes the available documentation of the calibration certificates (from the factory) as well as the calibration validation certifications performed at the test site. Note that for the two tested seasons, all CAL-V tests were performed by the same method and by the same technician.

Table 3-14: Summary of FT3's Calibration and CAL-V Records

Calibration Type	Season	S/N of FT3	Date of Test	CAL-V Result	CAL-V Value	CAL-V Verify
Factory Calibration	Winter	21773	02/23/2016	N/A	N/A	N/A
CAL-V			02/25/2016	PASS	21.8	4.05%
Factory Calibration		21775 (PRV)	02/22/2016	N/A	N/A	N/A
CAL-V			02/25/2016	PASS	22.81	0.01%
Factory Calibration		21776	02/22/2016	N/A	N/A	N/A
CAL-V			02/25/2016	PASS	22.84	3.15%
Factory Calibration	Summer	21773	06/13/2016	N/A	N/A	N/A
CAL-V			07/20/2016	PASS	22.17	2.68%
Factory Calibration		21775 (PRV)	06/10/2016	N/A	N/A	N/A
CAL-V			07/19/2016	PASS	22.81	0.32%
Factory Calibration		21776	06/10/2016	N/A	N/A	N/A
CAL-V			07/20/2016	PASS	22.84	3.91%

The above table indicates that the three Fox flow meters were accurate and within the manufacturer's specifications. The CAL-V values are typical and represent the ratio of the typical resistance of the 200-220 ohms RTD element with that of the maximum resistance that corresponds to the maximum temperature/current at which it can operate before it shuts down (factory set) and is typically in 9-10 ohms.

Following the summer phase testing, a series of post-test, "as-found" factory calibrations were performed on each meter using the gas compositions listed in Table 3-14. These "as found" meter calibrations were conducted to check for meter response drift (i.e. from the pre-test voltage vs. flow rate calibration curve). For the same voltage, the calibrated flow rate was compared to that of the 'post-test' flow rate, and the difference between the two flow rates (per voltage) was compared against the manufacturer specification reading.

Due to the fact that the meters were calibrated against a *modeled* flash gas composition, it was expected that during high flow rates the percent difference between the pre- and post-test calibration results would be smaller than during low flow rates since smaller flow rates are harder to measure. To evaluate the sensor response drift between the pre-test and post-test calibrations, voltage versus flow rate was compared, as shown in Figure 3-9.

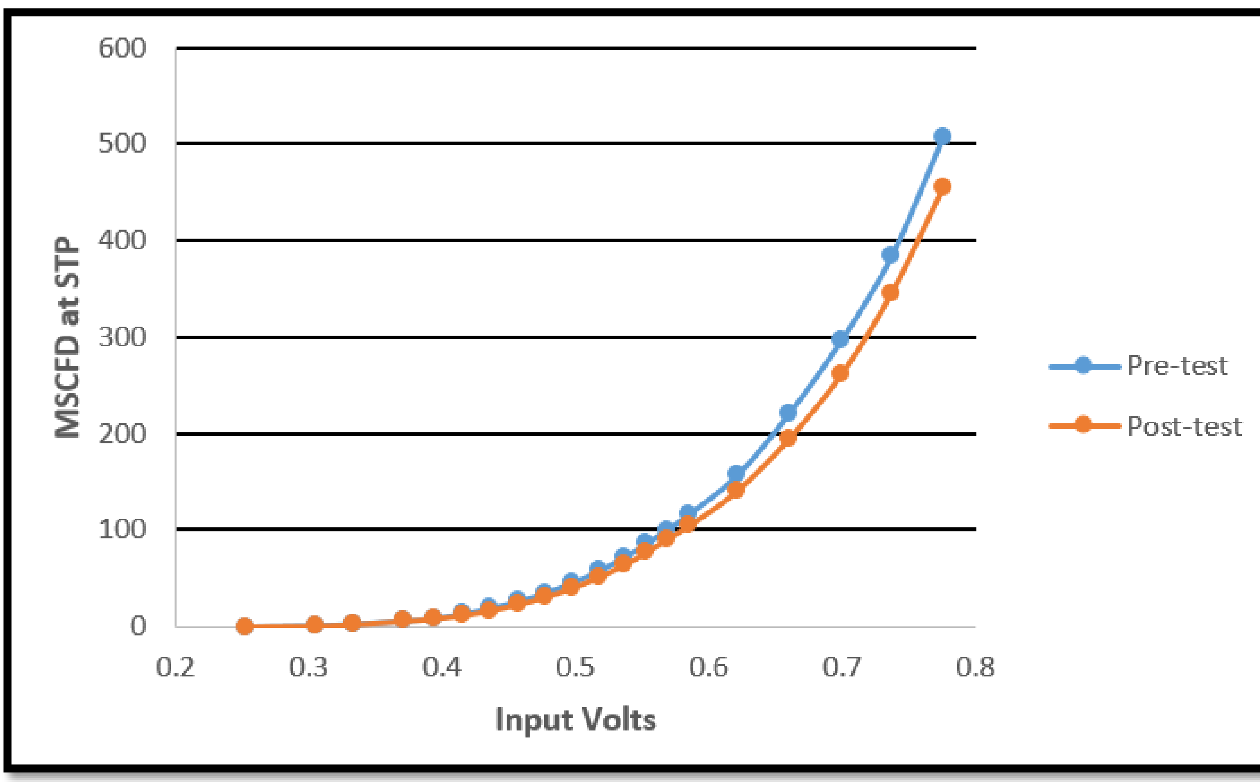

Figure 3-9. Pre-test and post-test calibration for FT3 S/N 21776 (gas curve 2)

As shown in Figure 3-9, during high flow rates the absolute sensor drift (pre-test calibration versus post-test calibration) is much larger than during low flow rates. Nevertheless, the relative difference between the pre-test and post-test readings is on average 10% (pre-test flow rates are higher) almost consistently through all flow rates larger than 9 MSCFD.

An additional source of uncertainty in the FT3 output is the FT3 location on the vertical pipe (i.e. tank-to-burner pipe, also called as “riser”). The 21773 meter was installed 60 inches below a 90-degree elbow, and 30 inches above the 21776 meter on the vertical pipe segment from the tank to the knockout pot. Figure 3-10 below illustrates the pre-test and post-test calibration for the upper FT3 meter.

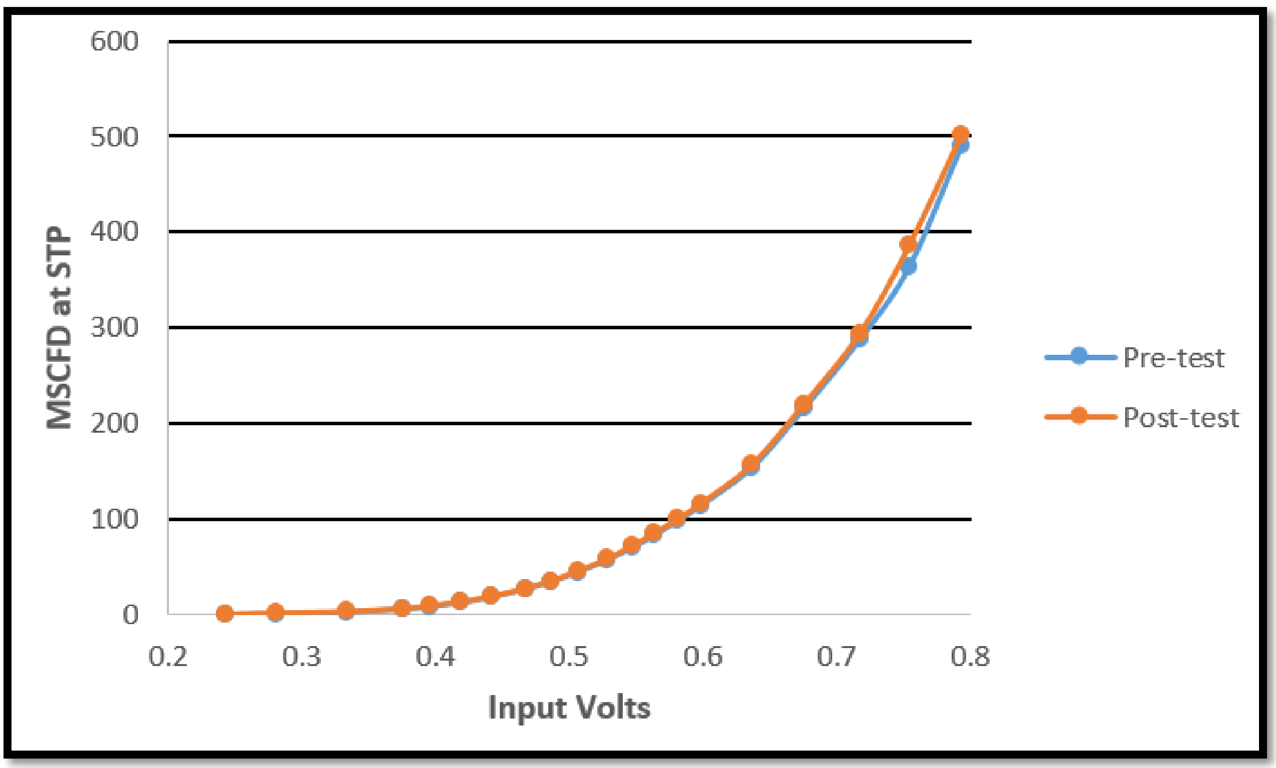

Figure 3-10. Pre-test and post-test calibration for FT3 S/N 21773 (gas curve 2)

As shown in Figure 3-10, and unlike the trend from Figure 3-9, it can be seen that for the upper meter closer to the 90-degree elbow, a negative drift exists (i.e. per specified voltage, the post-test flow rate is higher than the pre-test flow rate). This contrasts the bottom meter with a positive drift.

This trend was confirmed during the testing period, as the upper meter closer to the 90-degree elbow consistently depicted smaller integrated volumes by 5-10% than the lower meter (further away from the disturbance).

Given that the flash gas composition constantly changes due to various reasons (e.g. ambient temperature, liquid level in the tank and more), the flow rate and the integrated flow measurements become less accurate, and a correction factor needs to be applied to account for this compositional change.

The comparison of the pre-test and post-test calibration tests for the remaining gas curves are shown in Figures 3-11 through 3-15.

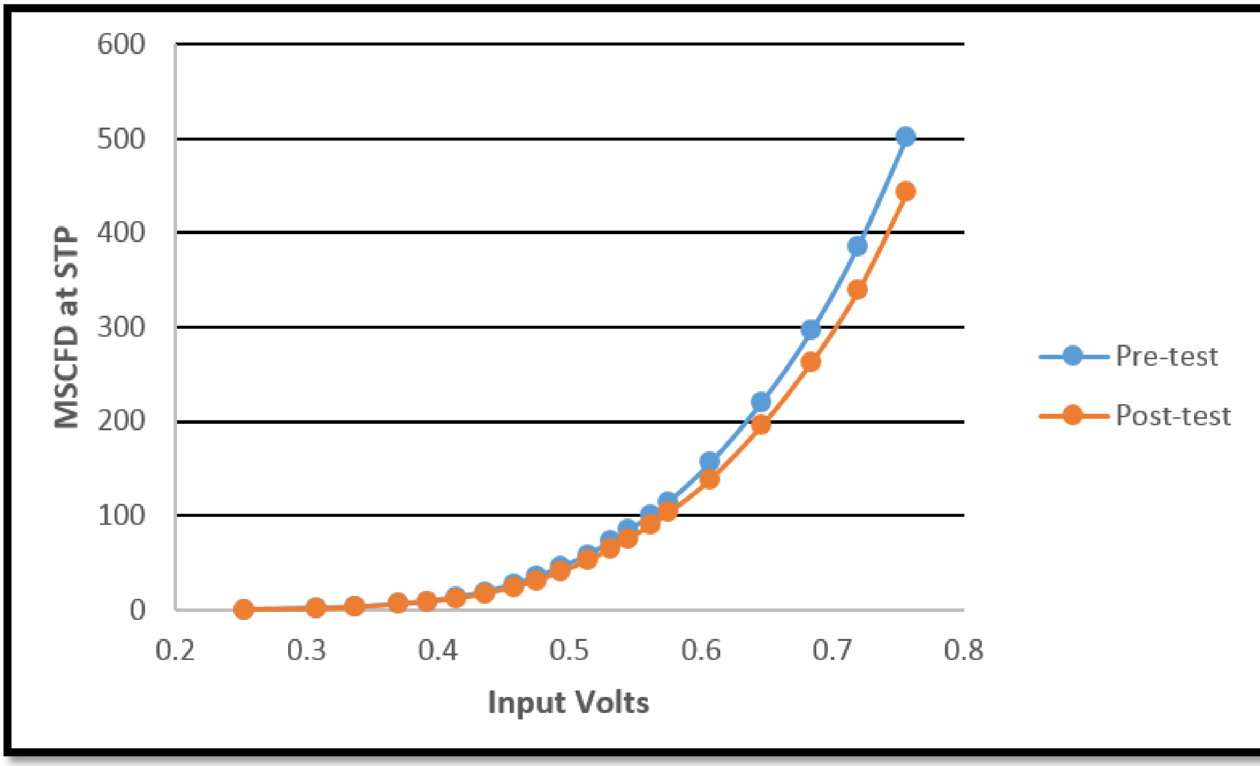

Figure 3-11. Pre-test and post-test calibration for FT3 S/N 21776 (gas curve 1)

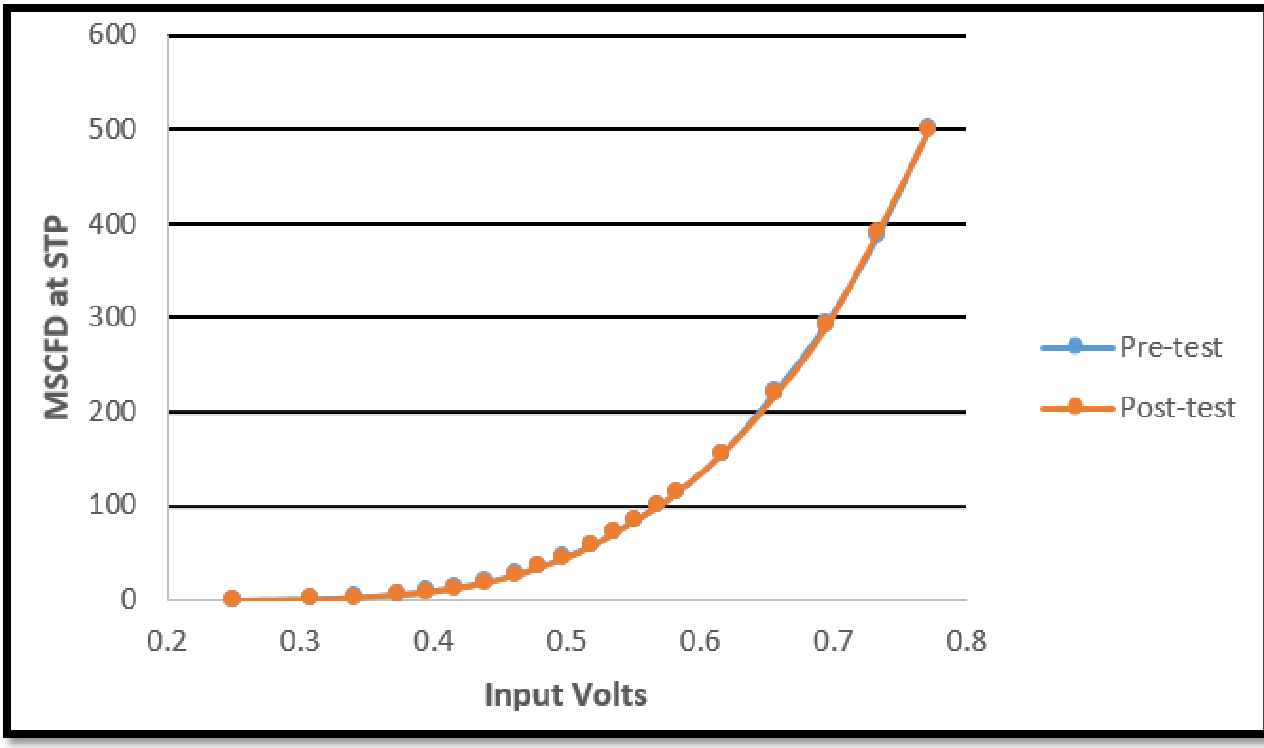

Figure 3-12. Pre-test and post-test calibration for FT3 S/N 21776 (gas curve 3)

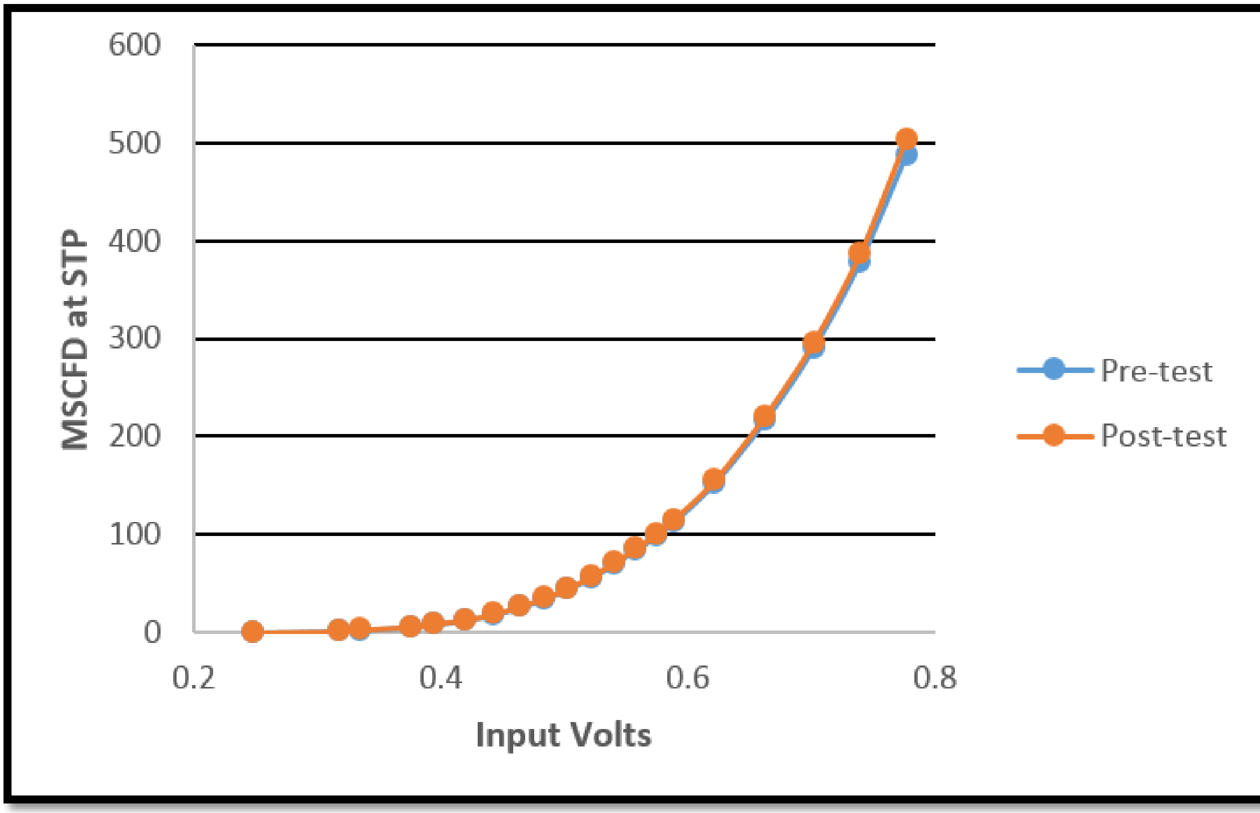

Figure 3-13. Pre-test and post-test calibration for FT3 S/N 21773 (gas curve 1)

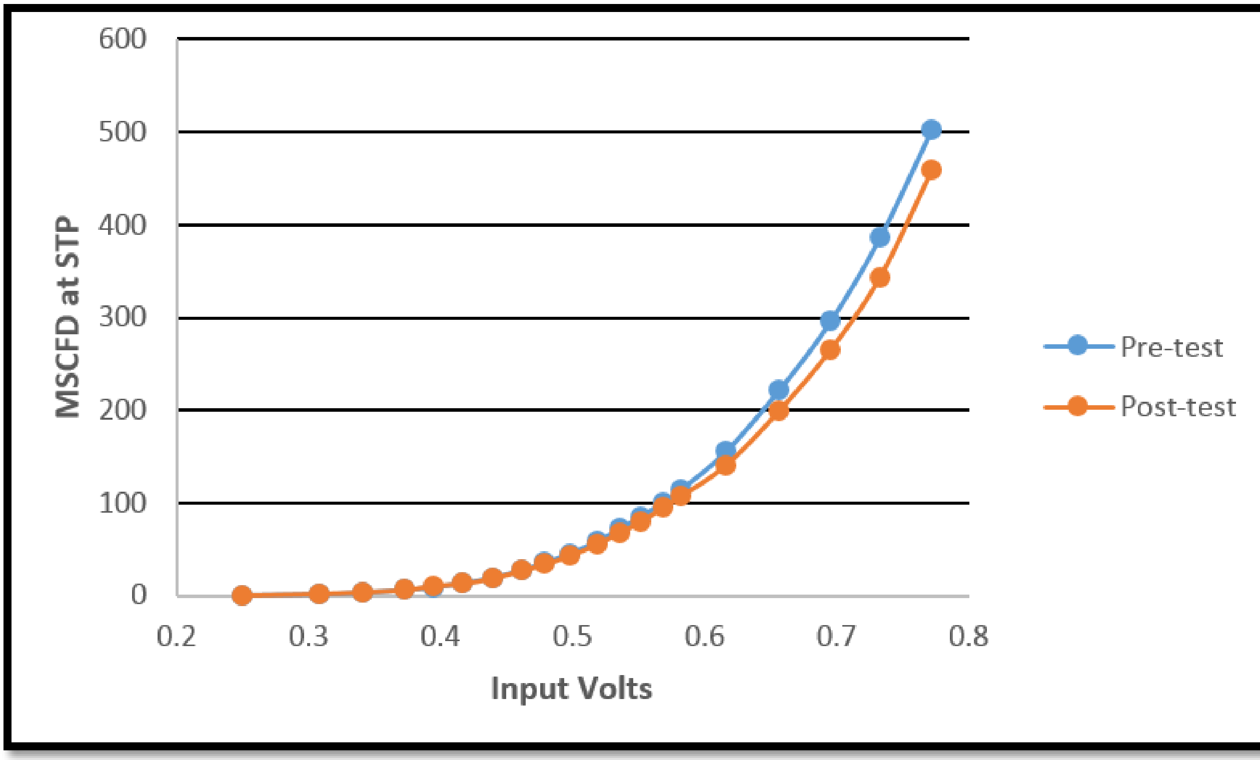

Figure 3-14. Pre-test and post-test calibration for FT3 S/N 21775 (gas curve 1)

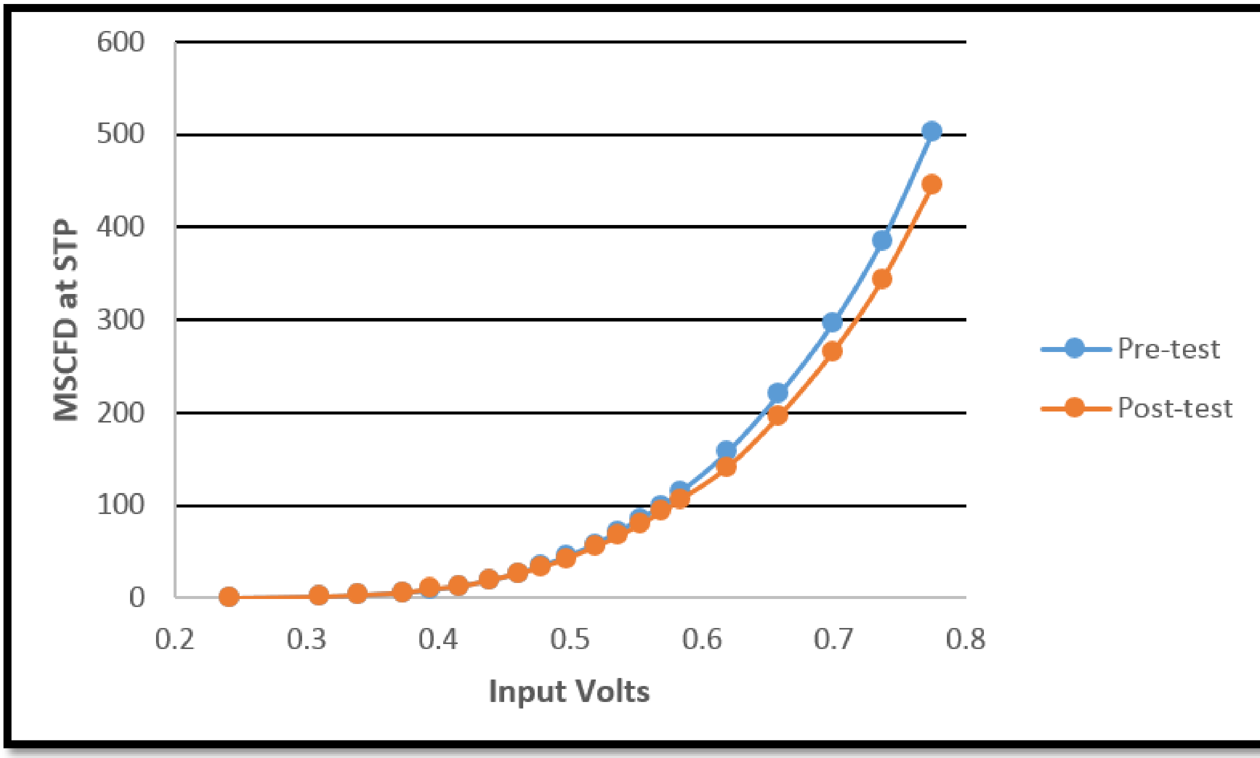

Figure 3-15. Pre-test and post-test calibration for FT3 S/N 21775 (gas curve 2)

Review of measurement uncertainty

The discussion above indicates that two major sources of uncertainty exist: (1) uncertainty of the actual FT3 measurement and (2) uncertainty of the calibration procedure itself. While the flow uncertainty (i.e. uncertainty of the actual FT3) is ± 1.0% of reading and ± 0.2% of full scale (with NIST standards in accordance with Mil-Std-45662A), the measurement uncertainty in actual conditions in the field may be larger because of compositional change (see below). To factory calibrate the FT3 meter, a source of known flow is needed as a reference. Consequently, Fox uses two types of calibration systems: (1) Positive Displacement Flowmeter-based standards and (2) Thermal Sensor-based transfer standard. For the purposes of this study, the thermal sensor-based calibration was applied.

In this calibration method, a thermal flow sensor is interfaced to the automated data acquisition system via a precision digital voltmeter calibrated to less than or equal to ± 0.0035 % uncertainty. These transfer standards measure directly in mass units without the need of pressure or temperature compensation. Thermal sensor-based calibration tunnels have a total system uncertainty of ± 0.50%.

Uncertainty due to compositional change

As discussed above, for this study, the calibration gas has a different composition than the measured gas due to dynamic field conditions (e.g. storage tank level, ambient temperature etc.). A compositional adjustment to the Fox thermal mass meters has been made by calculating heat transfer properties (e.g. Prandtl number etc.) using King's equation (3-7):

$$v_{act} = v_{cal} * \frac{\mu_{act} * \rho_{cal}}{\mu_{cal} * \rho_{act}} * \left(\frac{k_{cal} * {Pr_{cal}}^{1/3}}{k_{act} * {Pr_{act}}^{1/3}}\right)^{1/n} \quad (3\text{-}7)$$

Where:

v_{act} is the gas velocity of the actual gas composition (m/s)
v_{cal} is the gas velocity of the calibrated gas composition (m/s)
μ_{act} is the gas dynamic viscosity of the actual gas composition (Pa*s)
μ_{cal} is the gas dynamic viscosity of the calibrated gas composition (Pa*s)
k_{act} is the gas thermal conductivity of the actual gas composition (W/m/K)
k_{cal} is the gas thermal conductivity of the calibrated gas composition (W/m/K)
Pr_{act} is the gas Prandtl number of the actual gas composition (unitless)
Pr_{cal} is the gas Prandtl number of the calibrated gas composition (unitless)
n is a constant (unitless)

Equation (3-7) was used to estimate the corrected velocity adjusted for composition by considering all flow rate regimes as shown in the polynomial-shaped curves of the Fox thermal mass meters (Figures 3-9 through 3-15). The comparison between the measured and adjusted (averaged) flow rates recorded during all well cycles during the summer phase testing is shown in Figures 3-16a-b, respectively.

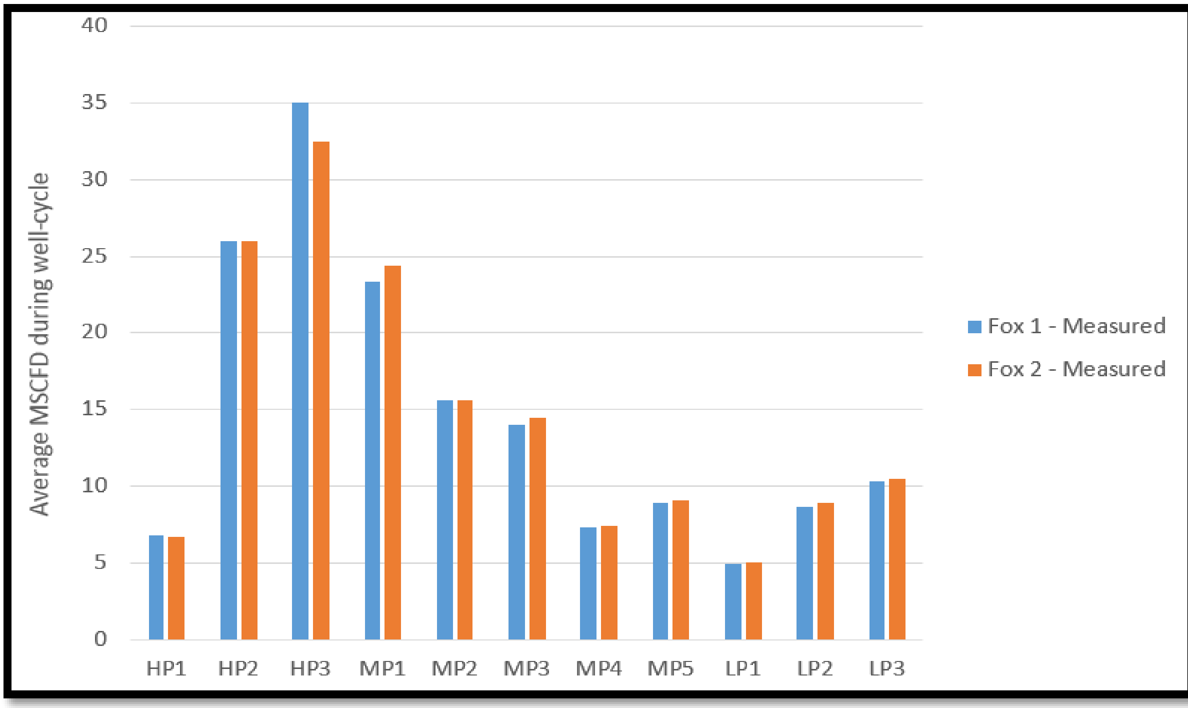

Figure 3-16a. Measured flow rate from the Fox thermal mass meter (pre-adjustment)

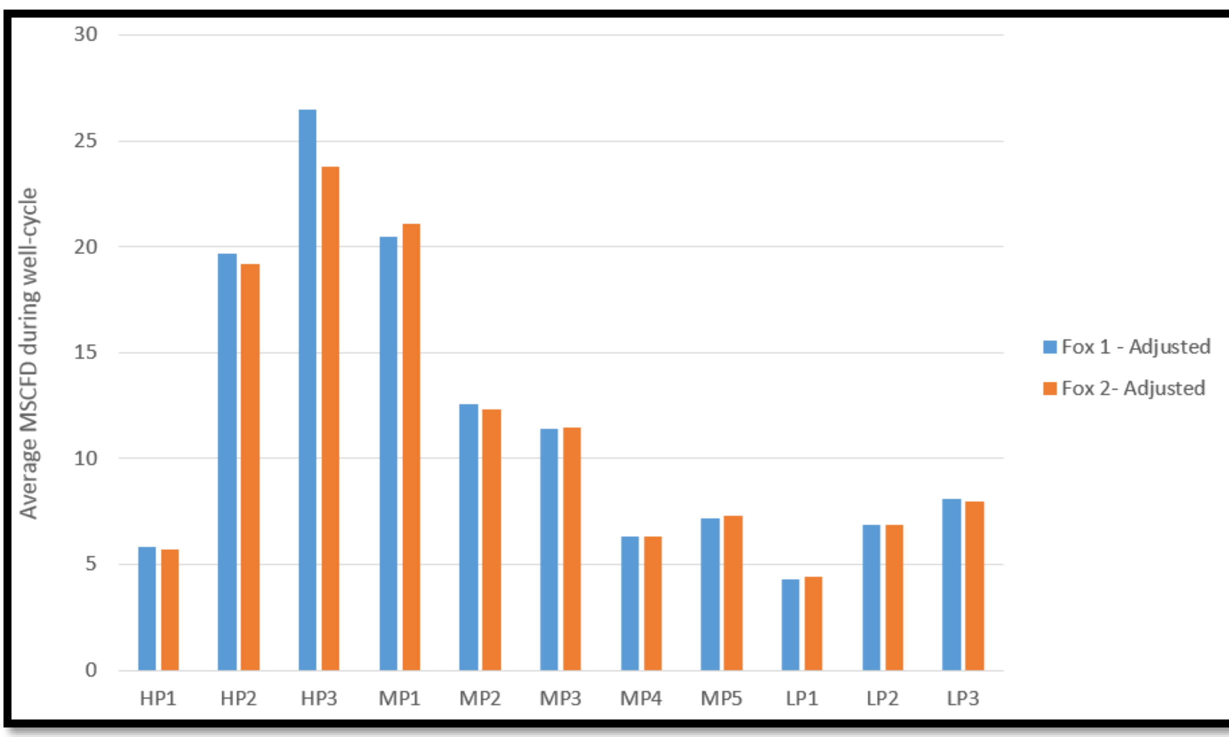

Figure 3-16b. Measured flow rate from the Fox thermal mass meter (post-adjustment)

The adjustment of the Fox thermal meters to take into consideration the compositional change was almost consistent between the two thermal mass meters installed on the riser. For the upper thermal mass meter (i.e. Fox 1), the post-adjustment correction was lower by 18.1% than the pre-adjustment (actual recording), while for the lower thermal mass meter (Fox 2), the post-adjustment correction was lower by 19.60%. Therefore, it is assumed in this report that the average uncertainty due to compositional change is the average between the two thermal mass meters, therefore 18.85%.

In conclusion, by combining the uncertainties discussed above, the total uncertainty of the FT3 can be determined from equation (2-5) in subsection 2.2:

$$\sqrt{(0.005^2) + (0.002^2) + (0.01^2) + (.1885)^2} = 18.88\%.$$

3.2.5 List of related files / documentation

For *each* testing season (i.e. winter and summer), the following tests were performed on three FT3 meters used at the test site, namely:

- Calibration report for FT3 on top of riser (S/N 21773) – two curves (2 gas compositions)
- Calibration report for FT3 on PRV (S/N 21775) – two curves (2 gas compositions)
- Calibration report for FT3 on top of riser (S/N 21776) – three curves (3 gas compositions)
- Winter CAL-V calibration validation for S/N 21773
- Winter CAL-V calibration validation for S/N 21775
- Winter CAL-V calibration validation for S/N 21776
- Summer CAL-V calibration validation for S/N 21773
- Summer CAL-V calibration validation for S/N 21775
- Summer CAL-V calibration validation for S/N 21776
- As-Found calibration certificate for S/N 21773 (summer testing only)
- As-Found calibration certificate for S/N 21775 (summer testing only)
- As-Found calibration certificate for S/N 21776 (summer testing only)

3.4 Vane Anemometer

3.4.1 Description and principle of operation

The vane anemometer (also known as vane wheel flow sensor) is a mechanical velocity anemometer that measures velocity and volumetric flow rate. It is used in conjunction to the Fox thermal mass meters to measure the flash gas volumetric flow rate during a well cycle. A vane anemometer consists of a small vane wheel that rotates in the same axis of rotation as that of the flow, as illustrated in Figure 3-17.

Figure 3-17. Vane anemometer wheel [11]

The rotational speed of the vane wheel (denoted as "ω") is directly proportional to the velocity of the gas (e.g. air, flash gas etc.) based on the following equation (3-8):

$$U = \omega * r \tag{3-8}$$

Where:

U is the velocity of the measured gas (m/s)
ω is the rotational speed of the vane wheel (rad/s)
r is the distance of each cup from the rotational axis (m)

3.4.2 Output specifications

The vane anemometer used in the test site was connected directly to the pipe. Any changes to the pipe diameter and the velocity profile were made through a HART communicator via modem adapter for PC connection and UCOM PC software. The specification for the vane anemometer are illustrated in Table 3-15.

Table 3-15: Specifications of Vane Wheel Flow Sensor ZS25

Specification	mA output
Analog output flow	4–20 mA Maximum resistance = 500 Ohms
Output limit value or quantity pulse	Potential-free relay contact (normally-open), Max = 300 mA / 27 VDC
Power supply	24 VDC (20–27 VDC)
Power consumption	< 5 W

3.4.3 Summary of calibration procedures

The calibration process of the vane anemometer is incorporated in the Quality Management Systems (QMS) DIN EN ISO 9001:2008 and is carried out in close compliance with ISO 17025. A series of six data points of known air velocities is compared with the measured velocity recorded by the anemometer.

To perform the calibration process, the vane anemometer flow rate was recorded in a 75 mm pipe diameter and a profile factor[3] of 0.796. The recorded flow rate was converted into a velocity using the following equation (3-9):

$$v_{measured} = Q_{measured} * \frac{1}{A_{75mm}} * \frac{1}{3{,}600} * \frac{1}{PF_{75mm}} \quad (3\text{-}9)$$

Where:

$V_{measured}$ is the calculated velocity (m/s)
$Q_{measured}$ is the recorded flow rate (m^3/hr)
A_{75mm} is the cross sectional area of the pipe (m^2)
PF_{75mm} is the position factor based on a pipe diameter of 75mm ($v_{average}$ / v_{local} = 0.796)
3,600 is the conversion factor (seconds/hour)

3.4.4 Summary of calibration results

The vane anemometer was calibrated against six known reference velocities from 1 to 20 m/s. The deviations of the recorded velocities from the reference velocities were recorded and plotted with a tolerance limit[4], as shown in Figure 3-18.

[3] The profile factor (denoted PF) specifies the ratio of mean flow velocity in the measuring section and the flow velocity measured in the sensor.
[4] The measurement uncertainty has less than 1.5% of the measured value and 0.5% of terminal value.

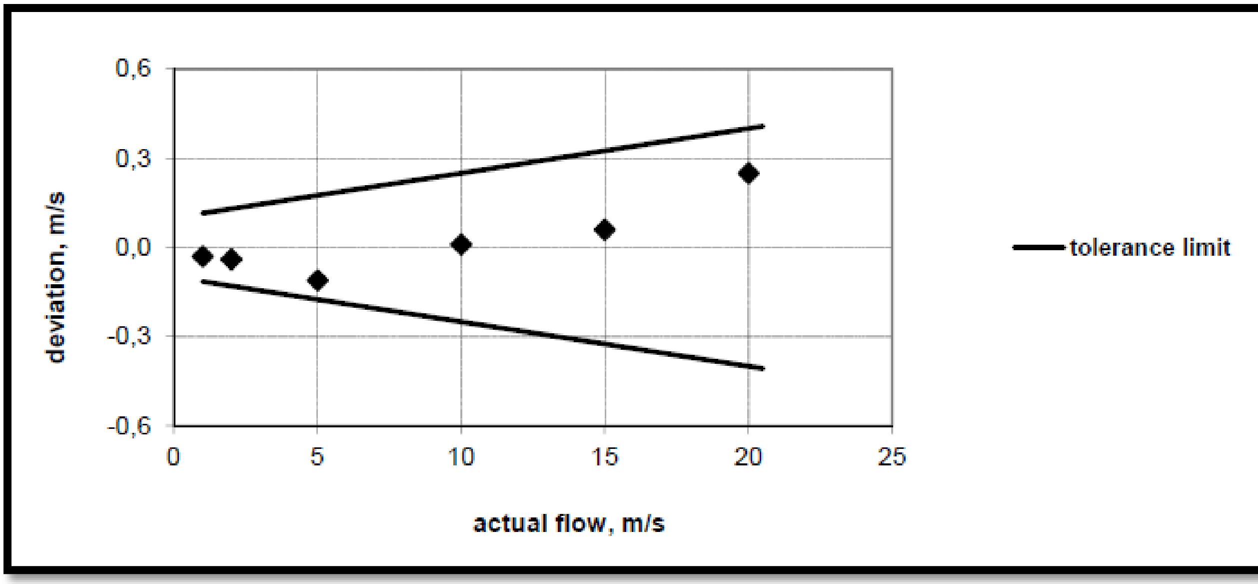

Figure 3-18. Vane anemometer calibration results with tolerance limit

Determination of measuring uncertainties

The measuring uncertainties shown on the calibration certificate are determined according to the "Guide of Expression of Uncertainty in Measurement". The expanded measurement uncertainties result from the standard measurement uncertainties being multiplied with the coverage factor k = 2. The value of the measureable variable lies as a rule with a probability of approximately 95% within the normal distribution. The standard uncertainty of measurement is determined according to DKD-3 / EAL – R2 (German translation of publication EAL-R2 Expression of the Uncertainty of Measurement in Calibration) [12].

Flow measurement in different pipe diameters

The in-situ measurements were conducted under a different pipe diameter than the calibration. Additionally, the calibration gas differs (in most cases) from the process gas being measured in the field, which consequently requires some adjustment to both the flow rate and the profile factor.

The actual local (i.e. centerline) velocity of the gas includes a gas density correction term that considers the density ratios, as show in equation (3-10):

$$v_{actual} = v_{measured} * \frac{v_{ref}}{v_{cal}} - v \tag{3-10}$$

Where:

v_{actual} is the actual local velocity (m/sec)
$v_{measured}$ is the local velocity measured by the vane anemometer from equation (3-9) (m/s)

v_{ref} is reference gas velocity from the vane anemometer calibration (m/s)
v_{cal} is the gas velocity measured by the vane anemometer during the calibration (m/s)
v is the gas correction value due to compositional change (m/s)

The density of gases can be strongly modified against pressure and temperature. Such severe modifications have a minor impact on the measured value of a vane wheel sensor. This impact manifests itself in a determinable correction value, which is added to or subtracted from the measured value. The percentage impact of this correction value is however negligible with average to high velocity flow. With low and very low values, consideration of the density correction becomes more expedient.

To determine this correction value the measuring range initial value (starting value) of a vane wheel is examined. The specified starting value in the vane wheel sensor (0.4 m/s) arises from a medium density of 1.204 kg/m³ (factory calibration). The only slightly deviating actual starting value, even with considerably different working density of the medium (in the actual application) ensues in good approximation of the following:

$$v_{0,real} = v_{0,spec} * \sqrt{\frac{1.204}{\rho_{real}}} \quad \text{(3-11a)}$$

Where:

$v_{0,real}$ is the actual smallest starting value (m/s)
$v_{0,spec}$ is the specified smallest starting value (m/s)
ρ_{real} is the actual gas density (kg/m^3)

The correction value is now the difference between real and specified starting value. The characteristic of the sensor is displaced by this value, as shown in equation (3-11b):

$$v = v_{0,real} - v_{0,spec} \quad \text{(3-11b)}$$

If the operating density of the medium is greater than the calibration density of 1.204 kg/m³, then the determined correction value must be deducted from the measured value. If it is less than the calibration density of 1.204 kg/m³, then the determined correction value must be added to the measured value.

Since the in-situ nominal pipe diameter is 3.068 inches (77.93 mm), a new profile factor is obtained to be 0.802. This results in a new equation to estimate the vane anemometer flow rate that is adjusted to pipe diameter and density change, based on the following equation (3-12).

$$Q_{actual} = v_{actual} * PF_{77.93mm} * A_{77.93mm} * 3{,}600 \quad \text{(3-12)}$$

Where:

Q_{actual} is the actual gas flowrate through the pipeline (m^3/hr)
v_{actual} is the actual local velocity (m/sec) – from equation (3-10)
$PF_{77.93mm}$ is the position factor based on a pipe diameter of 75mm ($v_{average}$ / v_{local} = 0.802)
$A_{77.93mm}$ is the cross sectional area of the in-situ pipe (m^2)
3,600 is the conversion factor (seconds/hour)

A post-summer, "as-found" test was performed on the vane anemometer (Figure 3-19), which attempted to check whether a drift in the anemometer's response has occurred during the testing period, as was indicated from the as-found test of the thermal meters used in adjacent to the vane anemometer during the summer testing period (Figures 3-19 and 3-20).

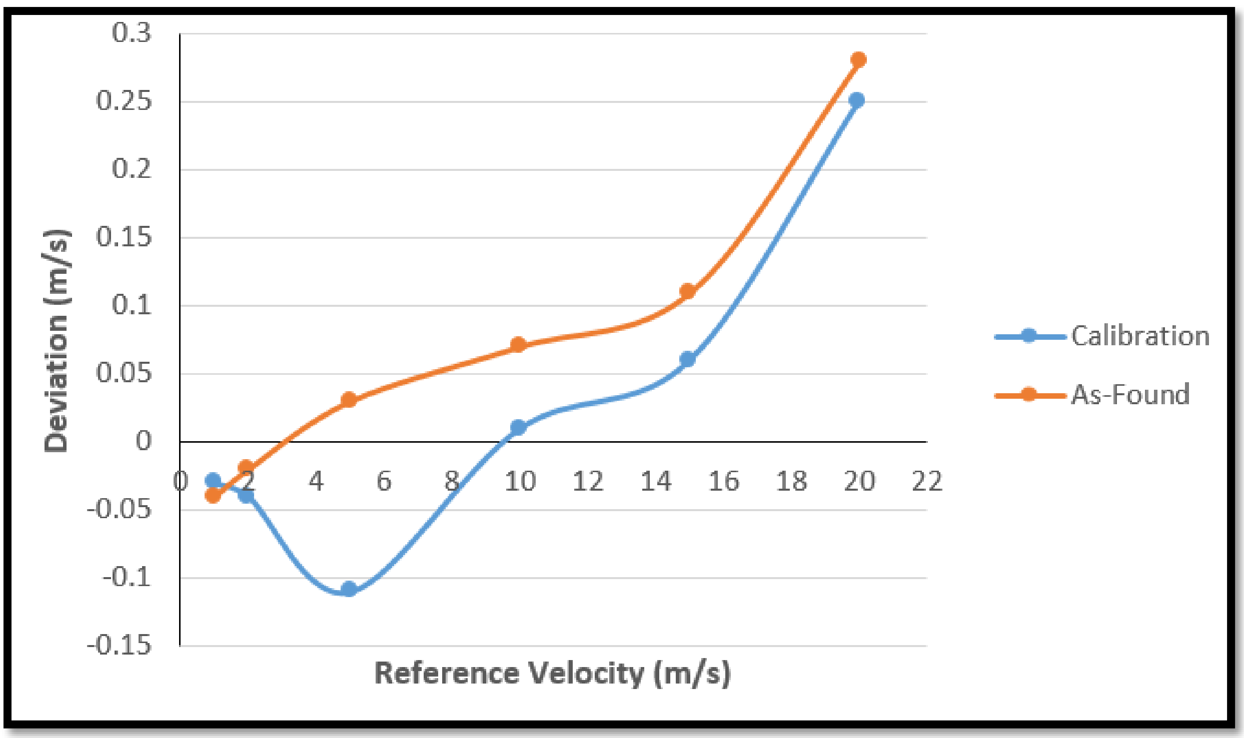

Figure 3-19. Pre-summer calibration and post-summer as-found tests for the vane anemometer

During active well-cycles, the typical highest instantaneous flow rate recorded by the vane anemometer was approximately 160 m^3/hr, or 9.3 m/s. However, for typical breathing losses during the day, the typical highest instantaneous flow rate was approximately 75 m^3/hr, or 4.3 m/s. As indicated from Figure 3-19, it is clear that the drift in the anemometer's response is the largest during lower flow rates, although it does not surpass 3%. This can be explained due to the fact that there are many more breathing cycles during the day than active well-cycles, which would most likely lead to higher fouling and consequently to a larger drift in the anemometer's response.

Similar to Figure 3-18, the as-found test is shown to be well within the tolerance limit of the measurements (less than 1.5% of the measured value and 0.5% of terminal value), as illustrated in Figure 3-20.

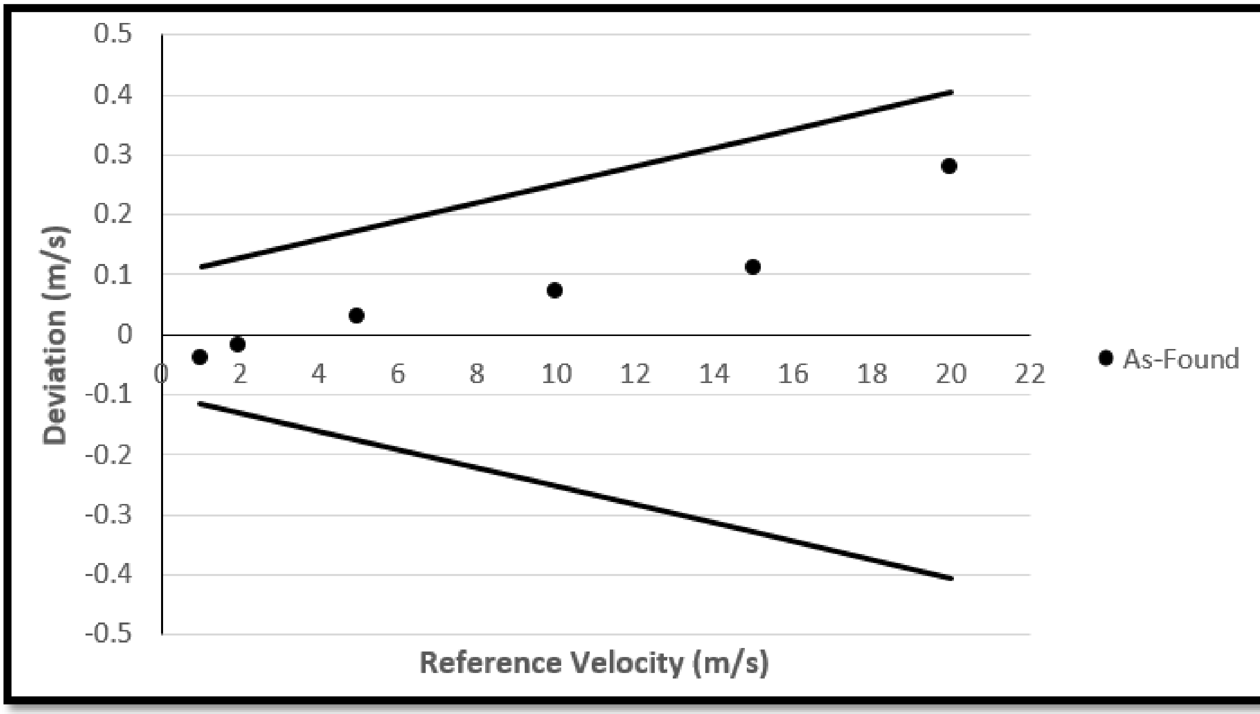

Figure 3-20. Tolerance limits (black lines) of as-found test (dots)

In conclusion, a drift was observed in the vane anemometer, in particularly at the flow velocity most common to its application (5 m/s), as explained above. However, since the as-found test has shown that the vane anemometer is within the measurement tolerance limits, no post-correction needs to be applied.

<u>Comparison of the vane anemometer with Fox thermal mass meters</u>

As discussed above, the main objective of the vane anemometer during this study was to serve as an additional check on the thermal mass meters, and *vice versa*. Since the vane is a mechanical velocity anemometer, whereas the Fox is a thermal mass meter, it was hoped that the two independent meter types would read similar values, therefore strengthening the estimation of the total gas volume produced during a cycle, a pertinent parameter for the mass balance calculations.

A comparison of the average gas flow rate during a well cycle, as recorded by the vane and computer for the two thermal mass meters (post-adjustment for compositional effect) is illustrated in Figure 3-21.

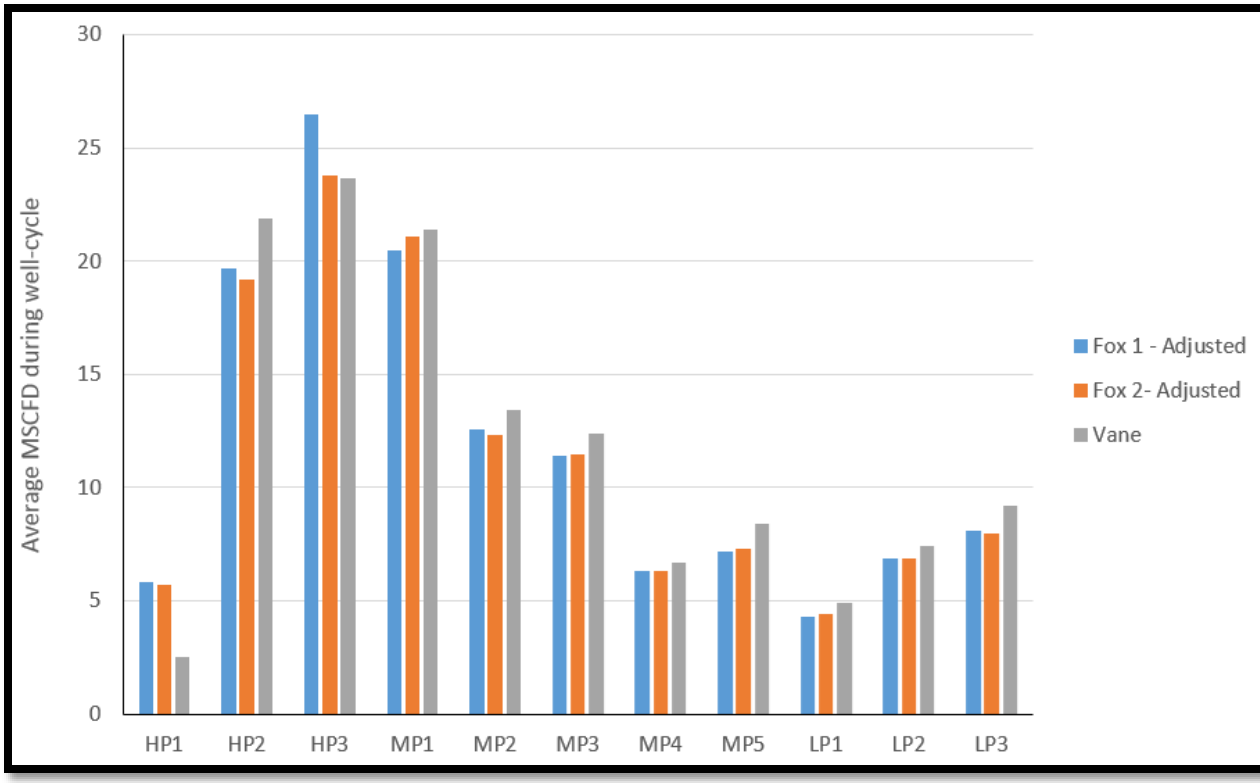

Figure 3-21. Comparison of the three gas meters during summer testing

After the compositional adjustment to the two Fox thermal mass meters, it is evident from Figure 3-21 that the three gas meters are in good agreement, aside from well cycle HP1 which had technical difficulties.

3.4.5 List of related files / documentation

- Vane anemometer operating manual
- Vane anemometer calibration certificate
- Vane anemometer as-found certificate

3.5 ABB Total Flow

3.5.1 Description and principle of operation

The in-situ ABB total flow is a device that measures the gas flow rate going from the high pressure separator to the sales line. The total flow measures the gas flow rate by a pressure differential (in inches of water), which can be converted to flow rate if the orifice size is known, as shown in equation (3-13) [14]:

$$Q_v = 7709.61 * E_v * Y_1 * C_d * d^2 * \sqrt{\frac{Z_s * P_{f1} * h_w}{G_r * Z_{f1} * T_f}} \qquad (3\text{-}13)$$

Where:

Q_v is the standard volume flow rate (standard ft^3/hr)
C_d is the orifice plate discharge coefficient[5] (dimensionless)
E_v is the velocity approach factor (dimensionless)
Y_1 is the upstream gas expansion factor (dimensionless)
d is the orifice bore diameter (inches)
G_r is the real gas relative density (dimensionless)
Z_s is the compressibility factor of gas at standard conditions (dimensionless)
Z_{f1} is the compressibility factor of the upstream gas at flowing conditions (dimensionless)
P_{f1} is the upstream pressure (psia)
T_f is the absolute temperature of gas at flowing conditions (degree Rankine)
h_w is the differential pressure (inches of water at 60^oF)

The velocity approach factor, E_v, relates to the geometry of the meter run by relating the velocity of the flowing fluid in the upstream pipe to the velocity in the orifice bore, as shown in equation (3-14) [14]:

$$E_v = \frac{1}{\sqrt{1-\beta^4}} \qquad (3\text{-}14)$$

Where:

β is the ratio of the orifice bore diameter to the pipe diameter.

The gas expansion factor, Y_1, relates to the geometry of the meter run, the fluid properties and the pressure drop. It is an empirical term used to adjust the coefficient of discharge to account for the change in the density from the fluid's velocity change and static pressure change as it moves through the orifice, as shown in equation (3-15) [14]:

[5] This is an empirical term that relates to the geometry of the meter run and relates the true flow rate to the theoretical flow rate. An approximate value is 0.6 (i.e., a square edged orifice passes about 60% of the flow one would expect through a hole the size of the orifice bore).

$$Y_1 = 1 - (0.41 + 0.35\beta^4)\frac{h_w}{27.707\kappa * P_{f1}} \quad (3\text{-}15)$$

Where:

κ is the isentropic exponent of the gas = C_p/C_v (dimensionless)

The real gas relative density is a property of the fluid and is defined in equation (3-16) [14]:

$$G_r = \left(\frac{MW_{gas}}{MW_{air}}\right)\left(\frac{Z_{b,air}}{Z_{b,gas}}\right) \quad (3\text{-}16)$$

Where:

MW_{gas} is the molecular weight of the measured gas (lb/lb-mol)
MW_{air} is the molecular weight of air (lb/lb-mol)
$Z_{b,air}$ is the compressibility factor of air at 14.73 psia and 60^{o}F
$Z_{b,gas}$ is the compressibility factor of the measured gas at 14.73 psia and 60^{o}F

3.5.2 Output specifications

Table 3-16: Specifications of ABB Total Flow (Model XFC G4 6413)

Specification	mA output
Analog input flow	0–5 VDC (Maximum resistance of 250 ohms)
Pulse input bandwidth	Up to 20 kHz
Maximum allowable voltage range (input)	-0.5 VDC to 15 VDC
Maximum allowable voltage range (output)	0.5 VDC to 26.5 VDC
Power supply	Battery 12 VDC
Charger	Solar of 14–26 VDC

3.5.3 Summary of calibration procedures

The main calibration tests of the ABB total flow include the following tests with accuracy traceable to NIST:

a. Calibration of the static pressure: 3 data points are applied to the cell from a known traceable source with resultant pressure values entered into the XFC G4 using PCCU software: (1) atmospheric pressure; (2) 50% of upper range limit (URL) and (3) 100% of URL (500 psia).
b. Calibration of the differential pressure: 3 data points are applied to the cell from a known traceable source with resultant pressure values entered into the XFC G4 using PCCU software: (1) zero; (2) 50% of URL and (3) 100% of URL (250 inches of water).

c. Calibration of thermoprobe: The calibration procedure are based on ASTM E-644-06. The probe is immersed in a constant temperature bath with a reference thermometer that determines the actual test temperature. The readings are compared, and correction factors for the probe are calculated. Verification of the thermoprobe is done at one point, as close to operating temperature as practical. The verification is done using a test thermos-well, thermometer and flowing gas temperature (if gas is flowing) or a bath and test thermometer. Must be calibrated to within ±0.5% of reading of calibration equipment reading.

From equation (3-13) it is evident that an inverse correlation exists between the recorded flow rate and the gas temperature. Furthermore, a direct relationship exists between the recorded temperature and pressure, therefore if the meter is all meters are not calibrated correctly, lower flow rates will be measured.

The calibration process is typically performed for orifice meters with beta ratios (orifice to pipe diameter ratio, d/D) from 0.20 to 0.60 on flange tap meters. However, unless otherwise approved or required by the BLM, the low flow cutoff (set up by the user) cannot be set higher than 0.5 inches of water otherwise the possible pulsation effects can be considered as a flow, even when the downstream valve (of the ABB total flow) is shut in (per requirement of API 21.1.4.2.3).

3.5.4 Summary of calibration results

Two calibration tests were performed on the ABB Total Flow meter prior to the winter and summer phase testing weeks. For each calibration test performed, if the as-found values were not within the uncertainty range, a new calibration has to be performed. These ranges are:

a. For the static pressure: ±0.25% (accuracy of the electronic flow meter) of the calibration equipment set point must be calibrated.
b. For the differential pressure calibration: ±0.12% (accuracy of the electronic flow meter).
c. For the temperature calibration: ±0.50% of reading.

A comparison between a standard and the as-found measurements was performed for the static pressure, differential pressure and the temperature, as shown below in Tables 3-17 through 3-19.

Table 3-17: ABB's Static Pressure Calibration

Standard (psia)	As-found "Winter" (psia)	Flow Rate Error%	As-found "Winter" (psia)	Flow Rate Error%
0.00	12.41	0.45	12.28	-0.08
250.00	262.56	0.05	262.10	-0.04
500.00	512.36	0.01	512.06	-0.02

Table 3-18: ABB's Differential Pressure Calibration

Standard (inches of water)	As-found "Winter" (inches of water)	Flow Rate Error%	As-found "Winter" (inches of water)	Flow Rate Error%
0.00	-0.01	0.45	0.00	
125.00	124.97	-0.05	125.01	0.00
250.00	249.94	-0.01	249.95	-0.01

Table 3-19: ABB's Temperature Calibration

Testing Season	Standard (^oF)	Winter "Actual" (^oF)	Flow Rate Error%
Winter	56.07	55.46	0.55
Summer	95.96	96.15	-0.10

The above tables indicate that the three major calibration parameters of the ABB Total Flow meter (static pressure, differential pressure and thermometer) have accuracy traceable to NIST, which implies that the recorded sales gas flow rates are representative of the actual flow rates of the tested high-pressure separator.

3.5.5 List of related files / documentation

- Calibration certification on the thermoprobe (measures temperature)
- Certification on the pressure equipment used to calibrate the total flow gas meter
- ABB Total Flow calibration certificate (static pressure, differential pressure and temperature) from 02/26/2016.
- ABB Total Flow calibration certificate (static pressure, differential pressure and temperature) from 07/20/2016.

3.6 Liquid Level Sensor (2100 DLS)

3.6.1 Description and principle of operation

The 2100 digital level sensor (DLS) is a device that measures and reports fluids level and temperatures in storage tanks. The sensor uses a float imbedded with magnets to sense the top of a liquid level. There is a temperature sensor mounted inside the tube one-foot from the bottom. When the sensor is polled for data, a series of microprocessors read and determine the position of the float along the sensor tube. The main microprocessor then calculates the level and temperature and returns the data in a serial stream. Additionally, the DLS monitors up to eight temperature sensors (RTD8 through RTD15) in the same tank at different heights.

3.6.2 Output specifications

Table 3-20: Model 2100 DLS Specifications

Category	Specification
Operating temperature range	(-)40°C–85°C
Power supply	5.6–12.9 VDC
Output signal	4–20 mA (when connected to digital-to-analog converter board)
Power consumption	15 mA nominal 20 mA maximum

3.6.3 Summary of calibration procedures

The only calibration required for the DLS is to set the offset value using the HHC-1000 Hand-Held Communicator. This can be done in the DLS or at the Electronic Flow Measurement (EFM), Remote Terminal Unit (RTU) or Programmable Logic Controller (PLC) by determining the difference of the level between the electronic reading and the actual fluid level in the tank, measured with an approved gauge line. Once the level offset is entered in either the DLS or SCADA system, the level offset will be added to the raw value of the DLS to provide and accurate fluid level.

The calibration procedure to set the initial offset is as following:

a. Using the Hand-Held Communicator (HHC-1000), connect to the DLS and take initial readings of level and temperature.
b. If readings are providing both water and oil levels, then verify that the two readings are more than 3 inches apart. If the difference is less than 3 inches, the two floats will be touching and a valid offset cannot be determined.

c. Verify that the water level is more than 3 inches. If less than 3 inches, then the water float is sitting on the bottom of the tank and level offset cannot be determined.
d. Using a gauge line, measure the actual level in the tank and note the level. Subtract the electronic reading from the gauged level to determine the level offset value.

As an example, if the actual level is 156.25” and the DLS reading is 155.50”, then the offset value will be 0.75” (156.25-155.50=0.75).

The temperature offset is determined by comparing the digital temperature signal from the in-situ sensors to a calibrated temperature sensor and obtaining the difference in temperature. This offset is added to or subtracted from the reported temperature and input into the EEPROM in the sensor. The level offset, for accuracy, can only be performed in the field in a tank that has sufficient fluid to raise the float. Since the float will float on the surface of a fluid at varying levels due to the specific gravity of the fluid, this can only be performed while the sensor is in service. This offset will only need to be performed once, during installation, since the buoyancy of the float will not change, and the specific gravity of the fluid is fairly constant.

3.6.4 Summary of calibration results

An as-found test on the liquid level sensor which was compared with a manual gauge was performed on 11/9/2016 prior to well cycle (1) and post-well cycle (2), as shown in Figure 3-22.

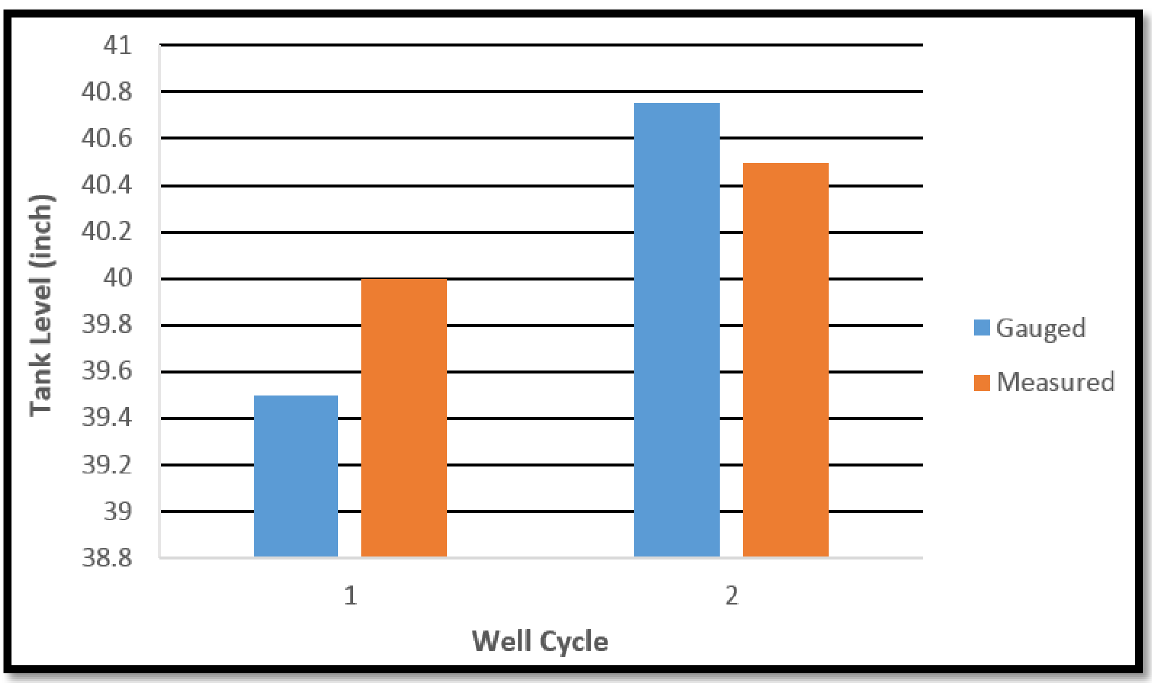

Figure 3-22. As-found test on the liquid level sensor

The as-found test indicates an average difference of ±3/8”, which is higher than the manufacturer’s specifications for this sensor (1/8”). This observed difference is consistent with field observations performed during the winter and summer testing periods.

Unlike the level sensor, an as-found test on the eight temperature sensors was not performed, since it was only done during installation (as indicated in the previous section). The temperature offset for each of the eight temperature sensors is summarized in Table 3-21.

Table 3-21: Temperature Offset of DLS Sensors

Data logger ID	Location	Temperature Offset (^oF)
RTD 8	In tank, cernterline, 14” above tank bottom	0
RTD 9	In tank, cernterline, 32” above tank bottom	0.5
RTD 10	In tank, cernterline, 52” above tank bottom	0.5
RTD 11	In tank, cernterline, 72” above tank bottom	1.5
RTD 12	In tank, cernterline, 92” above tank bottom	0.5
RTD 13	In tank, cernterline, 112” above tank bottom	2.0
RTD 14	In tank, cernterline, 135” above tank bottom	1.5
RTD 15	In tank, cernterline, 152” above tank bottom	-0.4

3.6.5 List of related files / documentation

- Digital Level Sensor 2100 – User Manual
- Temperature sensors calibration

3.7 Solar Radiation Meter (Pyranometer)

3.7.1 Description and principle of operation

A pyranometer measures the solar radiation received by a plane surface from a 180° field of view angle. The radiation, expressed in W/m^2, is called "hemispherical" solar radiation, covering a radiation spectrum between 285 and 3000 nm (see Figure 3-23). The pyranometer has two main components:

(1) A thermal sensor with black coating that absorbs all solar radiation and, at the moment of absorption, converts it to heat. The heat flows through the sensor to the sensor body. The thermopile sensor generates a voltage output signal that is proportional to the solar irradiance.

(2) A glass dome that limits the spectral range from 285 to 3000 nm, while preserving the 180° field of view angle. Another function of the dome is that it shields the thermopile sensor from the environment (convection, rain).

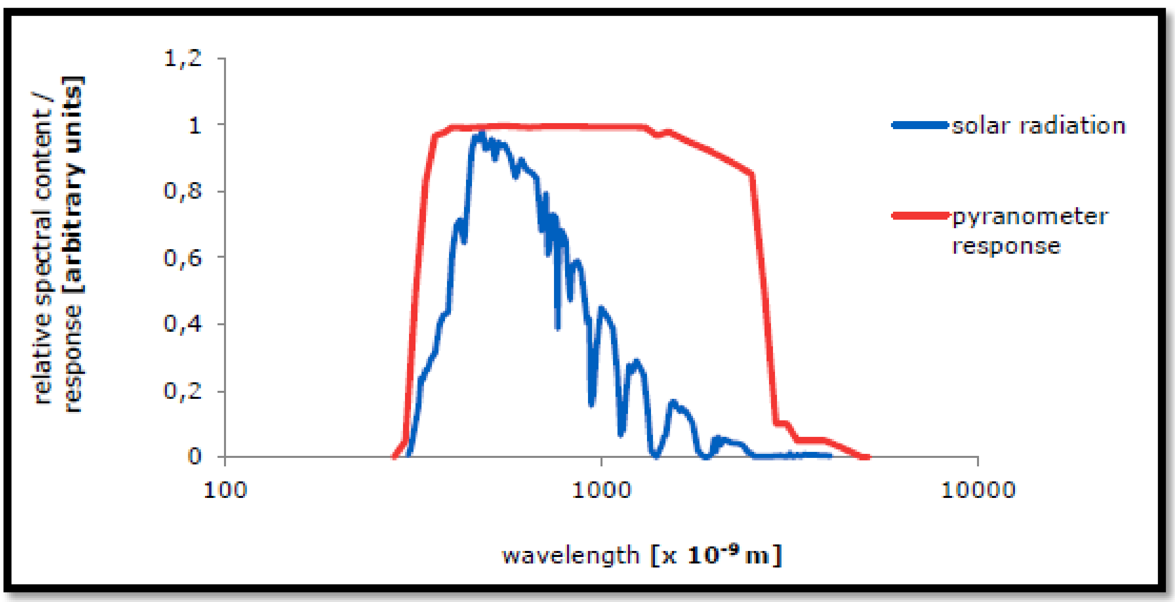

Figure 3-23. Spectral response of the pyranometer compared to the solar spectrum [16]

3.7.2 Output specifications

The SR05-DA2 measures irradiance in W/m^2 as a digital output and as a 4-20 mA output. It must be used in combination with suitable power supply and a data acquisition system which uses the Modbus communication protocol over TTL or one that is capable of handling a 4-20 mA current loop signal.

Table 3-22: Specifications of SR05-DA2

Specification	Value	Winter	Summer
Transmitted range	0–1600 W/m^2		
Supply voltage	5–30 VDC		
Analog output flow	4–20 mA		
Power consumption	< 240 mW at 12 VDC		
Response time	11.1 seconds		
Accuracy class[6]		Minute: <11.4% (±182.4 W/m^2)	Minute: <8.4% (±134.4 W/m^2)
		Hour: <9.9% (±158.4 W/m^2)	Hour: <6.2% (±99.2 W/m^2)
		Day: <8.1% (±129.6 W/m^2)	Day: <5.9% (±94.4 W/m^2)

3.7.3 Summary of calibration procedures

The SR05 is calibrated based on ISO 9847 (1992): Solar Energy – "calibration of field pyranometers by comparison to a reference pyranometer" [15] and is recommended by the manufacturer to be repeated every two years. The calibration procedure depends whether it is performed indoors or outdoors. The SR05 manufacturer (Hukseflux) calibrates based on the indoor calibration, therefore this procedure will be described in this sub-section. Calibration traceability was done based on the WRR (World Radiometric Reference) maintained at the World Radiation Center in Davos, Switzerland.

An overview of the indoor calibration procedure goes as following [15]:

a. The reference and test pyranometers are aligned together at the same orientation so that the hemispheres are geometrically symmetrical.
b. The reference and test pyranometers are connected to a common digital voltmeter, using a proper shielding. Once connected, the electrical continuity, signal polarity, signal strength and stability are compared.
c. The loci of both instruments is compared to test whether the two instruments receive the same irradiance.
d. Either:
    I. An instantaneous voltage readings of 21 points of the reference and test pyranometers is taken simultaneously. Or:
    II. Simultaneous integrated voltage readings of the reference and test pyranometers are taken over a minimum of five periods of sufficient length (8 minutes typically) to ensure an accuracy of 0.25% and a precision of ±0.25%.

[6] Accuracy values refer to mid-latitude conditions.

e. The bodies' temperature of both instruments are taken, as well as of the wall of the integrating sphere.
f. A general mathematical treatment described in section 5.4.1 of ISO 9847 is applied.

3.7.4 Summary of calibration results

The SR05 that was used in the test-site was well within the recommended two-year calibration window suggested by the manufacturer. The calibration results are as following:

a. Sensitivity: $S = 20.02 \times 10^{-6}$ V/(W/m^2)
b. Uncertainty: $\pm 0.24 \times 10^{-6}$ V/(W/m^2)

The Sensitivity of the test SR05 is 0.01 mA/(W/m^2). The calibration uncertainty of the SR05 (i.e. expanded uncertainty, K-2 coverage factor) as stated by the factory is 1.8%. The key specification criteria impacting measurement uncertainty at the field level are: calibration uncertainty, temperature response, directional response, and routine sensor maintenance (i.e. cleaning and checking instrument leveling).

3.7.5 List of related files / documentation

The following information is related to the SR05 pyranometer:

- Product certificate (including calibration results)
- SR05 manual

4.0 Pressure Indicating Transducer (PIT)

4.1 Background

A pressure transducer (often called a pressure transmitter) is a device that senses pressure and converts it into an electric signal where the amount depends upon the pressure applied. A pressure transducer consists of two main parts: (1) an elastic material which will deform when exposed to a pressurized medium (e.g. gas or liquid); and (2) an electrical device which detects the deformation.

The conversion of pressure into an electrical signal is achieved by the physical deformation of strain gages which are bonded into the diaphragm of the pressure transducer. Electrical resistance is proportional to the resistivity and length of the pressure-sensor channel and inversely proportional to the cross-sectional area of the channel according to the electric-resistance theory form given by equation (4-1):

$$R = \rho \left(\frac{l}{A}\right) \tag{4-1}$$

Where:

R is the electrical resistance (ohms)
ρ is the resistivity (ohms*m)
l is the length of the pressure sensor (m)
A is the cross-sectional area of the pressure sensor (m^2)

Pressure applied to the pressure transducer produces a deflection of the diaphragm, therefore changing its cross-sectional area. This change introduces a strain to the silicon gages within the sensor assembly. The differential pressure transducer measures the difference between two pressures applied to opposite sides of the silicon strain gauge microsensor. The resistance change is then converted to 4 to 20 mA signal (be taken into an analog input card in the PLC or it may be taken to a strain gage conditioner card in an instrumentation system) proportional to the square root of differential pressure.

Pressure transducers are generally available with three types of electrical output: (1) millivolt; (2) amplified voltage; and (3) 4-20 mA. In general, this chapter will address the different transducers in accordance with the above classification, such that [17]:

1. Pressure sensor (voltage output is normally around 30 millivolts): The actual output is directly proportional to the pressure transducer input power or excitation. If the excitation fluctuates, the output will change also. Because of this dependence on the excitation level, regulated power supplies are suggested for use with millivolt

transducers. Due to the low output signal, the pressure sensor is very susceptible to electrical noise.

2. Pressure transducer (voltage output is normally 1–5 VDC): Includes integral signal conditioning which provide an amplified voltage output than a millivolt transducer. The output of the transducer is not normally a direct function of excitation, therefore unregulated power supplies are often sufficient as long as they fall within a specified power range. Due to the higher level output (compared to pressure sensors), the pressure transducer is not as susceptible to electrical noises, thus making it very applicable to use in many industrial applications.
3. Pressure transmitter (4-20 mA signal): The 4-20mA signal is least affected by electrical noise and resistance in the signal wires, thus these transducers are best used when the signal must be transmitted long distances (not when lead wire is longer than 1000 ft).

4.2 PIT1

4.2.1 Description and principle of operation

PIT1 is a pressure transducer manufactured by Foxboro. It is located on the high-pressure separator's headspace volume. It is used in conjunction with PIT6 to (downstream of it) to determine the true pressure reading of the high pressure separator, which was manipulated by a back-pressure regulator.

4.2.2 Output specifications

Table 4-1: Specifications of PIT1

Specification	Value
Pressure range	0–500 psig
Analog input flow	9–30 VDC
Analog output flow	1–5 VDC
Accuracy class	±2% of measured flow

4.2.3 Summary of calibration procedures

The factory based calibration is characterized over the full rated differential pressure of the transducer. The applied differential pressure is measured and converted into an internal digital value that is always available (regardless if the transducer is or is not calibrated). This allows the transducer to measure any applied differential pressure within its range limits regardless of the calibrated range.

The transducer is factory calibrated to either a specified or a default calibration range. This calibration optimizes the accuracy of the internal digital value of differential pressure over that range (that is, calibration assures that the transducer rated accuracy is achieved over the calibration range). If no range is specified, the default range is zero to the sensor upper range limit (URL).

Field calibration is performed in-situ and is done based on a "3-point linear" method, where the lowest, highest and mid-point transducer's ranges are selected to test its functionality.

<u>In-situ calibration procedure ("3-point linear"):</u>

a. The pressure transducer is brought to atmospheric pressure to calibrate LOW_ADC. This calibration is done in the PLC by comparing RAW_ADC value to LOW_ADC value and adjusting LOW_ADC to match RAW_ADC value.
b. The pressure transducer is isolated and pressurized to max range to calibrate HIGH_ADC. This calibration is done in the PLC by comparing RAW_ADC value to HIGH_ADC value and adjusting HIGH_ADC to match RAW_ADC value.
c. The pressure transducer is isolated and pressurized to mid-range to verify linear calculation.
d. The pressure transducer will be blown down to atmospheric pressure and the LOW_ADC value will be adjusted. Then the PIT is pressurize to its maximum range (500 psig for PIT1) and the HIGH_ADC value is adjusted. Afterwards, the pressure is released down to the mid-range pressure (250 psig for PIT1) and verification that the above calculation is delivering an EU reading of 250 psig is performed. In the event that EU is reading incorrectly at mid-range, a second calibration test will be performed. In the event that EU reads incorrectly a second time, the PIT will be replaced and all calibration steps for this specific PIT will be repeated.

The engineering unit value from the analog transducer is determined (e.g. for PIT1 in this case) in the PLC using equation (4-2):

$$PIT1 = \left\{\left[\frac{(PIT1_{Raw\_ADC} - PIT1_{Low\_ADC})}{(PIT1_{High\_ADC} - PIT1_{Low\_ADC})}\right] * PIT1_{Range}\right\} + PIT1_{Low\_EU} \qquad (4\text{-}2)$$

Where:

$PIT1_{Raw\_ADC}$ is the current reading of the ADC
$PIT1_{Low\_ADC}$ is the reading of the ADC at the bottom of the range
$PIT1_{High\_ADC}$ is the reading of the ADC at the top of the range
$PIT1_{Range}$ is the total range of the analog device (e.g. 0 psig to 500 psig → Range = 500 psig)
$PIT1_{Low}$ is the calculated pressure at the bottom of the range

4.2.4 Summary of calibration results

The manufacturer did not produce a calibration certificate for this meter.

An “as-found” test performed on the transducer post-summer testing was carried out in-situ. The actual pressure readings were compared with five pressure points: 0 psig (smallest range), 175 psig (low pressure group category), 225 psig (medium pressure group category), 260 psig (high pressure group category) and 500 psig (maximum range) as illustrated in Figure 4-1.

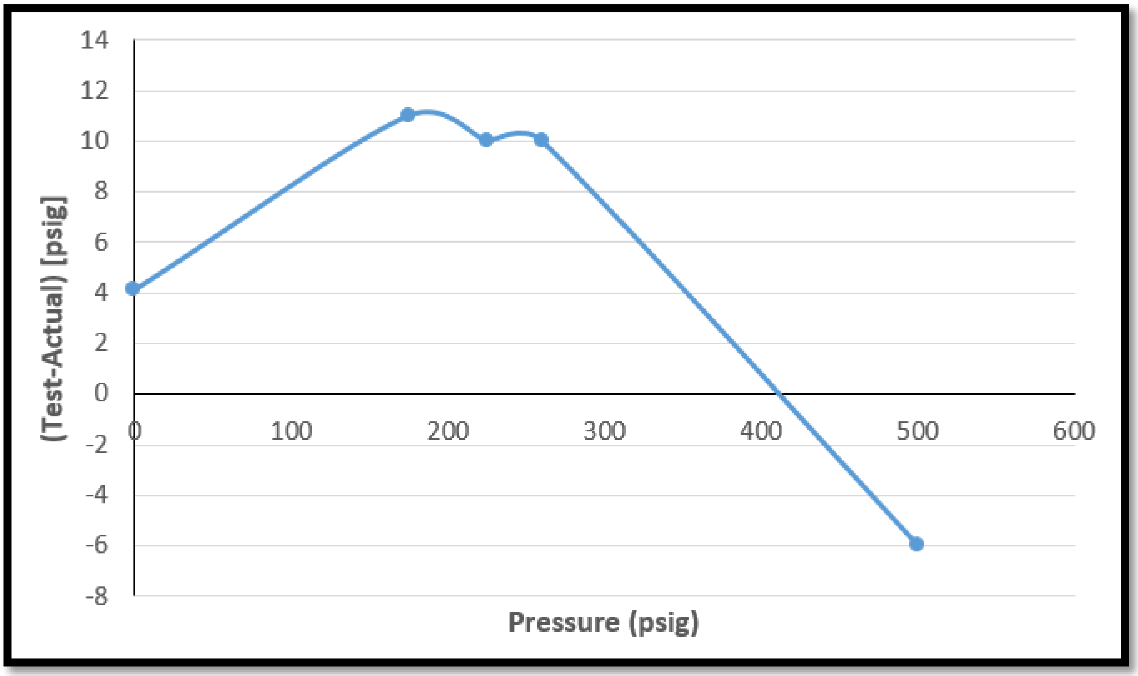

Figure 4-1. As-found test of PIT1

As illustrated from Figure 4-1, the as-found test indicates that the pressure transducer was over-reading the pressure by approximately 10 psig for the desired pressure ranges pertinent to the study. Nevertheless, since the as-found test carried out three months after the conclusion of the summer phase testing, the effect of time on the transducer’s reading is unknown.

4.2.5 List of related files / documentation

- Instruction manual for I/A Series Pressure Transmitters (Foxboro).

4.3 PIT2

4.3.1 Description and principle of operation

PIT2 is a pressure transducer manufactured by Ashcroft. It is located at the bulk tank headspace, measuring the gas headspace pressure (in oz/in^2). The upper range of PIT2 extends up to 24 oz/in^2, therefore implying that the typical gas pressures experienced at the tank headspace is well within its measurement range (i.e. ~14-15 oz/in^2 maximum).

4.3.2 Output specifications

Table 4-2: Specifications of PIT2

Specification	
Pressure range	0–1.5 psig
Analog input flow	10–30 VDC
Analog output flow	1–5 VDC
Temperature range	(-)4–185°F
Accuracy class	±0.5% of span (total error band)

4.3.3 Summary of calibration procedures

The pressure transducer is logged into a temperature compensated oven and is leak tested at full scale. The transducer is then run through calibration at different temperatures and is linearized at zero pressure, mid pressure and full scale pressures. This is done several times over the temperature specification range.

The manufacturing company of PIT2 (Ashcroft) performs the calibration process based on 9 point individual NIST-traceable chart. Nine different pressure points are selected so that the output (in VDC) is recorded. The certified calibration chart made per ASME B40.100 2013 (“Pressure gauges & attachments”) includes an accuracy range that was determined after considering non-linearity (terminal point method), hysteresis[7], non-repeatability, zero offset and span setting errors.

For in-situ calibration, see guidelines set forth in sub-section 4.2.3.

4.3.4 Summary of calibration results

Using the calibration procedure discussed above, the transducer’s accuracy was tested using nine pressure points. Calibration results indicated that all nine points were within the ±0.5% accuracy reading, with the highest uncertainty margins being between 45% and 75% of the

[7] The maximum deviation between the increasing and decreasing characteristic curves.

pressure (10.8 and 18 oz/in^2, respectively). All nine points had a positive error band, meaning that the instrument was over-reading the pressures. Summary of the calibration results is illustrated in Figure 4-2.

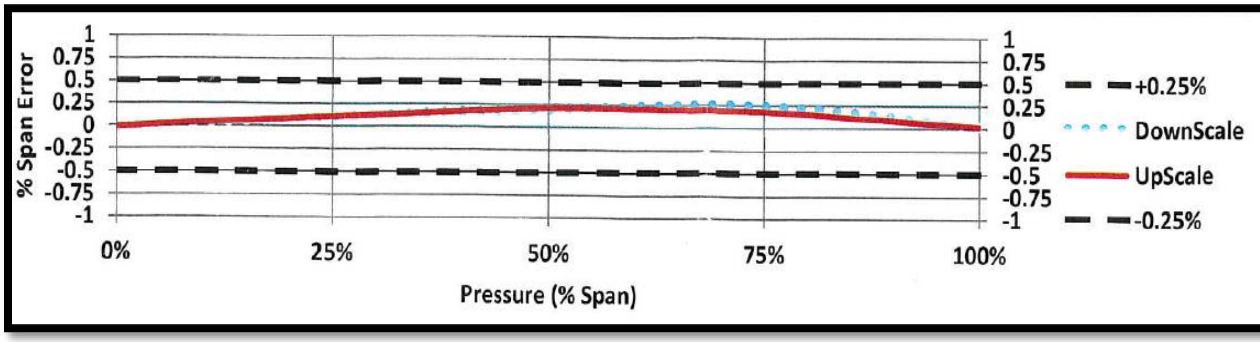

Figure 4-2. Calibration result of PIT2

An "as-found" test performed on the transducer post-summer testing was carried out in-situ. The actual pressure readings were compared with eight pressure points that are typical with the pressure reading of the tank headspace: 0 oz/in^2 (smallest range), 2 oz/in^2, 4 oz/in^2, 6 oz/in^2, 8 oz/in^2, 12 oz/in^2, 16 oz/in^2 and 24 oz/in^2 (maximum range) as illustrated in Figure 4-3.

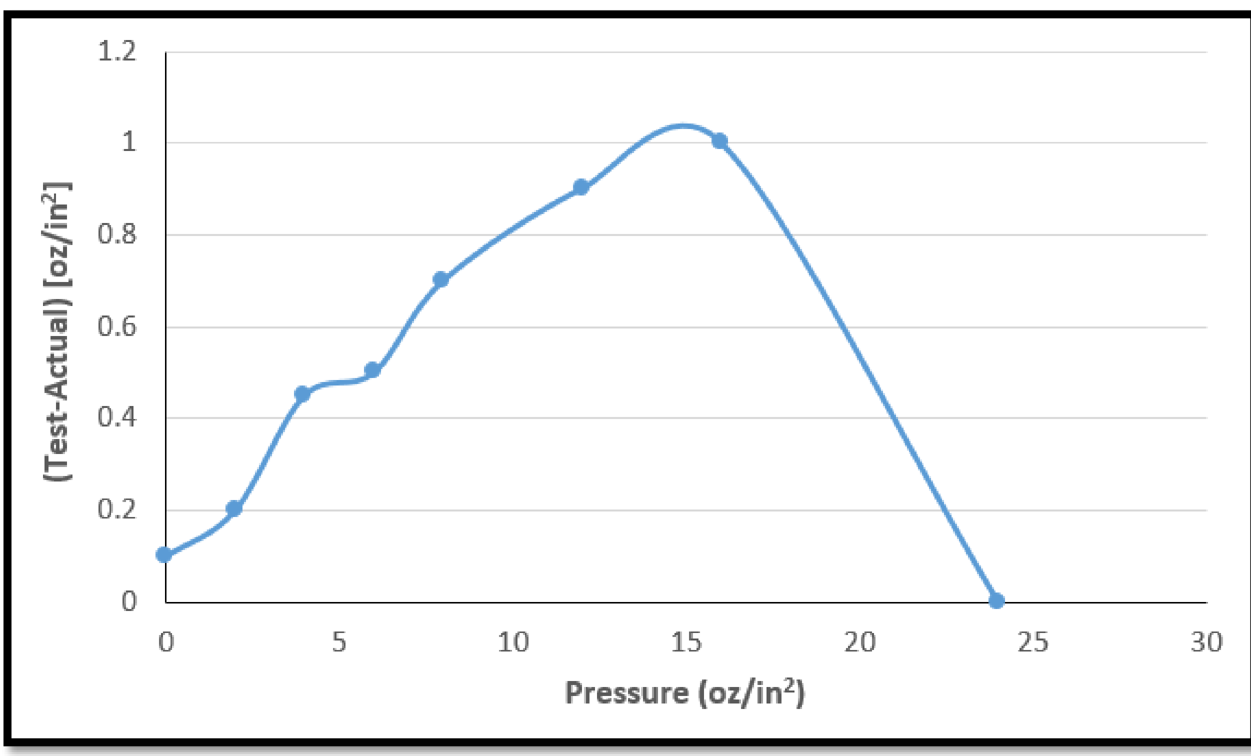

Figure 4-3. As-found test of PIT2

The as-found test performed on the transducer indicates a similar trend of having higher percentages of error for increasing pressure. Additionally, all data points are over-reading the pressures, which is another similarity to the original calibration certificate (i.e. a positive error band).

4.3.5 List of related files / documentation

- Calibration certificate from manufacturer.

4.4 PIT3

4.4.1 Description and principle of operation

PIT3 is a low-pressure transducer manufactured by American Sensor Technology, located at the tank VOC burner line (also known as "riser"). It has a very low pressure range (0-2 psig), which makes it suitable for the pertinent measurement of flash gas pressure exiting the storage tank.

4.4.2 Output specifications

Table 4-3: Specifications of PIT3

Specification	
Pressure range	0–2 psig
Analog input flow	10–28 VDC
Analog output flow	1–5 VDC
Accuracy class	< ±0.5% of measured value for 0-1 psig

4.4.3 Summary of calibration procedures

One test voltage between 10 and 28 VDC is selected, as the sensors will operate the same throughout this range. The pressure transducer is final tested in room temperature at zero pressure, midpoint pressure (1 psig) and full pressure (2 psig) with the corresponding output signals listed at zero pressure, full span and non-linearity. If the transducer meets the specifications in the data sheet (e.g. 1 VDC for zero pressure and < 5 VDC for max rated pressure etc.), the calibration report would read "Pass".

4.4.4 Summary of calibration results

A test voltage of 17 VDC was used to test the sensor functionality during the calibration process. At zero pressure the voltage reading was 0.998 whereas at full span the voltage reading was 4.005, with very small non-linearity (0.06%). This indicates that the sensor passed the calibration test.

In addition to the calibration test, an in-site as-found test was carried out post-summer testing at the test site, using the procedure discussed in sub-section 4.2.3. Similar to PIT2, the actual pressure readings were compared with eight pressure points that are typical with the pressure reading of the tank headspace: 0 oz/in^2 (smallest range), 2 oz/in^2, 4 oz/in^2, 6 oz/in^2, 8 oz/in^2, 12 oz/in^2, 16 oz/in^2 and 32 oz/in^2 (maximum range) as illustrated in Figure 4-4.

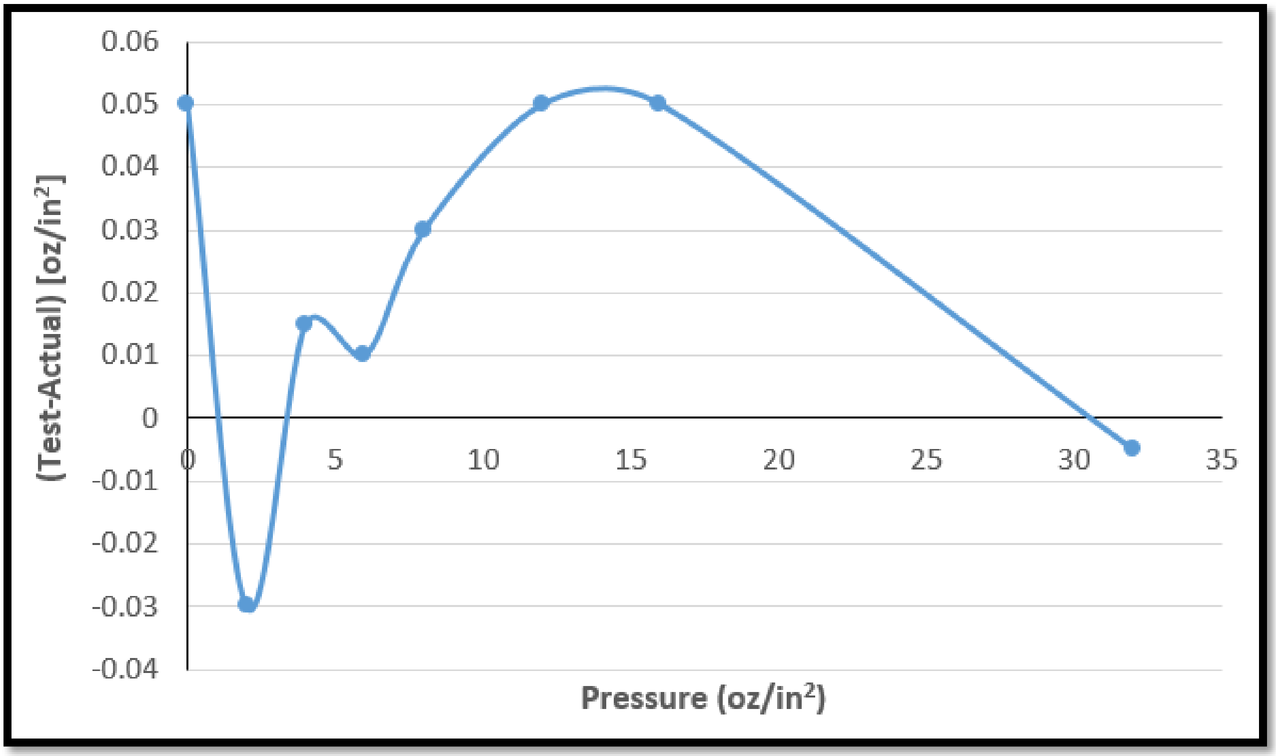

Figure 4-4. As-found test of PIT3

The as-found test on PIT3 has indicated that the pressure transducer reads very accurate values to the test pressure, as indicated by the small pressure differences. Based on the test, the average percent difference between the as-found and the calibrated values is approximately 0.45%, which is within the accuracy listed by the manufacturer, therefore giving a confidence that the pressure transducer has measured accurate pressure readings during the study.

4.4.5 List of related files / documentation

- Calibration certificate from manufacturer
- Data sheet of pressure transducer

4.5 PIT4

4.5.1 Description and principle of operation

PIT4 is a low-pressure transducer manufactured by Dylix Corporation. PIT4 measures the atmospheric pressure at the test site, and is located in the automation stand at the south-east corner of the storage tanks.

4.5.2 Output specifications

Table 4-4: Specifications of PIT4

Specification	
Pressure range	0–1 psig
Analog input flow	8–38 VDC
Analog output flow	1–5 VDC
Accuracy class	< ±0.25% of full-scale output (FSO)

4.5.3 Summary of calibration procedures

Calibration of PIT4 is performed in accordance to ISA-37.3-1982 (R1995) "Specifications and Tests for Strain Gage Pressure Transducers". Two or more complete calibration cycles (each with at least 11 data points) are run consecutively, using both ascending and descending directions.

From the data obtained during the calibration test, the following characteristics are determined: (1) end points; (2) full-scale output; (3) zero measured output; (4) linearity; (5) hysteresis; (6) hysteresis and linearity; (7) repeatability and (8) static error band.

Repeated calibration cycles over a specified period of time should establish both zero shift and sensitivity shift for this period of time.

4.5.4 Summary of calibration results

PIT4 was calibrated by using six different pressures with increments of 0.2 psig between each one (no check for hysteresis). The output (in VDC) was recorded for each pressure, indicating that for zero pressure the voltage was 1.017 VDC, whereas for the maximum pressure (1 psig) the recorded voltage output was 5.027 VDC. Additionally, the determined static accuracy (BFSL) was smaller than 0.25%.

In addition to the calibration test, an in-site as-found test was carried out post-summer testing at the test site, using the procedure discussed in sub-section 4.2.3. Since PIT4 is an ambient pressure, only three pressure points (zero, mid-range and full-range) were tested in the as-found test, using a base pressure of 12.20 psia. The as-found results are illustrated in Figure 4-5.

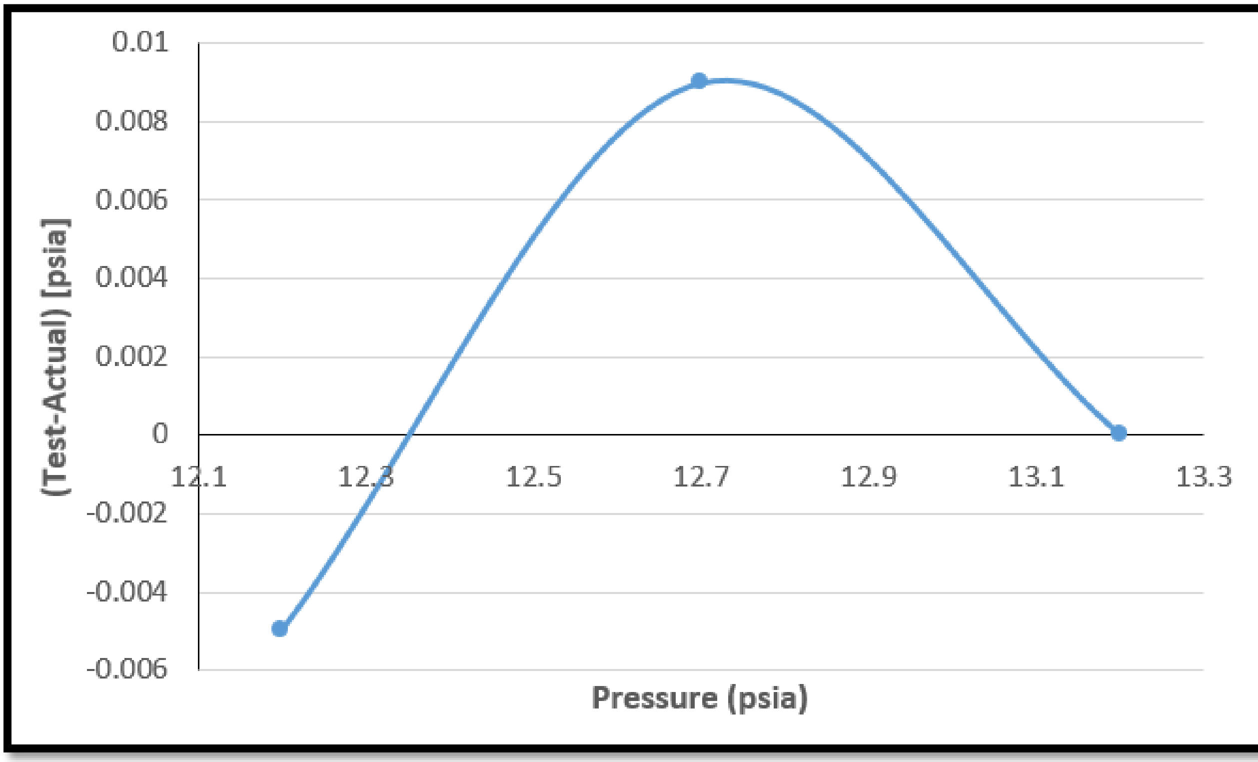

Figure 4-5. As-found test of PIT4

Results of both the calibration and the as-found tests indicate that the pressure transducer reads accurate values. However, this pressure transducer is different than the other transducers used in the test site since it needs to use a certain base pressure (12.2 psia = 0 psig), instead of measuring the barometric pressure. This implies that this pressure transducer may read inaccurate pressure readings that are not representative of the true ambient pressure.

4.5.5 List of related files / documentation

- Calibration certificate from manufacturer

4.6 PIT5

4.6.1 Description and principle of operation

PIT5 is a pressure transducer manufactured by Ashcroft. It is located at the point where the separator-to-oil tank pipeline comes to the surface (base of up-comer). It measures the oil pressure inside the pipe. This pressure transducer was used during the winter test period (Figure 3-1) until it was discovered that during active well cycles, the oil pressure exceeds the transducer's pressure ranges, therefore it was replaced by PIT8 during the summer phase testing period.

4.6.2 Output specifications

Table 4-5: Specifications of PIT5

Specification	
Pressure range	0–1.5 psig
Analog input flow	10–30 VDC
Analog output flow	1–5 VDC
Temperature range	(-)4–185°F
Accuracy class	±0.5% of span (total error band)

4.6.3 Summary of calibration procedures

See sub-section 4.3.3.

For in-situ calibration, see guidelines set forth in sub-section 4.2.3.

4.6.4 Summary of calibration results

Using the calibration procedure discussed above, the transducer's accuracy was tested using nine pressure points. Calibration results indicated that all nine points were within the ±0.5% accuracy reading, with the highest uncertainty margins being at around 50% of the pressure range (0.75 psig). All nine points had a positive error band, meaning that the instrument was over-reading the pressures. Summary of the calibration results is illustrated in Figure 4-5.

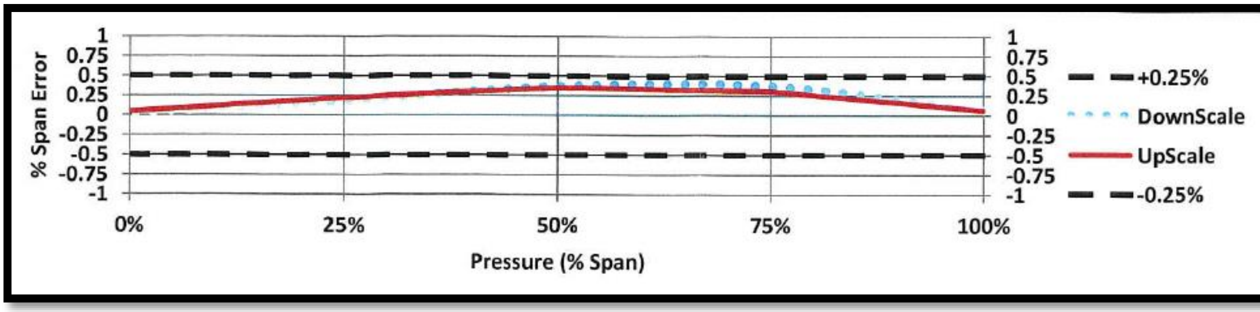

Figure 4-6. Calibration result of PIT5

No as-found test was performed on this pressure transducer.

4.6.5 List of related files / documentation

- Calibration record from manufacturer

4.7 PIT6

4.7.1 Description and principle of operation

PIT6 is a pressure transducer manufactured by Ashcroft. It is located at the separator dump leg, just upstream of the Coriolis meter. It is used in conjunction with PIT1 to monitor the separator pressure, as well as to calculate any potential losses between the bulk separator pressure and the dump pressure.

4.7.2 Output specifications

Table 4-6: Specifications of PIT6

Specification	
Pressure range	0–500 psig
Analog input flow	10–30 VDC
Analog output flow	1–5 VDC
Temperature range	(-)4–185°F
Accuracy class	±0.5% of span (total error band)

4.7.3 Summary of calibration procedures

See sub-section 4.3.3.

For in-situ calibration, see guidelines set forth in sub-section 4.2.3.

4.7.4 Summary of calibration results

No calibration certificate exists for this meter.

An "as-found" test performed on the transducer post-summer testing was carried out in-situ. The actual pressure readings were compared with five pressure points: 0 psig (smallest range), 175 psig (low pressure group category), 225 psig (medium pressure group category), 260 psig (high pressure group category) and 500 psig (maximum range) as illustrated in Figure 4-7.

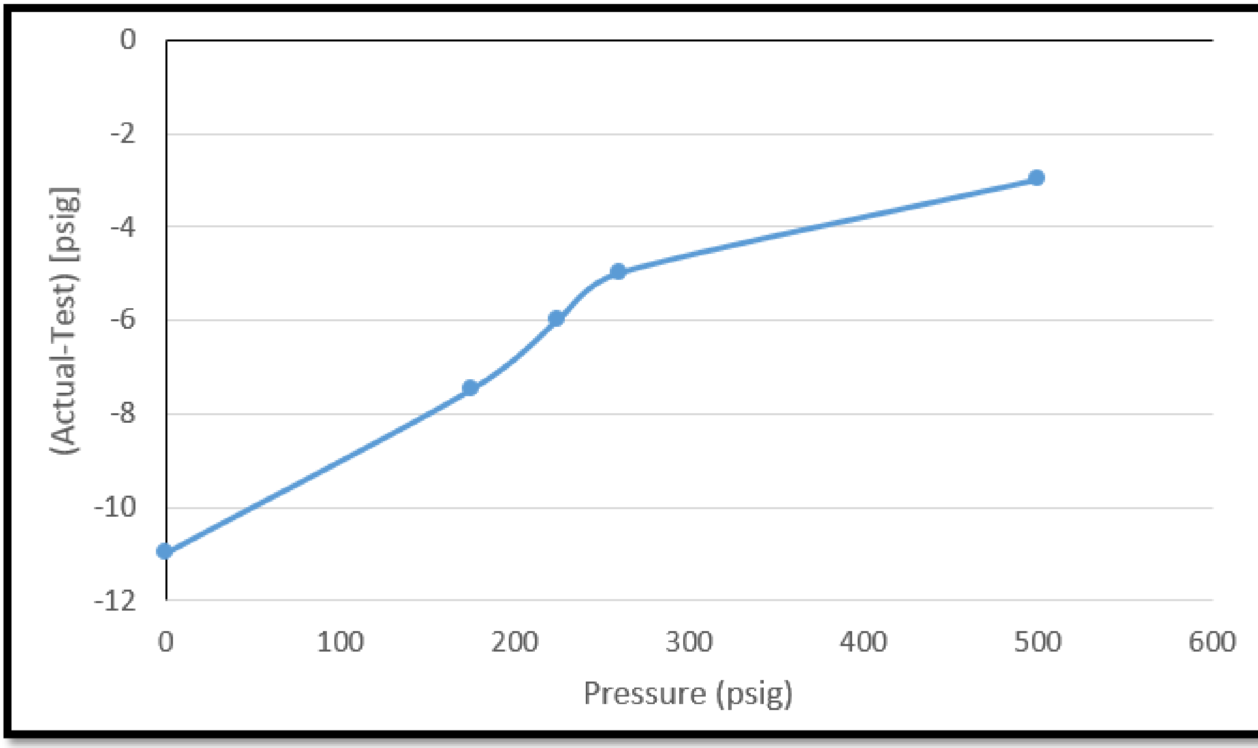

Figure 4-7. As-found test of PIT6

As indicated from the as-found test, the pressure transducer under-reads the actual pressure. For the pressure ranges applicable to the study (i.e. 175, 225 and 260 psig), the drift in transducer's response is, on average, 6 psig below the actual pressure. However, as indicated in the previous sub-sections, the effect of drift in transducer's response with time is unknown. Nevertheless, an external Crystal pressure gauge (provided by SPL) was used during both the winter and summer phase testing weeks, and showed close resemblance with PIT6 and PIT1.

4.7.5 List of related files / documentation

No documentation is available on this pressure transducer.

4.8 PIT7

4.8.1 Description and principle of operation

PIT7 is a pressure transmitter manufactured by Barksdale. It is located at the separator dump leg, downstream of the Coriolis meter. It was used in conjunction with PIT6 to check the pressure drop across the Coriolis meter, therefore indicating whether a two-phase flow existed during active well dumps.

4.8.2 Output specifications

Table 4-7: Specifications of PIT7

Specification	
Pressure range	0–100 psig
Analog input flow	12–28 VDC
Analog output flow	4–20 mA
Accuracy	±0.25% of measured pressure

4.8.3 Summary of calibration procedures

Calibration procedure is proprietary. However, the room sum square root of the linearization, hysteresis and repeatability is computed to produce the transducer's accuracy. In addition, the output at 4 mA and 20 mA is tested and compared with the transducer's pressure range.

4.8.4 Summary of calibration results

Neither calibration certificate nor as-found record exist for this pressure transmitter.

4.8.5 List of related files / documentation

- Manufacturer data sheet
- Manufacturer's installation and maintenance instructions

4.9 PIT8

4.9.1 Description and principle of operation

PIT8 is a pressure transmitter manufactured by Barksdale. It is located at the point where the separator-to-oil tank pipeline comes to the surface (base of up-comer). It measures the oil pressure inside the pipe. This pressure transmitter was used during the summer test period (Figure 3-2) after it was discovered that during active well cycles, the oil pressure exceeded PIT5's pressure ranges.

4.9.2 Output specifications

Table 4-8: Specifications of PIT8

Specification	
Pressure range	0–100 psig
Analog input flow	12–28 VDC
Analog output flow	4–20 mA
Accuracy	± 0.25% of measured pressure

4.9.3 Summary of calibration procedures

See sub-section 4.8.3.

4.9.4 Summary of calibration results

Neither calibration certificate nor as-found record exist for this pressure transmitter.

4.9.5 List of related files / documentation

- Manufacturer data sheet
- Manufacturer's installation and maintenance instructions

4.10 PIT9

4.10.1 Description and principle of operation

PIT9 is a pressure transducer manufactured by Ashcroft. It is located at the separator-to-tank pipe, just prior to entering the tank on the horizontal section. It measures the oil pressure at the top of the tank, a useful measurement for estimating the flow rate of the two-phase oil exiting the siphon hole[8] located one foot below, as illustrated in Figure 4-8.

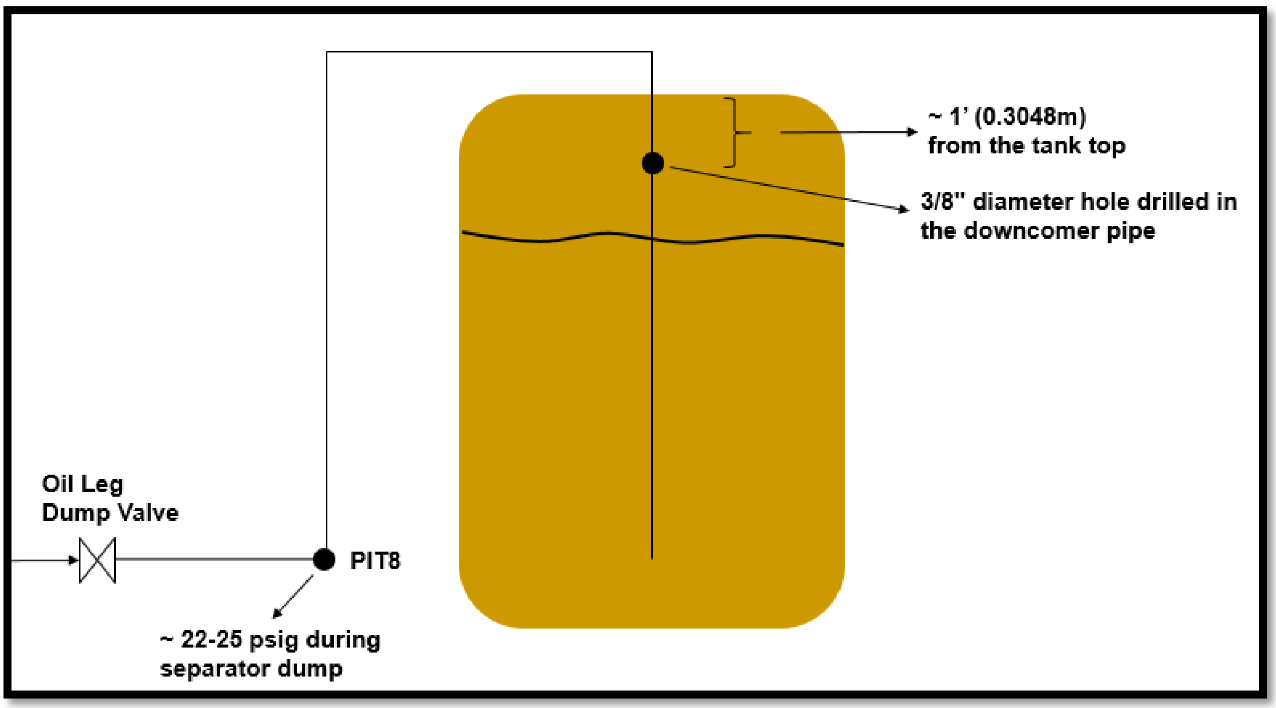

Figure 4-8. Illustration of the siphon hole location within the down-comer

4.10.2 Output specifications

Table 4-9: Specifications of PIT9

Specification	
Pressure range	0–1.5 psig
Analog input flow	10–30 VDC
Analog output flow	1–5 VDC
Temperature range	(-)4–185°F
Accuracy class	±0.5% of span (total error band)

[8] The siphon hole is 3/8" in diameter, and is supposed to avoid separator over-fill in case of an upset conditions where the oil flow is reversed from the tank back to the separator.

4.10.3 Summary of calibration procedures

See sub-section 4.3.3.

4.10.4 Summary of calibration results

No calibration certificate exists for this meter.

However, the observed pressure exceeded the transducer’s range by one order of magnitude, therefore any pressure readings from this transducer need to be flagged. Nonetheless, the pressure readings are considered (in bulk part) to perform estimate of flow discharge through the siphon hole.

4.10.5 List of related files / documentation

No documentation is available on this transducer.

5.0 Resistance Temperature Detector (RTD)

5.1 Background

A resistance temperature detector (RTD) is a temperature sensor that contains a resistor that changes resistance value as its temperature changes. The majority of the RTD elements consist of a length of fine coiled wire wrapped around a ceramic or glass core that is placed inside a sheathed probe to protect it due to its fragility. The RTD element is made from a pure material whose resistance at various temperatures has been documented [18] (e.g. a platinum RTD has a typical resistance of 100 ohms at 0^0C).

The relationship between an RTD's resistance and the surrounding temperature is highly predictable if the temperature coefficient (denoted as α), it allows an accurate and consistent temperature measurement. Although various manufacturers may specify α differently, it is defined over the temperature span of 0-100°C and is expressed as ohm/ohm/0°C. The formula for determining α is shown in equation (5-1):

$$\alpha = \frac{R_{100} - R_0}{R_0 * 100^0 C} \qquad (5\text{-}1)$$

Where:

α is the temperature coefficient (ohms/ohms/°C)
R_{100} is the resistance of the RTD at 100°C (ohms)
R_0 is the resistance of the RTD at 0°C (ohms)

In order to correct for the departure from linearity at temperatures other than 0-100°C, a curve fitting is required. The Callendar-Van Dusen (CVD) equation (5-2a) is commonly used to approximate the RTD curve for temperatures of the range -200°C ≤ T ≤ 0°C, while equation (5-2b) is used for T > 0°C:

$$R_T = R_0[1 + AT + BT^2 + C(T - 100)T^3] \qquad (5\text{-}2a)$$

$$R_T = R_0[1 + AT + BT^2] \qquad (5\text{-}2b)$$

Where:

T is the temperature in °C
R_T is the resistance of the RTD at temperature "T" (ohms)
A, B, C are coefficients of the CVD equation shown in Table 5-1.

Table 5-1: Callendar-Van Dusen Coefficients Corresponding to Common RTDs [18]

Standard	α (Ω/Ω/°C)	A	B	C[9]
DIN 43760	0.003850	3.9080×10^{-3}	-5.8019×10^{-7}	-4.2735×10^{-12}
American	0.003911	3.9692×10^{-3}	-5.8495×10^{-7}	-4.2325×10^{-12}
ITS-90	0.003926	3.9848×10^{-3}	-5.870×10^{-7}	-4.0000×10^{-12}

The CVD constants can be also calculated empirically, as shown in equations [18] (5-3a-c).

$$A = \alpha + \frac{\alpha\delta}{100} \tag{5-3a}$$

$$B = \frac{-\alpha\delta}{100^2} \tag{5-3b}$$

$$C = \frac{-\alpha\beta}{100^4} \tag{5-3c}$$

Where:

β is obtained by calibration at a negative temperature (e.g. triple point of mercury and argon, or liquid nitrogen), and is determined by the manufacturer if T < 0oC, otherwise it is zero.

δ is obtained by calibration at a high temperature [19] (e.g. freezing point of zinc or aluminum), and is determined by the manufacturer, or empirically from equation (5-3d):

$$\delta = \frac{R_0(1+\alpha*260)-R_{200}}{4.16*R_0*\alpha} \tag{5-3d}$$

Where:

R_{200} is the resistance of the RTD at 200°C

For temperature range of 0°C ≤ T ≤ 661°C, equation (5-2) is reduced to a quadratic form. Thus, by supplying an RTD with a constant current and measuring the resulting voltage drop across the resistor, the RTD's resistance can be calculated, and the temperature can be determined based on equation (5-4) [18]:

$$T = \frac{2(V_0 - I_{EX}R_0)}{I_{EX}R_0\left[A + \sqrt{A^2 + 4B\frac{(V_0 - I_{EX}R_0)}{I_{EX}R_0}}\right]} \tag{5-4}$$

Where:

V_0 is the measured RTD voltage (VDC)
I_{EX} is the excitation current (ampere)

[9] For temperatures below 0° C only; C = 0.0 for temperatures above 0° C

5.2 RTD1

5.2.1 Description and principle of operation

RTD1 is a 100 ohm platinum RTD manufactured by Thermocouple Technology (TTEC), located within the separator oil layer. RTD1 conforms to the European Curve / DIN 43760 standards, therefore using a temperature coefficient of 0.00385 (See Table 5-1).

5.2.2 Output specifications

Table 5-2: RTD1 Output Specifications

Specification	
Temperature range	0–250^{o}F
Analog input flow	12 VDC
Analog output flow	1–5 VDC
Accuracy class	±2^{o}F

5.2.3 Summary of calibration procedures

Calibration procedure was not provided by manufacturer.

In-situ calibration procedure

The RTD is calibrated with a calibration bath to signal exactly 1 VDC at bottom of range and 5 VDC at top of range. After installation, in order to remove variables from signal resistance, a 1VDC is sent individually through the signal wire to the PLC where LOW_ADC value is compared to RAW_ADC value and adjusted to match RAW_ADC value. Afterwards, a 5VDC is then sent through the signal wire to the PLC where HIGH_ADC value is compared to RAW_ADC value and adjusted to match RAW_ADC value.

5.2.4 Summary of calibration results

No calibration record exists for this RTD.

An in-situ, "as-found" test was performed on RTD1 based on the in-situ calibration procedure discussed in sub-section 5.2.3. The as-found test was performed by varying the voltage between 1 and 5 VDC and recording the output temperature, as shown below in Figure 5-1.

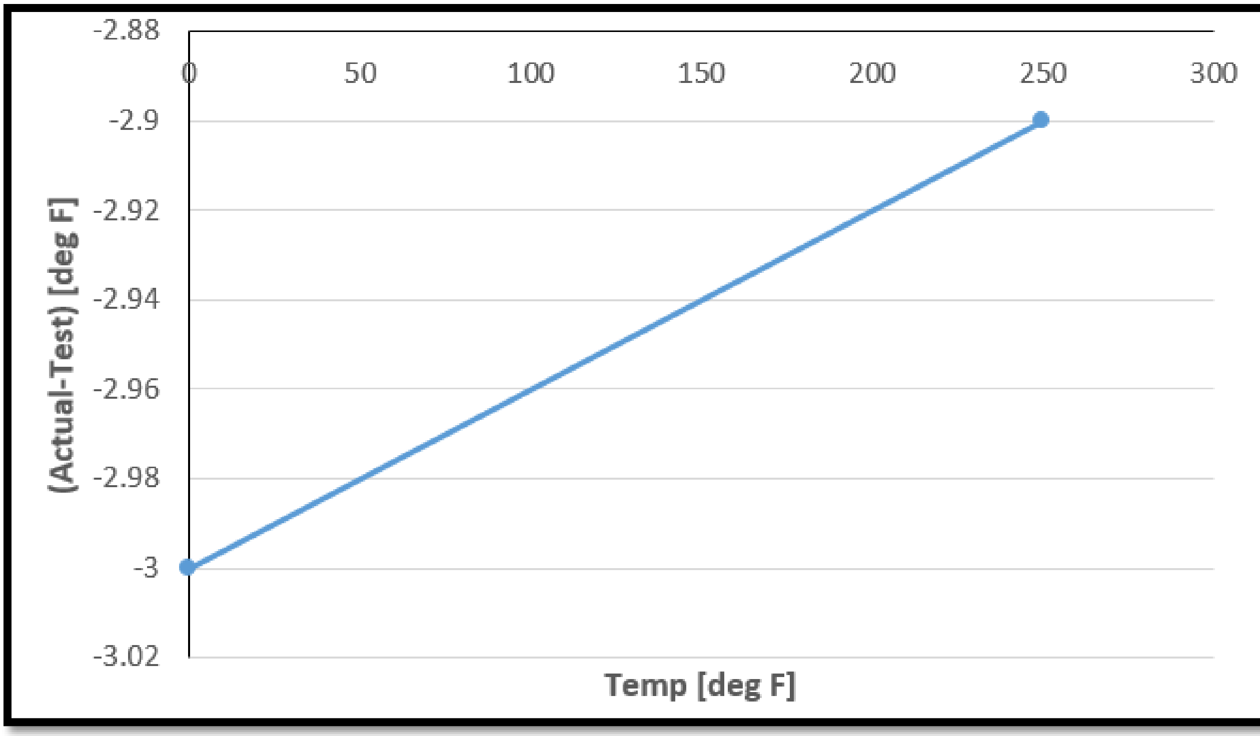

Figure 5-1. As-found test results on RTD1

It is illustrated from Figure 5-1 that the deviation in temperature is almost identical for both the low end of the temperature spectrum (1 VDC, 0^{o}F) and of the high end of the temperature spectrum (5 VDC, 250^{o}F). Since RTD1 may under-read the temperature, it may be suspected as a bias.

5.2.5 List of related files / documentation

No documentation is available on this transducer.

5.3 RTD2

5.3.1 Description and principle of operation

RTD2 is a 100 ohm platinum RTD manufactured by Thermocouple Technology (TTEC), located within the separator gas headspace. RTD2 conforms to the European Curve / DIN 43760 standards, therefore using a temperature coefficient of 0.00385 (See Table 5-1).

5.3.2 Output specifications

Table 5-3: RTD2 Output Specifications

Specification	
Temperature range	0–250°F
Analog input flow	12 VDC
Analog output flow	1–5 VDC
Accuracy class	±2°F

5.3.3 Summary of calibration procedures

See sub-section 5.2.3.

5.3.4 Summary of calibration results

No calibration certificate exists for this meter.

An in-situ, "as-found" test was performed on RTD2 based on the in-situ calibration procedure discussed in sub-section 5.2.3. The as-found test was performed by varying the voltage between 1 and 5 VDC and recording the output temperature, as shown below in Figure 5-2.

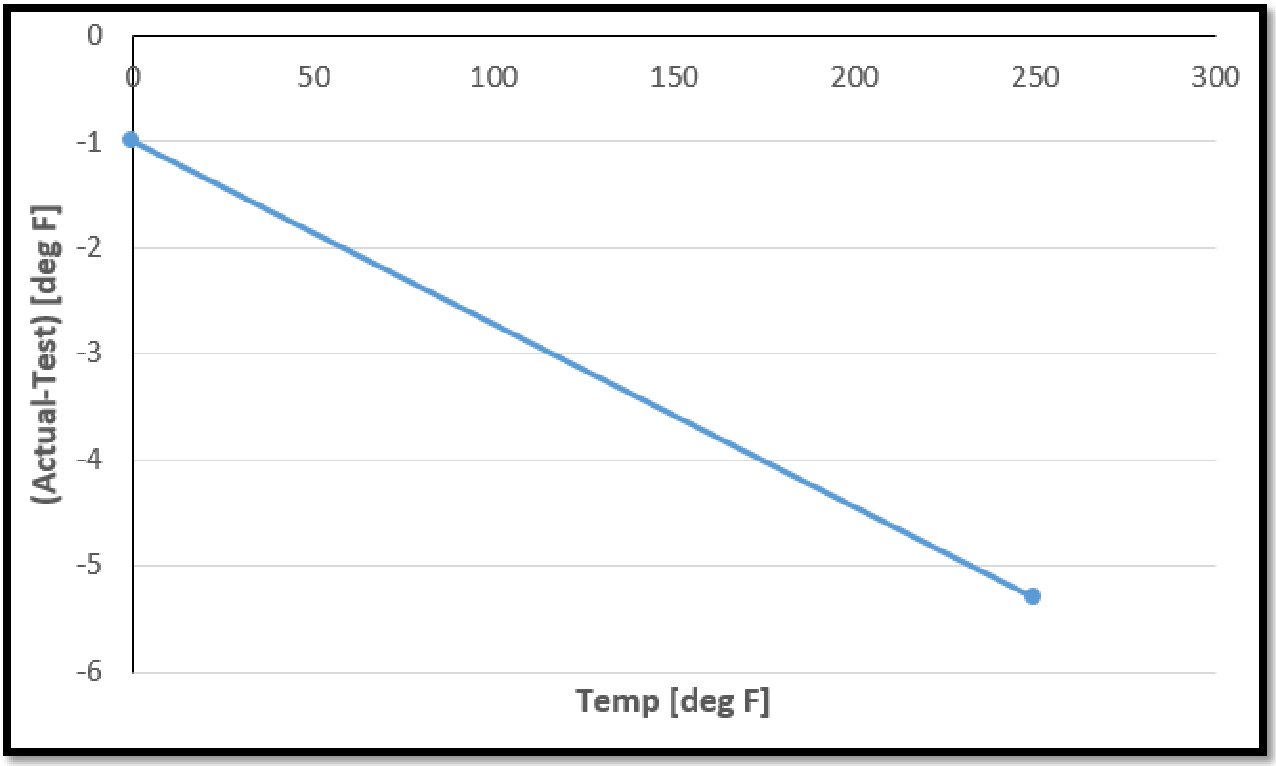

Figure 5-2. As-found test results on RTD2

In contrast to Figure 5-1, it is evident that for RTD2 there is a large drift in the high temperature range of the RTD sensor.

5.3.5 List of related files / documentation

No documentation is available on this transducer.

5.4 RTD3

5.4.1 Description and principle of operation

RTD3 is a 100 ohm platinum RTD manufactured by Thermocouple Technology (TTEC), located at the top of the storage tank. RTD3 conforms to the European Curve / DIN 43760 standards, therefore using a temperature coefficient of 0.00385 (See Table 5-1).

5.4.2 Output specifications

Table 5-4: RTD3 Output Specifications

Specification	
Temperature range	(-)25–175°F
Analog input flow	12 VDC
Analog output flow	1–5 VDC
Accuracy class	±2°F

5.4.3 Summary of calibration procedures

See sub-section 5.2.3.

5.4.4 Summary of calibration results

No calibration certificate exists for this meter.

An in-situ, “as-found” test was performed on RTD3 based on the in-situ calibration procedure discussed in sub-section 5.2.3. The as-found test was performed by varying the voltage between 1 and 5 VDC and recording the output temperature, as shown below in Figure 5-3.

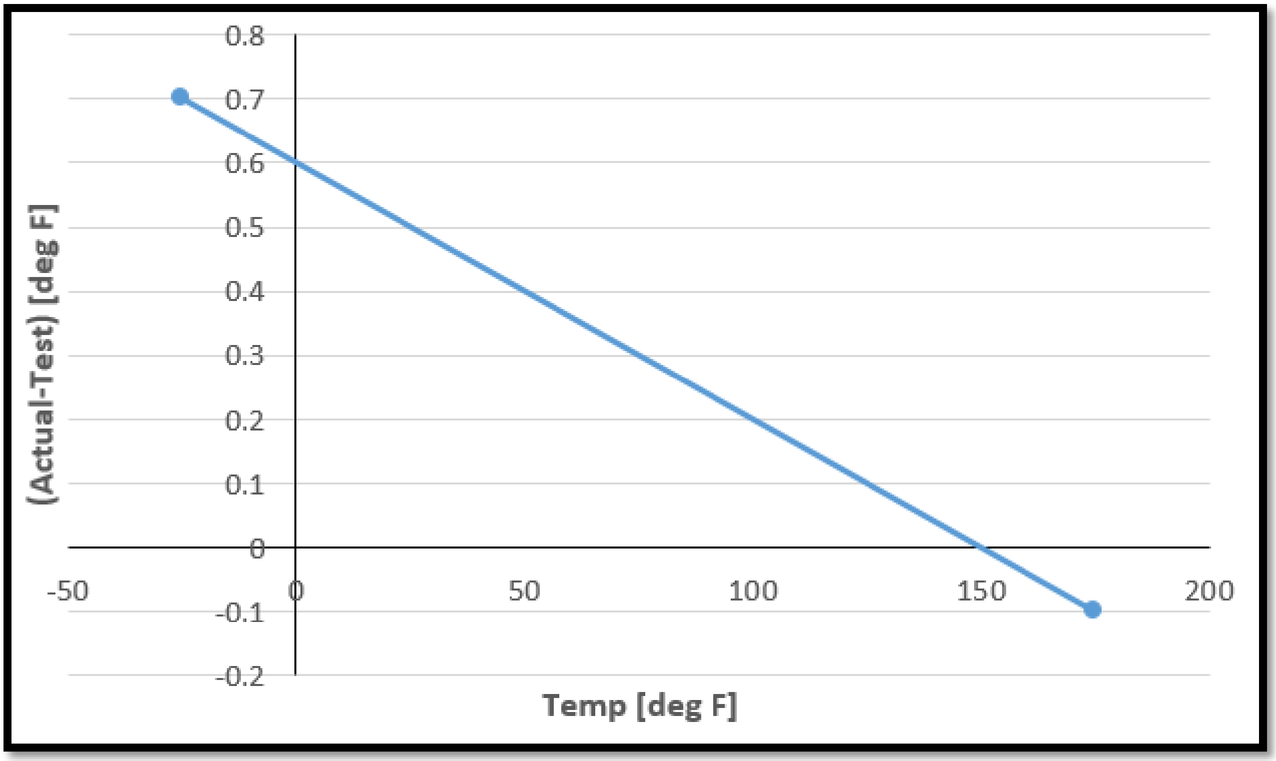

Figure 5-3. As-found test results on RTD3

5.4.5 List of related files / documentation

No documentation is available on this transducer.

5.5 RTD4

5.5.1 Description and principle of operation

RTD4 is a 100 ohm platinum RTD manufactured by Thermocouple Technology (TTEC), located at the separator-to-oil tank pipe, just prior to entering the tank on the horizontal section. RTD4 conforms to the European Curve / DIN 43760 standards, therefore using a temperature coefficient of 0.00385 (See Table 5-1).

5.5.2 Output specifications

Table 5-5: RTD4 Output Specifications

Specification	
Temperature range	0–250°F
Analog input flow	12 VDC
Analog output flow	1–5 VDC
Accuracy class	±2°F

5.5.3 Summary of calibration procedures

See sub-section 5.2.3.

5.5.4 Summary of calibration results

No calibration certificate exists for this meter.

An in-situ, “as-found” test was performed on RTD4 based on the in-situ calibration procedure discussed in sub-section 5.2.3. The as-found test was performed by varying the voltage between 1 and 5 VDC and recording the output temperature, as shown below in Figure 5-4.

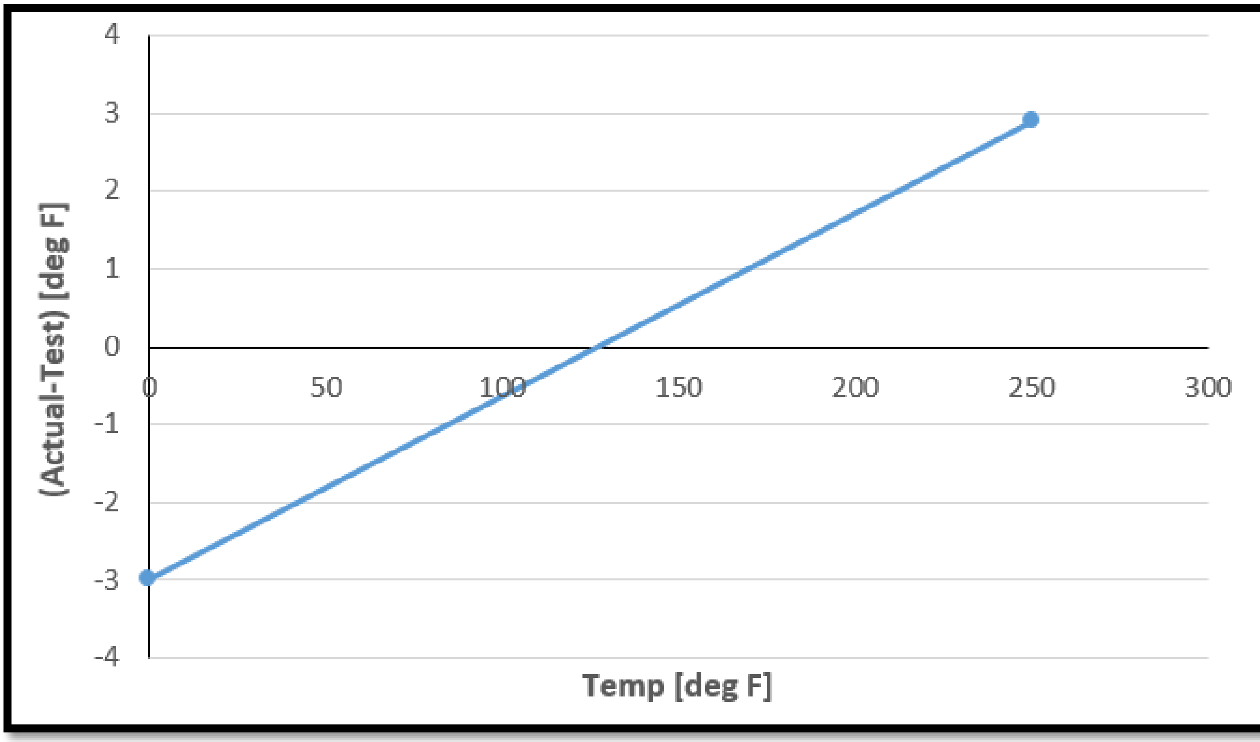

Figure 5-4. As-found test results on RTD4

5.5.5 List of related files / documentation

No documentation is available on this transducer.

5.6 RTD5

5.6.1 Description and principle of operation

A resistance temperature detector (RTD)

5.6.2 Output specifications

Table 5-6: RTD5 Output Specifications

Specification	
Temperature range	0–200°F
Analog input flow	< 30 VDC
Analog output flow	4–20 mA
Accuracy class	±2°F

5.6.3 Summary of calibration procedures

See sub-section 5.2.3.

5.6.4 Summary of calibration results

No calibration certificate exists for this meter.

5.6.5 List of related files / documentation

No documentation is available on this transducer.

5.7 RTD6

5.7.1 Description and principle of operation

A resistance temperature detector (RTD)

5.7.2 Output specifications

Table 5-7: RTD6 Output Specifications

Specification	
Temperature range	(-)30–150°F
Analog input flow	9–30 VDC
Analog output flow	1–5 VDC
Accuracy class	±2°F

5.7.3 Summary of calibration procedures

See sub-section 5.2.3.

5.7.4 Summary of calibration results

No calibration certificate exists for this meter.

An in-situ, “as-found” test was performed on RTD6 based on the in-situ calibration procedure discussed in sub-section 5.2.3. The as-found test was performed by varying the voltage between 1 and 5 VDC and recording the output temperature, as shown below in Figure 5-5.

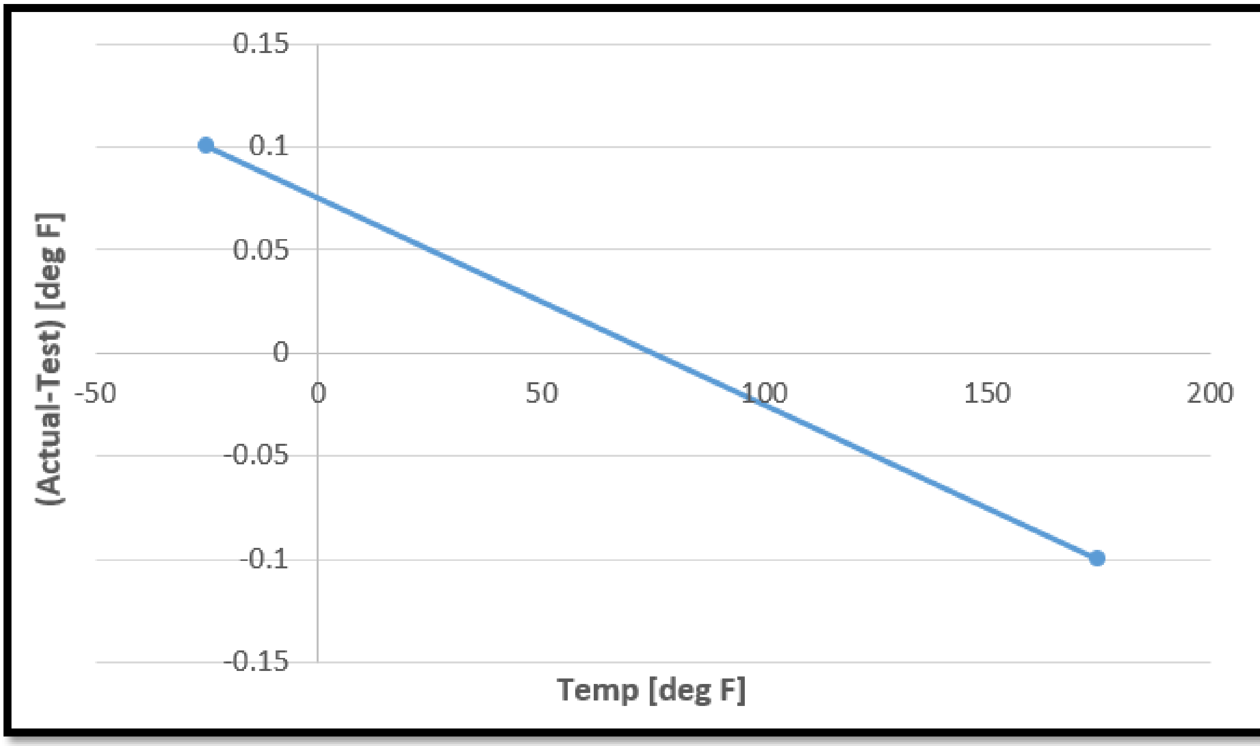

Figure 5-5. As-found test results on RTD6

5.7.5 List of related files / documentation

No documentation is available on this transducer.

5.8 RTD7

5.8.1 Description and principle of operation

A resistance temperature detector (RTD)

5.8.2 Output specifications

Table 5-8: RTD7 Output Specifications

Specification	
Temperature range	(-)25–175°F
Analog input flow	12 VDC
Analog output flow	1–5 VDC
Accuracy class	±2°F

5.8.3 Summary of calibration procedures

See sub-section 5.2.3.

5.8.4 Summary of calibration results

No calibration certificate exists for this meter.

5.8.5 List of related files / documentation

No documentation is available on this transducer.

5.9 RTD16

5.9.1 Description and principle of operation

RTD16 is a 100 ohm platinum RTD manufactured by Thermocouple Technology (TTEC), located at the top of the storage tank. RTD3 conforms to the European Curve / DIN 43760 standards, therefore using a temperature coefficient of 0.00385 (See Table 5-1).

5.9.2 Output specifications

Table 5-9: RTD16 Output Specifications

Specification	
Temperature range	(-)25–175°F
Analog input flow	12 VDC
Analog output flow	1–5 VDC
Accuracy class	±2°F

5.9.3 Summary of calibration procedures

See sub-section 5.2.3.

5.9.4 Summary of calibration results

No calibration certificate exists for this meter.

5.9.5 List of related files / documentation

No documentation is available on this transducer.

6.0 References

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[19] Standard Callendar-Van Dusen. Available online from: http://www.sensingdevices.com/cvd-table.php

7.0 Calibration Records

APEX INSTRUMENTS

7200 E. Dry Creek Rd. C-102
Centennial, Co. 80112
303-804-0667
cal.lab@apex-instruments.com

Automation X
2881 S. 31st Ave, #21
Greeley, CO 80631

Page 1

CALIBRATION CERTIFICATE: 9691-HP

Feb 19 2016

Device Informaton:	DUT	Reference
Model	IS33	6270A
Manufacturer	Crystal Engineering	Fluke
Serial Number	2262-340160	3270005
Pressure Range	0.000 to 3000.000	30, 300, 1000, 3000 psi
Tolerance	0.005 %Span + 0.05 %Rdg	+/- 0.003% span or 0.01% Rdg
Data Aquisition Mode	RS232	RS232
Date of Calibration	Feb 19 2016	Sep 10 2015
Calibration Due	Feb 19 2017	Sep 10 2016

Test Information

Test Lable	- 3000 psi
Date	Feb 19 2016
Time	9:0:42 AM
Operator	Steven L
Station ID	APEX-HP2-HP

Conditions

Ambient Pressure	
Ambient Temperature	23 deg C +/- 3 C
Ambient Relative Humidity	20% - 60%

As Received Data:

Test Point	Reference Pressure psi	DUT Pressure psi	DUT Raw Output psi	Abs. Error psi	"% Span" Error %	DUT Tolerance psi	Status
1	0.00002	0.000	0.000	0.000	0.0000	0.150	Pass
2	600.00025	599.911	599.911	-0.089	-0.0030	0.450	Pass
3	1199.99842	1199.941	1199.941	-0.057	-0.0019	0.750	Pass
4	1800.00005	1799.900	1799.900	-0.100	-0.0033	1.050	Pass
5	2399.99853	2399.840	2399.840	-0.159	-0.0053	1.350	Pass
6	2999.99755	2999.839	2999.839	-0.159	-0.0053	1.650	Pass
7	2400.00117	2399.900	2399.900	-0.101	-0.0034	1.350	Pass
8	1800.00042	1799.971	1799.971	-0.029	-0.0010	1.050	Pass
9	1199.99960	1200.040	1200.040	0.040	0.0013	0.750	Pass
10	599.99831	600.011	600.011	0.013	0.0004	0.450	Pass
11	-0.00001	0.006	0.006	0.006	0.0002	0.150	Pass

As Received First Order Fit: y = 1.000052E00x + -1.374852E-02

As Left Data:

Test Point	Reference Pressure psi	DUT Pressure psi	DUT Raw Output psi	Abs. Error psi	"% Span" Error %	DUT Tolerance psi	Status
1	0.00002	0.000	0.000	0.000	0.0000	0.150	Pass

Crystal Certification Calibrating Total Flow DP and SP

ThermoProbe

Report of Test

This report is to certify that the instrument listed below has been calibrated by ***Thermo*Probe**, Inc. to NIST traceable criteria.

Report No.: **2015-11-18 - 1-15668**
Model: TL1-A

Unit SN: 1-15668

Calibration Date: **11/18/2015**
Ambient Temp: 75 °F +/- 2°
Calibrated By: MS

Calibration Data As Found

New Unit or no "As Found" data available

Calibration Data As Left

This device has been adjusted to read as closely as possible to actual temperature.
Tested temperatures and corrections are as follows:

Nominal Value		Actual Test Temp.		Reading of TL		Correction		Tolerance		In Tolerance	Measurement Uncertainty	
°F	°C	°F	°C	°F	°C	°F	°C	°F	°C		°F	°C
32	0	32.010	0.006	32.03	0.02	-0.02	-0.01	0.10	0.06	Yes	0.030	0.017
120	49	120.003	48.891	120.01	48.89	-0.01	0.00	0.10	0.06	Yes	0.030	0.017
199	93	199.036	92.798	199.04	92.80	0.00	0.00	0.10	0.06	Yes	0.030	0.017
300	149	300.202	149.001	300.21	149.01	-0.01	0.00	0.10	0.06	Yes	0.030	0.017

Callendar Van Dusen Coefficients:
R0: 100.00 A: 3.91400E-03 B: -6.03510E-07 C: -4.17100E-11

Report of Test

Test Method: The calibration procedures used were *ThermoProbe, Inc. Calibration Procedures* based on ASTM E-644-06. This probe was immersed in a constant temperature bath with a reference thermometer which determined the actual test temperature. The readings were compared and correction factors for the probe were calculated. The As Left readings reflect the TL's readings after calibration

Nominal Temp		Bath	Fluid	Reference	Calibration Date	Next Calibration Due
(-)20.0° C	(-)4.0° F	Fluke 7340	water/glycol	TL2-0029	4/15/2015	4/15/2016
0.0° C	32.0° F	Fluke 7340	water/glycol	TL2-0016	4/15/2015	4/15/2016
48.9° C	120.0° F	PolyScience 8101	mineral oil	TL2 - 0008	4/15/2015	4/15/2016
92.8° C	199.0° F	Fluke 6330	mineral oil	Fluke 1502A - ASP WSP500	4/15/2015	4/15/2016
149.0° C	300.2° F	Fluke 6330	silicon oil	Fluke 1502A - ASP WSP500	4/15/2015	4/15/2016
290.0° C	554.0° F	PolyScience 8102	metrology well	TL2A-0053	8/18/2015	8/18/2016

Traceability: This calibration and the references stated above are traceable to NIST through an unbroken chain of comparisons.

Uncertainty Statement: Uncertainties were computed using the concepts, methods and techniques of the ISO Guide to the Expression of Uncertainty in Measurement (the GUM). The calculated uncertainty is an expanded uncertainty (k=2). It does not consider errors due to possible damage to the TL from shipping, temperature drift, or thermal hysteresis effect. To maintain the accuracy of the TL, users should take care to protect it during shipping, avoid using it to measure temperatures significantly above the highest calibrated temperature, and have the TL recalibrated annually.

Calibrator's Signature: Mike Alvarez

Test Results Approved by: M. C.

Date: **11/18/2015**

The results stated on this report relate only to the items specifically identified. This test report or calibration certificate shall not be reproduced except in full, without written approval of the laboratory.

Thermoprobe Certification for Calibrating Total Flow Temp

Orifice Meter Test Report

Meter: 0000001 - Bernhart 31-32 | **Date Performed: February 26, 2016 10:20 Rev 1**

Company:		City:		State ID:		User Defined 1:	
Division:		County:	Weld	Federal ID:		User Defined 2:	
Area:		State:	Colorado	API Code:		User Defined 3:	
Sub-Area:		Agency:		Latitude:		User Defined 4:	
Last Test:	02/26/2016	Reason for Test:	Calibration	Longitude:		Site Elevation:	

Flowing Conditions

	Found	Left	Average
Differential:	0.00	34.04	25.00
Pressure:	150.18	166.18	160.00
Temperature:	54.73	66.30	50.00
RTU Flow Rate:	0.00	726.21	
Found:			
Meter Time:			

Meter Constants

Calculation Method:	AGA3-1992	FPV Method:	AGA8-Detail
PSIA/PSIG:	PSIA	Measured HV:	1261.00000
Atmos. Press.:	12.30	Specific Gravity:	0.75200
Pressure Base:	14.73	N2:	0.21060
Temp. Base:	60	CO2:	2.30060

Meter Inspection

PrimBrand:	Daniels	Model:	Junior	Ser #:	C100530.001
RTUBrand:	Totalflow	Model:	XFC G4	Ser #:	T121881581
DP Range:	0-250	Model:	XFC G4	Ser #:	
SP Range:	0-500	Model:	XFC G4	Ser #:	
Tmp Range:	0-150	Model:	XFC G4	Ser #:	

Static Location: Upstream   Tap Type: Flange

Leak Test: Zero Cutoff: 0.50

DP Calibration

Standard	Found	Left	Flow Rate Error
Reset A.P.0	-0.01		
Reset W.P.0	0.00	-0.02	
0.00	-0.01	0.00	
125.00	124.97	125.01	-0.01 %
250.00	249.94	250.03	-0.01 %

Orifice Plate

Plate Size Existing:	1.250	Orifice Serial:	
Plate Size Found:	1.250	Seal Inspection:	
Meter Tube Size Existi	2.069	ter Tube Size Left:	

Plate Inspected:	Yes	Plate Clean	No	Edge Sharp	Yes	Oily	Yes
		Smooth	No	Surface Flat	No	Dirty	Yes
		Bevel	No	Beveled DS	No	Rough	No
		Bowed	No	Nicked	No		

Plate Changed: No   New Plate Serial:

Plate Size Left:

SP Calibration

Atmos. Press. Source: Fixed   Obs. Atmos. Press: 12.30

Standard (PSIG)	Found (PSIA)	Left (PSIA)	Flow Rate Error
0.00	12.41	12.31	0.45 %
250.00	262.56	262.30	0.05 %
500.00	512.36	512.13	0.01 %

Temperature Calibration

Standard	Found	Left	Flow Rate Error
56.07	55.46	56.00	0.55 %

Total Error:

Remarks:

Calibrated SP
Calibrated DP
Calibrated TF

Witness: Signed: Cody Winberg

Test It Report Total Flow Calibration Documentation

FOX THERMAL INSTRUMENTS, INC.
Fox is ISO 9001 certified
THERMAL MASS FLOW METERS

399 RESERVATION ROAD
MARINA, CA 93933 USA
PHONE: 831-384-4300
FAX: 831-384-4312
sales@foxthermalinstruments.com
www.foxthermalinstruments.com

FLOW METER CALIBRATION CERTIFICATE

Serial #: 21773 **Dia. =** 3.068 in

Model #: FT3-18R **Area =** 0.0513379 Ft^2

Fluid Type: 20.89% CH_4, 18.16% C_2H_6, 16.52% C_3H_8, 17.99% C_4H_{10}, 15.49% C_5H_{12}, 2.63% C_6H_{14}, 1.85% C_7H_{16}, 1.32% CO_2, et al.

STP: 60 F, 14.73 psia **4 mA =** 0 MSCFD

IDTag: - **20 mA =** 500.00 MSCFD

Curve 2

Data Point	Input Volts	NMPH at 0 C 760 mmHg	MSCFD at STP
1	0.29208	0.00	0.00
2	0.31595	341.27	1.45
3	0.34680	651.22	2.78
4	0.38240	1409.38	6.01
5	0.39980	2059.42	8.78
6	0.42058	3043.10	12.97
7	0.44783	4771.99	20.34
8	0.47022	6602.29	28.15
9	0.48841	8362.92	35.65
10	0.50701	10581.30	45.11
11	0.52915	13701.29	58.41
12	0.54871	16803.46	71.63
13	0.56416	19971.47	85.14
14	0.58204	23777.46	101.37
15	0.59446	26554.77	113.21
16	0.63171	36360.68	155.01
17	0.67714	52418.20	223.46
18	0.72152	70628.48	301.10
19	0.75849	90707.97	386.70
20	0.81519	117529.30	501.04

This unit was calibrated using calibration standards traceable to National Institute of Standards and Technology (NIST), to an uncertainty of +/-1.0% of reading +/- 0.2% of full scale. Fox Thermal Instruments, Inc. is an ISO 9001 certified company.

Approved By: Octavio Avila **Cal Date:** **2/23/2016 10:04**

Calibration Standards

Description	Inst. ID #	Due Date
Meter DVM	FOX A009	10/06/2016
Ref1 DVM	FOX A0121	10/06/2016
Pressure transducer	PRESS-007	08/06/2016
Thermometer	TEMP-SYS-001	10/07/2016
Therm Flowmeter	2135	12/11/2016

Fox maintains all equipment according to the *Equipment Control Procedure* (P-060).

FOX
THERMAL INSTRUMENTS, INC.
Fox is ISO 9001 certified
THERMAL MASS FLOW METERS

399 RESERVATION ROAD
MARINA, CA 93933 USA
PHONE: 831-384-4300
FAX: 831-384-4312
sales@foxthermalinstruments.com
www.foxthermalinstruments.com

FLOW METER CALIBRATION CERTIFICATE

Serial #:	21773	**Dia. =**	3.068	in
Model #:	FT3-18R	**Area =**	0.0513379	Ft^2
Fluid Type:	32.43% CH4, 25.81% C2H6, 18.17% C3H8, 12.39% C4H10, 6.51% C5H12, 1.98% CO2, et al.			
STP:	60 F, 14.73 psia	**4 mA =**	0	MSCFD
IDTag:	-	**20 mA =**	500.00	MSCFD

Curve 1

Data Point	Input Volts	NMPH at 0 C 760 mmHg	MSCFD at STP
1	0.28017	0.00	0.00
2	0.32885	354.78	1.51
3	0.35290	690.55	2.94
4	0.38273	1436.51	6.12
5	0.39977	2168.65	9.25
6	0.42200	3153.77	13.44
7	0.44582	4632.18	19.75
8	0.46787	6554.38	27.94
9	0.48560	8471.47	36.11
10	0.50338	10746.84	45.81
11	0.52672	13651.86	58.20
12	0.54271	17065.97	72.75
13	0.55720	20008.41	85.30
14	0.57476	23673.33	100.92
15	0.59194	26798.56	114.25
16	0.62213	37159.18	158.41
17	0.67087	54703.91	233.21
18	0.70071	68748.61	293.08
19	0.73779	89843.52	383.01
20	0.76997	117554.28	501.15

This unit was calibrated using calibration standards traceable to National Institute of Standards and Technology (NIST), to an uncertainty of +/-1.0% of reading +/- 0.2% of full scale. Fox Thermal Instruments, Inc. is an ISO 9001 certified company.

Approved By: Octavio Avila **Cal Date:** **2/23/2016 8:58**

Calibration Standards

Description	Inst. ID #	Due Date
Meter DVM	FOX A009	10/06/2016
Ref1 DVM	FOX A0121	10/06/2016
Pressure transducer	PRESS-007	08/06/2016
Thermometer	TEMP-SYS-001	10/07/2016
Therm Flowmeter	2135	12/11/2016

Fox maintains all equipment according to the *Equipment Control Procedure* (P-060).

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CAL-V™ CERTIFICATE
CALIBRATION VALIDATION

CAL-V™ Performed on:	February 25 2016	16:54:20	CAL-V™ Results:	PASS
Firmware Version:	FT3 V3.11		CAL-V™ Value:	21.8
Fox Meter Serial Number:	21773		CAL-V™ Verify:	4.05%

Tag #/Meter location: 21773

Test performed by: Cody Winberg

Additional Comments: Middle Fox Thermal

Calibration Table Stored in Flow Meter

Compare the below Calibration Table to the original Calibration Certificate

Data Point	Input Volts	NMPH at 0 C 760 mmHg
1	0.28017	0.00
2	0.32885	354.78
3	0.35290	690.55
4	0.38273	1436.51
5	0.39977	2168.65
6	0.42200	3153.77
7	0.44582	4632.18
8	0.46442	6145.22
9	0.48560	8471.47
10	0.50338	10746.84
11	0.52672	13651.86
12	0.54271	17065.97
13	0.55720	20008.41
14	0.57476	23673.33
15	0.59194	26798.56
16	0.62213	37159.18
17	0.67087	54703.91
18	0.70071	68748.61
19	0.73779	89843.52
20	0.76997	117554.30

CAL-V™ is an in-situ calibration routine that validates the flow meter's calibration accuracy by testing the functionality of the sensor and its associated signal processing circuitry.

At the conclusion of the test, the meter will display a pass/fail message and the CAL-V™ data.

A "pass" result confirms the meter is measuring accurately.

1. The CAL-V™ test is valid for checking the calibration accuracy of flow meters installed in the application for which it was calibrated, including the gas/gas mixture, calibration range and pipe size shown on the Calibration Certificate.
2. For applications with temperature exceeding 250°F (121°C), CAL-V™ test results may vary.

Fox Flow Meter 21773 Certification Documentation, Pre-Winter Testing

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www.foxthermalinstruments.com

FLOW METER CALIBRATION CERTIFICATE

Serial #: 21775 **Dia. =** 3.068 in

Model #: FT3-18R **Area =** 0.0513379 Ft^2

Fluid Type: 20.89% CH4, 18.16% C2H6, 16.52% C3H8, 17.99% C4H10, 15.49% C5H12, 2.63% C6H14, 1.85% C7H16, 1.32% CO2, et al.

STP: 60 F, 14.73 psia **4 mA =** 0 MSCFD
20 mA = 500.00 MSCFD

IDTag: -

Curve 2

Data Point	Input Volts	NMPH at 0 C 760 mmHg	MSCFD at STP
1	0.28430	0.00	0.00
2	0.31238	359.44	1.53
3	0.35289	744.89	3.18
4	0.37780	1386.57	5.91
5	0.39517	2093.77	8.93
6	0.41648	3050.97	13.01
7	0.43739	4278.50	18.24
8	0.46593	6591.17	28.10
9	0.48435	8370.50	35.68
10	0.50246	10605.27	45.21
11	0.52497	13676.75	58.31
12	0.54697	17139.31	73.07
13	0.56197	20204.12	86.13
14	0.57635	23678.74	100.95
15	0.59038	26924.54	114.78
16	0.62776	36047.90	153.68
17	0.67590	52495.28	223.79
18	0.71660	70126.07	298.96
19	0.75506	89572.62	381.86
20	0.80352	118364.75	504.60

This unit was calibrated using calibration standards traceable to National Institute of Standards and Technology (NIST), to an uncertainty of +/-1.0% of reading +/- 0.2% of full scale. Fox Thermal Instruments, Inc. is an ISO 9001 certified company.

Approved By: Octavio Avila **Cal Date:** 2/22/2016 15:56

Calibration Standards

Description	Inst. ID #	Due Date
Meter DVM	FOX A009	10/06/2016
Ref1 DVM	FOX A0121	10/06/2016
Pressure transducer	PRESS-007	08/06/2016
Thermometer	TEMP-SYS-001	10/07/2016
Therm Flowmeter	2135	12/11/2016

Fox maintains all equipment according to the *Equipment Control Procedure* (P-060).

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FLOW METER CALIBRATION CERTIFICATE

Serial #:	21775	**Dia. =**	3.068	in
Model #:	FT3-18R	**Area =**	0.0513379	Ft^2
Fluid Type:	Custom			
	32.43% CH4, 25.81% C2H6, 18.17% C3H8, 12.39% C4H10, 6.51% C5H12, 1.98% CO2, et al.			
STP:	60 F, 14.73 psia	**4 mA =**	0	MSCFD
IDTag:	-	**20 mA =**	500.00	MSCFD

Curve 1

Data Point	Input Volts	NMPH at 0 C 760 mmHg	MSCFD at STP
1	0.30134	0.00	0.00
2	0.31387	358.06	1.53
3	0.34322	672.74	2.87
4	0.37469	1419.33	6.05
5	0.39900	2321.25	9.90
6	0.41589	3059.22	13.04
7	0.44029	4508.14	19.22
8	0.46231	6386.19	27.23
9	0.47947	8237.14	35.12
10	0.49716	10472.63	44.65
11	0.52055	13709.28	58.44
12	0.53799	17092.68	72.87
13	0.55243	19960.94	85.10
14	0.56917	23606.45	100.64
15	0.58428	27364.50	116.66
16	0.61203	35898.55	153.04
17	0.65934	52814.23	225.15
18	0.69945	70303.82	299.71
19	0.72635	86878.24	370.37
20	0.77338	117733.63	501.91

This unit was calibrated using calibration standards traceable to National Institute of Standards and Technology (NIST), to an uncertainty of +/-1.0% of reading +/- 0.2% of full scale. Fox Thermal Instruments, Inc. is an ISO 9001 certified company.

Approved By: Octavio Avila **Cal Date:** **2/22/2016 14:48**

Calibration Standards

Description	Inst. ID #	Due Date
Meter DVM	FOX A009	10/06/2016
Ref1 DVM	FOX A0121	10/06/2016
Pressure transducer	PRESS-007	08/06/2016
Thermometer	TEMP-SYS-001	10/07/2016
Therm Flowmeter	2135	12/11/2016

Fox maintains all equipment according to the *Equipment Control Procedure* (P-060).

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CAL-V™ CERTIFICATE

CALIBRATION VALIDATION

CAL-V™ Performed on:	February 25 2016	17:03:49	CAL-V™ Results:	PASS
Firmware Version:	FT3 V3.11		CAL-V™ Value:	22.81
Fox Meter Serial Number:	21775		CAL-V™ Verify:	0.01%

Tag #/Meter location: 21775

Test performed by: Cody Winberg

Additional Comments: Highest Fox Thermal

Calibration Table Stored in Flow Meter

Compare the below Calibration Table to the original Calibration Certificate

Data Point	Input Volts	NMPH at 0 C 760 mmHg
1	0.30134	0.00
2	0.31387	358.06
3	0.34322	672.75
4	0.37469	1419.33
5	0.39900	2321.25
6	0.41589	3059.22
7	0.44029	4508.14
8	0.46231	6386.19
9	0.47947	8237.14
10	0.49716	10472.63
11	0.52055	13709.28
12	0.53799	17092.68
13	0.55243	19960.94
14	0.56917	23606.45
15	0.58428	27364.50
16	0.61203	35898.55
17	0.65934	52814.24
18	0.69945	70303.82
19	0.72635	86878.24
20	0.77338	117733.60

CAL-V™ is an in-situ calibration routine that validates the flow meter's calibration accuracy by testing the functionality of the sensor and its associated signal processing circuitry.

At the conclusion of the test, the meter will display a pass/fail message and the CAL-V™ data.

A "pass" result confirms the meter is measuring accurately.

1. The CAL-V™ test is valid for checking the calibration accuracy of flow meters installed in the application for which it was calibrated, including the gas/gas mixture, calibration range and pipe size shown on the Calibration Certificate.
2. For applications with temperature exceeding 250°F (121°C), CAL-V™ test results may vary.

Fox Flow Meter 21775 Certification Documentation, Pre-Winter Testing

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FLOW METER CALIBRATION CERTIFICATE

Serial #: 21776 **Dia. =** 3.068 in

Model #: FT3-18R **Area =** 0.0513379 Ft^2

Fluid Type: 20.89% CH4, 18.16% C2H6, 16.52% C3H8, 17.99% C4H10, 15.49% C5H12, 2.63% C6H14, 1.85% C7H16, 1.32% CO2, et al.

STP: 60 F, 14.73 psia **4 mA =** 0 MSCFD
20 mA = 500.00 MSCFD

IDTag: -

CURVE #2

Data Point	Input Volts	NMPH at 0 C 760 mmHg	MSCFD at STP
1	0.24167	0.00	0.00
2	0.31024	354.49	1.51
3	0.34274	704.73	3.00
4	0.37016	1367.35	5.83
5	0.38913	2085.69	8.89
6	0.41190	3056.25	13.03
7	0.43537	4425.56	18.87
8	0.46017	6268.45	26.72
9	0.48454	8630.13	36.79
10	0.50280	10696.79	45.60
11	0.52490	13551.34	57.77
12	0.54688	16922.84	72.14
13	0.56388	20045.33	85.46
14	0.58215	23559.30	100.44
15	0.59510	26738.73	113.99
16	0.63196	36180.04	154.24
17	0.67660	51580.91	219.90
18	0.72560	70070.96	298.72
19	0.76541	90640.58	386.41
20	0.81299	118131.44	503.61

This unit was calibrated using calibration standards traceable to National Institute of Standards and Technology (NIST), to an uncertainty of +/-1.0% of reading +/- 0.2% of full scale. Fox Thermal Instruments, Inc. is an ISO 9001 certified company.

Approved By: Octavio Avila **Cal Date:** 2/22/2016 9:43

Calibration Standards

Description	Inst. ID #	Due Date
Meter DVM	FOX A009	10/06/2016
Ref1 DVM	FOX A0121	10/06/2016
Pressure transducer	PRESS-007	08/06/2016
Thermometer	TEMP-SYS-001	10/07/2016
Therm Flowmeter	2135	12/11/2016

Fox maintains all equipment according to the *Equipment Control Procedure* (P-060).

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www.foxthermalinstruments.com

FLOW METER CALIBRATION CERTIFICATE

Serial #: 21776 — **Dia. =** 3.068 in

Model #: FT3-18R — **Area =** 0.0513379 Ft^2

Fluid Type: 26.25% CH4, 22.05% C2H6, 18.19% C3H8, 15.96% C4H10, 10.64% C5H12, 1.45% C6H14, 1.63% CO2, et al.

STP: 60 F, 14.73 psia — **4 mA =** 0 MSCFD

IDTag: - — **20 mA =** 500.00 MSCFD

CURVE #3 (data only not installed on meter)

Data Point	Input Volts	NMPH at 0 C 760 mmHg	MSCFD at STP
1	0.24265	0.00	0.00
2	0.31321	332.05	1.42
3	0.34452	699.90	2.98
4	0.37666	1416.74	6.04
5	0.39232	2023.77	8.63
6	0.41797	3133.14	13.36
7	0.43920	4467.50	19.05
8	0.46380	6328.54	26.98
9	0.48009	8117.45	34.61
10	0.50128	10517.43	44.84
11	0.52387	13758.16	58.65
12	0.54394	16740.18	71.37
13	0.56081	19895.07	84.81
14	0.57444	23573.91	100.50
15	0.59333	27454.67	117.04
16	0.62496	36550.09	155.82
17	0.66858	51953.37	221.48
18	0.70878	69970.88	298.29
19	0.74904	91525.16	390.18
20	0.79236	117882.04	502.54

This unit was calibrated using calibration standards traceable to National Institute of Standards and Technology (NIST), to an uncertainty of +/-1.0% of reading +/- 0.2% of full scale. Fox Thermal Instruments, Inc. is an ISO 9001 certified company.

Approved By: Octavio Avila — **Cal Date:** **2/22/2016 9:44**

Calibration Standards

Description	Inst. ID #	Due Date
Meter DVM	FOX A009	10/06/2016
Ref1 DVM	FOX A0121	10/06/2016
Pressure transducer	PRESS-007	08/06/2016
Thermometer	TEMP-SYS-001	10/07/2016
Therm Flowmeter	2135	12/11/2016

Fox maintains all equipment according to the *Equipment Control Procedure* (P-060).

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FLOW METER CALIBRATION CERTIFICATE

Serial #:	21776	**Dia. =**	3.068	in
Model #:	FT3-18R	**Area =**	0.0513379	Ft^2
Fluid Type:	32.43% CH4, 25.81% C2H6, 18.17% C3H8, 12.39% C4H10, 6.51% C5H12, 1.98% CO2, et al.			
STP:	60 F, 14.73 psia	**4 mA =**	0	MSCFD
IDTag:	-	**20 mA =**	500.00	MSCFD

CURVE #1

Data Point	Input Volts	NMPH at 0 C 760 mmHg	MSCFD at STP
1	0.24594	0.00	0.00
2	0.30973	335.67	1.43
3	0.34114	688.36	2.93
4	0.37186	1386.33	5.91
5	0.38804	2072.60	8.84
6	0.41072	3034.09	12.93
7	0.43504	4428.54	18.88
8	0.45752	6364.54	27.13
9	0.47453	8150.92	34.75
10	0.49398	10534.52	44.91
11	0.51585	13467.07	57.41
12	0.53645	16817.01	71.69
13	0.55486	20041.29	85.44
14	0.57197	23495.03	100.16
15	0.59094	27004.66	115.12
16	0.62026	36767.85	156.75
17	0.66113	51776.19	220.73
18	0.69811	70148.38	299.05
19	0.73877	89759.54	382.65
20	0.77817	117832.35	502.33

This unit was calibrated using calibration standards traceable to National Institute of Standards and Technology (NIST), to an uncertainty of +/-1.0% of reading +/- 0.2% of full scale. Fox Thermal Instruments, Inc. is an ISO 9001 certified company.

Approved By: Octavio Avila **Cal Date:** **2/22/2016 9:42**

Calibration Standards

Description	Inst. ID #	Due Date
Meter DVM	FOX A009	10/06/2016
Ref1 DVM	FOX A0121	10/06/2016
Pressure transducer	PRESS-007	08/06/2016
Thermometer	TEMP-SYS-001	10/07/2016
Therm Flowmeter	2135	12/11/2016

Fox maintains all equipment according to the *Equipment Control Procedure* (P-060).

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CAL-V™ CERTIFICATE
CALIBRATION VALIDATION

CAL-V™ Performed on:	February 25 2016	16:46:06	CAL-V™ Results:	PASS
Firmware Version:	FT3 V3.11		CAL-V™ Value:	22.84
Fox Meter Serial Number:	21776		CAL-V™ Verify:	3.15%

Tag #/Meter location: 21776

Test performed by: Cody Winberg

Additional Comments: Lowest Fox Thermal

Calibration Table Stored in Flow Meter

Compare the below Calibration Table to the original Calibration Certificate

Data Point	Input Volts	NMPH at 0 C 760 mmHg
1	0.24594	0.00
2	0.30973	335.67
3	0.34114	688.36
4	0.37186	1386.33
5	0.38804	2072.60
6	0.41072	3034.09
7	0.43504	4428.54
8	0.45752	6364.54
9	0.47453	8150.92
10	0.49398	10534.51
11	0.51585	13467.07
12	0.53645	16817.01
13	0.55486	20041.30
14	0.57197	23495.03
15	0.59094	27004.66
16	0.62026	36767.85
17	0.66113	51776.19
18	0.69811	70148.37
19	0.73877	89759.55
20	0.77817	117832.40

CAL-V™ is an in-situ calibration routine that validates the flow meter's calibration accuracy by testing the functionality of the sensor and its associated signal processing circuitry.

At the conclusion of the test, the meter will display a pass/fail message and the CAL-V™ data.

A "pass" result confirms the meter is measuring accurately.

1. The CAL-V™ test is valid for checking the calibration accuracy of flow meters installed in the application for which it was calibrated, including the gas/gas mixture, calibration range and pipe size shown on the Calibration Certificate.
2. For applications with temperature exceeding 250°F (121°C), CAL-V™ test results may vary.

Fox Flow Meter 21776 Certification Documentation, Pre-Winter Testing

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FLOW METER CALIBRATION CERTIFICATE

Serial #: 21773 **Dia. =** 3.068 in

Model #: FT3-18R **Area =** 0.0513379 Ft^2

Fluid Type: 32.43% CH4, 25.81% C2H6, 18.17% C3H8, 12.4% C4H10, 6.51% C5H12, 1.98% CO2 et al.

STP: 60 F, 14.73 psia **4 mA =** 0 MSCFD

IDTag: - **20 mA =** 500.00 MSCFD

CURVE #1 (WINTER PHASE)

Data Point	Input Volts	NMPH at 0 C 760 mmHg	MSCFD at STP
1	0.24843	0.00	0.000
2	0.31411	361.57	1.541
3	0.34489	720.92	3.073
4	0.37772	1416.74	6.040
5	0.39928	2124.81	9.058
6	0.42117	3047.04	12.990
7	0.44471	4479.92	19.098
8	0.46667	6337.85	27.019
9	0.48473	8213.58	35.015
10	0.50410	10681.78	45.538
11	0.52471	13620.33	58.065
12	0.54271	16871.31	71.924
13	0.55893	20039.26	85.430
14	0.57581	23476.32	100.082
15	0.59098	27135.50	115.682
16	0.62424	36702.57	156.467
17	0.66444	51551.51	219.770
18	0.70342	69025.67	294.264
19	0.74421	91700.81	390.931
20	0.78249	118310.34	504.370

This unit was calibrated using calibration standards traceable to National Institute of Standards and Technology (NIST), to an uncertainty of +/-1.0% of reading +/- 0.2% of full scale. Fox Thermal Instruments, Inc. is an ISO 9001 certified company.

Approved By: Ross Johnson **Cal Date:** **6/13/2016 9:31**

Calibration Standards

Description	Inst. ID #	Due Date
Meter DVM	FOX A009	10/06/2016
Ref1 DVM	FOX A0121	10/06/2016
Pressure transducer	PRESS-007	08/06/2016
Thermometer	TEMP-SYS-001	10/07/2016
Therm Flowmeter	2135	12/11/2016

Fox maintains all equipment according to the *Equipment Control Procedure* (P-060).

F-131, Flow Meter Calibration Certificate Rev. C, 05/08/14

FOX

399 Reservation Road, Marina, California 93933 (831) 384-4300

AS LEFT CALIBRATION CERTIFICATE

Serial #:	21773
Model #:	FT3-18R
Fluid Type:	32.43% CH4, 25.81% C2H6, 18.17% C3H8, 12.4% C4H10, 6.51% C5H12, 1.98% CO2 et al.
Calibration Range:	0 to 100 MSCFD

Actual Flow MSCFD	Device Under Test MSCFD	Error MSCFD	Error % Reading	Fox Specification % Reading
0	0	0.00	0.00%	± 0.00%
6.32	6.20	-0.11	-1.81%	± 4.16%
12.16	12.39	0.24	1.96%	± 2.65%
25.03	25.19	0.15	0.62%	± 1.80%
50.65	51.05	0.40	0.78%	± 1.39%
75.51	76.02	0.51	0.68%	± 1.26%
100.19	100.16	-0.03	-0.03%	± 1.20%

This calibration is traceable to the National Institute of Standards and Technology to an uncertainty of +/-1% of reading +/- .2% of full scale using measurements traceable to NIST Standards in accordance with Mil-Std-45662A.

Prepared By:	Ross Johnson	Cal. Equip. No:	2135
Date:	June 13, 2016		

12/08/11. ALT/CHG

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sales@foxthermalinstruments.com
www.foxthermalinstruments.com

FOX THERMAL INSTRUMENTS, INC.
Fox is ISO 9001 certified
THERMAL MASS FLOW METERS

FLOW METER CALIBRATION CERTIFICATE

Serial #: 21773
Model #: FT3-18R
Dia. = 3.068 in
Area = 0.0513379 Ft^2
Fluid Type: 20.89% CH4, 18.16% C2H6, 16.52% C3H8, 17.99% C4H10, 15.49% C5H12, 2.63% C6H14, 1.85% C7H16, 1.32% CO2 et al.
STP: 60 F, 14.73 psia
4 mA = 0 MSCFD
20 mA = 500.00 MSCFD
IDTag: -

CURVE #2 (SUMMER PHASE)

Data Point	Input Volts	NMPH at 0 C 760 mmHg	MSCFD at STP
1	0.24207	0.00	0.000
2	0.30961	347.59	1.482
3	0.34132	692.77	2.953
4	0.37812	1439.68	6.138
5	0.40067	2138.94	9.119
6	0.42172	3089.35	13.170
7	0.44412	4511.51	19.233
8	0.46814	6414.52	27.346
9	0.48823	8335.38	35.535
10	0.50664	10514.75	44.826
11	0.52997	13737.18	58.563
12	0.54990	16973.42	72.360
13	0.56658	20114.83	85.752
14	0.58277	23461.18	100.018
15	0.60025	27264.21	116.230
16	0.63782	36519.42	155.686
17	0.67888	52024.99	221.788
18	0.72084	69134.47	294.728
19	0.76361	90832.28	387.228
20	0.79654	117734.83	501.916

This unit was calibrated using calibration standards traceable to National Institute of Standards and Technology (NIST), to an uncertainty of +/-1.0% of reading +/- 0.2% of full scale. Fox Thermal Instruments, Inc. is an ISO 9001 certified company.

Approved By: Ron R. Johnson **Cal Date:** 6/13/2016 0:00

Calibration Standards

Description	Inst. ID #	Due Date
Meter DVM	FOX A009	10/06/2016
Ref1 DVM	FOX A0121	10/06/2016
Pressure transducer	PRESS-007	08/06/2016
Thermometer	TEMP-SYS-001	10/07/2016
Therm Flowmeter	2135	12/11/2016

Fox maintains all equipment according to the *Equipment Control Procedure* (P-060).

F-131, Flow Meter Calibration Certificate

Rev. C, 05/08/14

FOX

399 Reservation Road, Marina, California 93933 (831) 384-4300

AS LEFT CALIBRATION CERTIFICATE

Serial #:	21773
Model #:	FT3-18R
Fluid Type:	20.89% CH4, 18.16% C2H6, 16.52% C3H8, 17.99% C4H10, 15.49% C5H12, 263% C6H14, 1.85% C7H16, 1.32% CO2 et al.
Calibration Range:	0 to 100 MSCFD

Actual Flow MSCFD	Device Under Test MSCFD	Error MSCFD	Error % Reading	Fox Specification % Reading
0	0	0.00	0.00%	± 0.00%
6.36	6.49	0.13	2.04%	± 4.15%
12.71	12.94	0.23	1.81%	± 2.57%
25.22	25.64	0.42	1.66%	± 1.79%
50.18	50.55	0.37	0.74%	± 1.40%
75.86	76.17	0.32	0.42%	± 1.26%
100.38	100.57	0.19	0.19%	± 1.20%

This calibration is traceable to the National Institute of Standards and Technology to an uncertainty of +/-1% of reading +/- .2% of full scale using measurements traceable to NIST Standards in accordance with Mil-Std-45662A.

Prepared By:	Ross Johnson	Cal. Equip. No:	2135
Date:	June 13, 2016		

12/08/11, ALT/CHG

Fox Flow Meter 21773 Certification Documentation, Pre-Summer Testing

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THERMAL MASS FLOW METERS

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www.foxthermalinstruments.com

FLOW METER CALIBRATION CERTIFICATE

Serial #:	21775	**Dia. =**	3.068	in
Model #:	FT3-18R	**Area =**	0.0513379	Ft^2

Fluid Type: 32.43% CH_4, 25.81% C_2H_6, 18.17% C_3H_8, 12.4% C_4H_{10}, 6.51% C_5H_{12}, 1.98% CO_2 et al.

STP:	60 F, 14.73 psia	**4 mA =**	0	MSCFD
		20 mA =	500.00	MSCFD
IDTag:	-			

CURVE #1 (WINTER PHASE)

Data Point	Input Volts	NMPH at 0 C 760 mmHg	MSCFD at STP
1	0.24956	0.00	0.000
2	0.30806	325.85	1.389
3	0.34091	713.84	3.043
4	0.37326	1408.25	6.004
5	0.39505	2111.87	9.003
6	0.41702	3085.73	13.155
7	0.43996	4489.01	19.137
8	0.46208	6443.38	27.469
9	0.47936	8287.92	35.332
10	0.49824	10623.15	45.288
11	0.51875	13682.28	58.329
12	0.53634	16985.44	72.411
13	0.55162	19936.80	84.993
14	0.56887	23558.24	100.431
15	0.58253	26849.46	114.462
16	0.61645	36463.13	155.446
17	0.65672	51955.80	221.493
18	0.69528	69190.18	294.965
19	0.73299	90524.99	385.918
20	0.77205	117683.74	501.699

This unit was calibrated using calibration standards traceable to National Institute of Standards and Technology (NIST), to an uncertainty of +/-1.0% of reading +/- 0.2% of full scale. Fox Thermal Instruments, Inc. is an ISO 9001 certified company.

Approved By: Ross Johnson **Cal Date:** **6/10/2016 15:21**

Calibration Standards

Description	Inst. ID #	Due Date
Meter DVM	FOX A009	10/06/2016
Ref1 DVM	FOX A0121	10/06/2016
Pressure transducer	PRESS-007	08/06/2016
Thermometer	TEMP-SYS-001	10/07/2016
Therm Flowmeter	2135	12/11/2016

Fox maintains all equipment according to the *Equipment Control Procedure* (P-060).

FOX

399 Reservation Road, Marina, California 93933 (831) 384-4300

AS LEFT CALIBRATION CERTIFICATE

Serial #:	21775
Model #:	FT3-18R
Fluid Type:	32.43% CH4, 25.81% C2H6, 18.17% C3H8, 12.4% C4H10, 6.51% C5H12, 1.98% CO2 et al.
Calibration Range:	0 to 100 MSCFD

Actual Flow MSCFD	Device Under Test MSCFD	Error MSCFD	Error % Reading	Fox Specification % Reading
0	0	0.00	0.00%	± 0.00%
6.27	6.45	0.19	2.96%	± 4.19%
12.14	12.39	0.25	2.02%	± 2.65%
25.53	25.98	0.45	1.75%	± 1.78%
50.22	50.05	-0.17	-0.33%	± 1.40%
75.88	76.44	0.56	0.74%	± 1.26%
100.15	100.55	0.40	0.40%	± 1.20%

This calibration is traceable to the National Institute of Standards and Technology to an uncertainty of +/-1% of reading +/- .2% of full scale using measurements traceable to NIST Standards in accordance with Mil-Std-45662A.

Prepared By:	Ross Johnson	Cal. Equip. No:	2135
Date:	June 10, 2016		

12/08/11, ALT/CHG

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www.foxthermalinstruments.com

FLOW METER CALIBRATION CERTIFICATE

Serial #: 21775

Model #: FT3-18R

Dia. = 3.068 in

Area = 0.0513379 Ft^2

Fluid Type: 20.89% CH4, 18.16% C2H6, 16.52% C3H8, 17.99% C4H10, 15.49% C5H12, 2.63% C6H14, 1.85% C7H16, 1.32% CO2 et al.

STP: 60 F, 14.73 psia

4 mA = 0 MSCFD
20 mA = 500.00 MSCFD

IDTag: -

CURVE #2 (SUMMER PHASE)

Data Point	Input Volts	NMPH at 0 C 760 mmHg	MSCFD at STP
1	0.25087	0.00	0.000
2	0.30618	346.13	1.476
3	0.34148	742.08	3.164
4	0.37384	1424.38	6.072
5	0.39636	2165.37	9.231
6	0.41655	3077.94	13.122
7	0.44074	4555.05	19.419
8	0.46176	6358.24	27.106
9	0.48202	8269.25	35.253
10	0.50132	10577.25	45.092
11	0.52306	13755.86	58.643
12	0.54156	16863.68	71.892
13	0.55842	20119.64	85.772
14	0.57475	23601.98	100.618
15	0.59140	27175.32	115.851
16	0.62831	36421.34	155.268
17	0.66842	51472.13	219.431
18	0.71273	69968.20	298.282
19	0.74875	89856.30	383.067
20	0.78550	117844.08	502.382

This unit was calibrated using calibration standards traceable to National Institute of Standards and Technology (NIST), to an uncertainty of +/-1.0% of reading +/- 0.2% of full scale. Fox Thermal Instruments, Inc. is an ISO 9001 certified company.

Approved By: Ross Johnson

Cal Date: **6/10/2016 16:19**

Calibration Standards

Description	Inst. ID #	Due Date
Meter DVM	FOX A009	10/06/2016
Ref1 DVM	FOX A0121	10/06/2016
Pressure transducer	PRESS-007	08/06/2016
Thermometer	TEMP-SYS-001	10/07/2016
Therm Flowmeter	2135	12/11/2016

Fox maintains all equipment according to the *Equipment Control Procedure* (P-060).

FOX

399 Reservation Road, Marina, California 93933 (831) 384-4300

AS LEFT CALIBRATION CERTIFICATE

Serial #:	21775
Model #:	FT3-18R
Fluid Type:	20.89% CH_4, 18.16% C_2H_6, 16.52% C_3H_8, 17.99% C_4H_{10}, 15.49% C_5H_{12}, 2.63% C_6H_{14}, 1.85% C_7H_{16}, 1.32% CO_2 et al.
Calibration Range:	0 to 100 MSCFD

CURVE #2

Actual Flow MSCFD	Device Under Test MSCFD	Error MSCFD	Error % Reading	Fox Specification % Reading
0	0	0.00	0.00%	± 0.00%
6.27	6.36	0.09	1.45%	± 4.19%
12.54	12.86	0.32	2.53%	± 2.59%
25.65	26.03	0.38	1.48%	± 1.78%
50.50	50.26	-0.24	-0.48%	± 1.40%
76.03	76.43	0.40	0.53%	± 1.26%
100.80	101.06	0.27	0.27%	± 1.20%

This calibration is traceable to the National Institute of Standards and Technology to an uncertainty of +/-1% of reading +/- .2% of full scale using measurements traceable to NIST Standards in accordance with Mil-Std-45662A.

Prepared By:	Ross Johnson	Cal. Equip. No:	2135
Date:	June 10, 2016		

12/08/11, ALT/CHG

Fox Flow Meter 21775 Certification Documentation, Pre-Summer Testing

FOX THERMAL INSTRUMENTS, INC.
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www.foxthermalinstruments.com

FLOW METER CALIBRATION CERTIFICATE

Serial #: 21776
Model #: FT3-18R
Fluid Type: 32.43% CH4, 25.81% C2H6, 18.17% C3H8, 12.39% C4H10, 6.51% C5H12, 1.98% CO2 et al.
STP: 60 F, 14.73 psia
IDTag: -

Dia. = 3.068 in
Area = 0.0513379 Ft^2
4 mA = 0 MSCFD
20 mA = 500.00 MSCFD

CUREV#1 (WINTER PHASE)

Data Point	Input Volts	NMPH at 0 C 760 mmHg	MSCFD at STP
1	0.25281	0.00	0.000
2	0.30696	338.93	1.445
3	0.33680	713.76	3.043
4	0.37021	1390.98	5.930
5	0.39197	2100.04	8.953
6	0.41356	3077.17	13.118
7	0.43567	4431.26	18.891
8	0.45820	6410.16	27.327
9	0.47524	8248.02	35.162
10	0.49336	10594.71	45.166
11	0.51357	13637.28	58.137
12	0.53108	16960.82	72.306
13	0.54525	19884.95	84.772
14	0.56214	23565.38	100.462
15	0.57555	26940.11	114.849
16	0.60708	36597.02	156.017
17	0.64608	51663.01	220.245
18	0.68398	69499.35	296.283
19	0.71948	90617.97	386.314
20	0.75660	117840.11	502.365

This unit was calibrated using calibration standards traceable to National Institute of Standards and Technology (NIST), to an uncertainty of +/-1.0% of reading +/- 0.2% of full scale. Fox Thermal Instruments, Inc. is an ISO 9001 certified company.

Approved By: Ross Johnson **Cal Date:** 6/10/2016 12:55

Calibration Standards

Description	Inst. ID #	Due Date
Meter DVM	FOX A009	10/06/2016
Ref1 DVM	FOX A0121	10/06/2016
Pressure transducer	PRESS-007	08/06/2016
Thermometer	TEMP-SYS-001	10/07/2016
Therm Flowmeter	2135	12/11/2016

Fox maintains all equipment according to the *Equipment Control Procedure* (P-060).

F-131, Flow Meter Calibration Certificate
Rev. C. 05/08/14

FOX

399 Reservation Road, Marina, California 93933 (831) 384-4300

AS LEFT CALIBRATION CERTIFICATE

Serial #:	21776
Model #:	FT3-18R
Fluid Type:	32.43% CH4, 25.81% C2H6, 18.17% C3H8, 12.39% C4H10, 6.51% C5H12, 1.98% CO2 et al.
Calibration Range:	0 to 100 MSCFD

Actual Flow MSCFD	Device Under Test MSCFD	Error MSCFD	Error % Reading	Fox Specification % Reading
0	0	0.00	0.00%	± 0.00%
6.63	6.84	0.21	3.17%	± 4.02%
12.04	12.30	0.26	2.16%	± 2.66%
25.47	25.81	0.34	1.35%	± 1.79%
50.42	50.57	0.15	0.30%	± 1.40%
76.32	77.03	0.71	0.93%	± 1.26%
100.30	100.35	0.05	0.05%	± 1.20%

This calibration is traceable to the National Institute of Standards and Technology to an uncertainty of +/-1% of reading +/- .2% of full scale using measurements traceable to NIST Standards in accordance with Mil-Std-45662A.

Prepared By:	Ross Johnson	Cal. Equip. No:	2135
Date:	June 10, 2016		

12/08/11, ALT/CHG

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sales@foxthermalinstruments.com
www.foxthermalinstruments.com

FLOW METER CALIBRATION CERTIFICATE

Serial #: 21776

Model #: FT3-18R

Dia. = 3.068 in

Area = 0.0513379 Ft^2

Fluid Type: 20.89% CH_4, 18.16% C_2H_6, 16.52% C_3H_8, 17.99% C_4H_{10}, 15.49% C_5H_{12}, 2.63% C_6H_{14}, 1.85% C_7H_{16}, 1.32% CO_2 et al.

STP: 60 F, 14.73 psia

4 mA = 0 MSCFD

20 mA = 500.00 MSCFD

IDTag: -

CURVE# 2 (SUMMER PHASE)

Data Point	Input Volts	NMPH at 0 C 760 mmHg	MSCFD at STP
1	0.25202	0.00	0.000
2	0.30420	305.49	1.302
3	0.33253	675.84	2.881
4	0.37029	1415.01	6.032
5	0.39308	2110.01	8.995
6	0.41437	3108.68	13.253
7	0.43513	4448.27	18.963
8	0.45737	6290.17	26.816
9	0.47725	8208.03	34.992
10	0.49705	10652.81	45.414
11	0.51776	13668.24	58.269
12	0.53657	16982.11	72.397
13	0.55249	20099.58	85.687
14	0.56809	23503.04	100.196
15	0.58426	27281.23	116.303
16	0.62062	36716.38	156.526
17	0.65979	51800.27	220.830
18	0.69911	69658.95	296.964
19	0.73679	90127.54	384.223
20	0.77558	119101.22	507.741

This unit was calibrated using calibration standards traceable to National Institute of Standards and Technology (NIST), to an uncertainty of +/-1.0% of reading +/- 0.2% of full scale. Fox Thermal Instruments, Inc. is an ISO 9001 certified company.

Approved By: Ross Johnson

Cal Date: 6/10/2016 13:47

Calibration Standards

Description	Inst. ID #	Due Date
Meter DVM	FOX A009	10/06/2016
Ref1 DVM	FOX A0121	10/06/2016
Pressure transducer	PRESS-007	08/06/2016
Thermometer	TEMP-SYS-001	10/07/2016
Therm Flowmeter	2135	12/11/2016

Fox maintains all equipment according to the *Equipment Control Procedure* (P-060).

FOX

399 Reservation Road, Marina, California 93933 (831) 384-4300

AS LEFT CALIBRATION CERTIFICATE

Serial #:	21776
Model #:	FT3-18R
Fluid Type:	20.89% CH_4, 18.16% C_2H_6, 16.52% C_3H_8, 17.99% C_4H_{10}, 15.49% C_5H_{12}, 2.63% C_6H_{14}, 1.85% C_7H_{16}, 1.32% CO_2 et al.
Calibration Range:	0 to 100 MSCFD

CURVE #2

Actual Flow MSCFD	Device Under Test MSCFD	Error MSCFD	Error % Reading	Fox Specification % Reading
0	0	0.00	0.00%	± 0.00%
5.90	6.04	0.14	2.29%	± 4.39%
12.19	12.41	0.22	1.78%	± 2.64%
25.37	25.70	0.33	1.32%	± 1.79%
50.44	50.33	-0.11	-0.21%	± 1.40%
75.06	75.71	0.65	0.87%	± 1.27%
101.03	101.07	0.04	0.04%	± 1.20%

This calibration is traceable to the National Institute of Standards and Technology to an uncertainty of +/-1% of reading +/- .2% of full scale using measurements traceable to NIST Standards in accordance with Mil-Std-45662A.

Prepared By:	Ross Johnson	Cal. Equip. No:	2135
Date:	June 10, 2016		

12/08/11, ALT/CHG

Fox

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THERMAL MASS FLOW METERS

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www.foxthermalinstruments.com

FLOW METER CALIBRATION CERTIFICATE

Serial #: 21776

Model #: FT3-18R

Dia. = 3.068 in

Area = 0.0513379 Ft^2

Fluid Type: 26.25% CH4, 22.05% C2H6, 18.19% C3H8, 15.96% C4H12, 10.64% C5H12, 1.45% C6H14, 1.63% CO2 et al.

STP: 60 F, 14.73 psia

4 mA = 0 MSCFD

20 mA = 500.00 MSCFD

IDTag: -

Curve #3 Intermediate phase (data only)

Data Point	Input Volts	NMPH at 0 C 760 mmHg	MSCFD at STP
1	0.24538	0.00	0.000
2	0.31373	365.69	1.559
3	0.33771	707.65	3.017
4	0.37373	1435.64	6.120
5	0.39553	2112.35	9.005
6	0.41609	3063.63	13.061
7	0.43854	4402.57	18.769
8	0.46190	6398.36	27.277
9	0.47934	8211.05	35.005
10	0.49880	10552.38	44.986
11	0.51905	13658.25	58.227
12	0.53839	16926.08	72.158
13	0.55452	20172.90	85.999
14	0.56928	23476.98	100.085
15	0.58245	26972.29	114.986
16	0.61628	36642.51	156.211
17	0.65654	52129.83	222.235
18	0.69279	69619.08	296.794
19	0.72998	90912.78	387.571
20	0.76891	119171.89	508.043

This unit was calibrated using calibration standards traceable to National Institute of Standards and Technology (NIST), to an uncertainty of +/-1.0% of reading +/- 0.2% of full scale. Fox Thermal Instruments, Inc. is an ISO 9001 certified company.

Approved By: Ross Johnson

Cal Date: 6/10/2016 12:02

Calibration Standards

Description	Inst. ID #	Due Date
Meter DVM	FOX A009	10/06/2016
Ref1 DVM	FOX A0121	10/06/2016
Pressure transducer	PRESS-007	08/06/2016
Thermometer	TEMP-SYS-001	10/07/2016
Therm Flowmeter	2135	12/11/2016

Fox maintains all equipment according to the *Equipment Control Procedure* (P-060).

F-131, Flow Meter Calibration Certificate

Rev. C, 05/08/14

FOX

399 Reservation Road, Marina, California 93933 (831) 384-4300

AS LEFT CALIBRATION CERTIFICATE

Serial #:	21776
Model #:	FT3-18R
Fluid Type:	26.25% CH4, 22.05% C2H6, 18.19% C3H8, 15.96% C4H12, 10.64% C5H12, 1.45% C6H14, 1.63% CO2 et al.
Calibration Range:	0 to 100 MSCFD

Curev #3 Intermidiate phase (data only)

Actual Flow MSCFD	Device Under Test MSCFD	Error MSCFD	Error % Reading	Fox Specification % Reading
0	0	0.00	0.00%	± 0.00%
6.03	6.11	0.08	1.31%	± 4.32%
12.63	12.89	0.26	2.04%	± 2.58%
25.71	25.92	0.20	0.79%	± 1.78%
50.74	50.79	0.05	0.10%	± 1.39%
75.93	75.81	-0.12	-0.16%	± 1.26%
100.51	100.34	-0.17	-0.17%	± 1.20%

This calibration is traceable to the National Institute of Standards and Technology to an uncertainty of +/-1% of reading +/- .2% of full scale using measurements traceable to NIST Standards in accordance with Mil-Std-45662A.

Prepared By:	Ross Johnson	Cal. Equip. No:	2135
Date:	June 10, 2016		

12/08/11, ALT/CHG

Flow Meter 21776 Certification Documentation, Pre-Summer Testing

FOX

399 Reservation Road, Marina, California 93933 (831) 384-4300

AS FOUND CALIBRATION CERTIFICATE

Serial #:	21773
Model #:	FT3
Fluid Type:	Curve 2
Calibration Range:	0 to 500.00 MSCFD

June MSCFD	October MSCFD	CSV VOLTS	Error % Reading	Fox Specification % Reading
0.00	0.00	0.2421	0.00%	
0.84	1.48	0.2802	-76.88%	± 120.54%
2.51	3.01	0.3327	-19.85%	± 40.85%
5.86	6.09	0.3754	-3.94%	± 18.08%
8.37	8.87	0.3955	-6.06%	± 12.95%
12.55	13.17	0.4188	-4.92%	± 8.97%
18.40	18.96	0.4413	-3.04%	± 6.43%
26.77	26.93	0.4666	-0.61%	± 4.74%
34.30	34.97	0.4854	-1.97%	± 3.92%
44.34	45.13	0.5057	-1.80%	± 3.26%
57.72	58.24	0.5286	-0.89%	± 2.73%
70.27	71.95	0.5471	-2.39%	± 2.42%
82.82	84.63	0.5631	-2.20%	± 2.21%
98.71	100.02	0.5813	-1.33%	± 2.01%
113.77	115.42	0.5977	-1.45%	± 1.88%
153.92	156.38	0.6364	-1.60%	± 1.65%
214.99	218.73	0.6748	-1.74%	± 1.47%
287.77	293.12	0.7172	-1.86%	± 1.35%
363.89	385.50	0.7542	-5.94%	± 1.27%
491.04	501.04	0.7934	-2.04%	± 1.20%

This calibration is traceable to the National Institute of Standards and Technology to an uncertainty of +/-1% of reading +/- .2% of full scale using measurements traceable to NIST Standards in accordance with Mil-Std-45662A.

Prepared By:	Octavio Avila	Cal. Equip. No:	2135
Date:	October 26, 2016		

12/08/11, ALT/CHG

FOX

399 Reservation Road, Marina, California 93933 (831) 384-4300

AS FOUND CALIBRATION CERTIFICATE

Serial #:	21773
Model #:	FT3
Fluid Type:	Curve 1
Calibration Range:	0 to 500.00 MSCFD

June MSCFD	October MSCFD	CSV VOLTS	Error % Reading	Fox Specification % Reading
0.00	0.00	0.2484	0.00%	
1.68	1.46	0.3173	13.41%	± 60.48%
2.52	2.99	0.3349	-18.60%	± 40.65%
5.88	6.07	0.3763	-3.17%	± 17.99%
8.41	9.04	0.3950	-7.57%	± 12.90%
12.61	13.08	0.4193	-3.72%	± 8.93%
18.49	18.95	0.4426	-2.47%	± 6.41%
26.06	27.07	0.4642	-3.89%	± 4.84%
34.47	35.26	0.4836	-2.30%	± 3.90%
44.55	45.04	0.5024	-1.08%	± 3.24%
56.32	57.69	0.5221	-2.43%	± 2.78%
70.61	71.86	0.5411	-1.77%	± 2.42%
84.06	85.47	0.5573	-1.67%	± 2.19%
98.35	100.09	0.5740	-1.77%	± 2.02%
112.64	114.95	0.5881	-2.05%	± 1.89%
152.99	155.45	0.6216	-1.61%	± 1.65%
216.88	221.34	0.6628	-2.06%	± 1.46%
290.85	296.36	0.7018	-1.89%	± 1.34%
379.12	387.21	0.7396	-2.13%	± 1.26%
488.40	504.33	0.7771	-3.26%	± 1.20%

This calibration is traceable to the National Institute of Standards and Technology to an uncertainty of +/-1% of reading +/- .2% of full scale using measurements traceable to NIST Standards in accordance with Mil-Std-45662A.

Prepared By:	Octavio Avila	Cal. Equip. No:	2135
Date:	October 26, 2016		

12/08/11, ALT/CHG

Flow Meter 21773 Certification Documentation, Post-Summer Testing

FOX

399 Reservation Road, Marina, California 93933 (831) 384-4300

AS FOUND CALIBRATION CERTIFICATE

Serial #:	21776			
Model #:	FT3			
Fluid Type:	Curve 2			
Calibration Range:	0	to	500.00	MSCFD

June MSCFD	October MSCFD	CSV VOLTS	Error % Reading	Fox Specification % Reading
0.00	0.00	0.2520	0.00%	
1.30	0.84	0.3042	35.84%	± 77.79%
2.88	2.51	0.3325	13.00%	± 35.71%
6.03	5.85	0.3703	3.04%	± 17.58%
9.00	8.36	0.3931	7.11%	± 12.12%
13.25	11.70	0.4144	11.73%	± 8.55%
18.96	16.71	0.4351	11.88%	± 6.27%
26.82	23.40	0.4574	12.76%	± 4.73%
34.99	30.92	0.4773	11.65%	± 3.86%
45.41	40.11	0.4971	11.69%	± 3.20%
58.27	51.80	0.5178	11.10%	± 2.72%
72.40	64.34	0.5366	11.13%	± 2.38%
85.69	76.87	0.5525	10.29%	± 2.17%
100.20	90.24	0.5681	9.94%	± 2.00%
116.30	104.44	0.5843	10.20%	± 1.86%
156.53	140.37	0.6206	10.32%	± 1.64%
220.83	194.68	0.6598	11.84%	± 1.45%
296.96	261.52	0.6991	11.93%	± 1.34%
384.22	345.91	0.7368	9.97%	± 1.26%
507.74	455.37	0.7756	10.31%	± 1.20%

This calibration is traceable to the National Institute of Standards and Technology to an uncertainty of +/-1% of reading +/- .2% of full scale using measurements traceable to NIST Standards in accordance with Mil-Std-45662A.

Prepared By:	Octavio Avila	Cal. Equip. No:	2135
Date:	October 26, 2016		

12/08/11, ALT/CHG

FOX

399 Reservation Road, Marina, California 93933 (831) 384-4300

AS FOUND CALIBRATION CERTIFICATE

Serial #:	21776
Model #:	FT3
Fluid Type:	Curve 2
Calibration Range:	0 to 500.00 MSCFD

June MSCFD	October MSCFD	CSV VOLTS	Error % Reading	Fox Specification % Reading
0.00	0.00	0.2520	0.00%	
1.30	0.84	0.3042	35.84%	± 77.79%
2.88	2.51	0.3325	13.00%	± 35.71%
6.03	5.85	0.3703	3.04%	± 17.58%
9.00	8.36	0.3931	7.11%	± 12.12%
13.25	11.70	0.4144	11.73%	± 8.55%
18.96	16.71	0.4351	11.88%	± 6.27%
26.82	23.40	0.4574	12.76%	± 4.73%
34.99	30.92	0.4773	11.65%	± 3.86%
45.41	40.11	0.4971	11.69%	± 3.20%
58.27	51.80	0.5178	11.10%	± 2.72%
72.40	64.34	0.5366	11.13%	± 2.38%
85.69	76.87	0.5525	10.29%	± 2.17%
100.20	90.24	0.5681	9.94%	± 2.00%
116.30	104.44	0.5843	10.20%	± 1.86%
156.53	140.37	0.6206	10.32%	± 1.64%
220.83	194.68	0.6598	11.84%	± 1.45%
296.96	261.52	0.6991	11.93%	± 1.34%
384.22	345.91	0.7368	9.97%	± 1.26%
507.74	455.37	0.7756	10.31%	± 1.20%

This calibration is traceable to the National Institute of Standards and Technology to an uncertainty of +/-1% of reading +/- .2% of full scale using measurements traceable to NIST Standards in accordance with Mil-Std-45662A.

Prepared By:	Octavio Avila	Cal. Equip. No:	2135
Date:	October 26, 2016		

12/08/11, ALT/CHG

FOX

399 Reservation Road, Marina, California 93933 (831) 384-4300

AS FOUND CALIBRATION CERTIFICATE

Serial #:	21776
Model #:	FT3
Fluid Type:	Curve 1
Calibration Range:	0 to 500.00 MSCFD

June MSCFD	October MSCFD	CSV VOLTS	Error % Reading	Fox Specification % Reading
0.00	0.00	0.2528	0.00%	
1.44	0.84	0.3070	41.94%	± 70.21%
3.04	2.52	0.3368	17.29%	± 33.86%
5.93	5.87	0.3702	0.97%	± 17.86%
8.95	8.39	0.3920	6.30%	± 12.17%
13.12	11.74	0.4136	10.47%	± 8.62%
18.89	16.78	0.4357	11.19%	± 6.29%
27.33	24.33	0.4582	10.98%	± 4.66%
35.16	31.04	0.4752	11.73%	± 3.84%
45.17	40.27	0.4934	10.85%	± 3.21%
58.14	52.01	0.5136	10.54%	± 2.72%
72.31	64.59	0.5311	10.67%	± 2.38%
84.77	75.50	0.5453	10.94%	± 2.18%
100.46	90.60	0.5621	9.82%	± 2.00%
114.85	103.18	0.5756	10.16%	± 1.87%
156.02	138.42	0.6071	11.28%	± 1.64%
220.25	195.46	0.6461	11.25%	± 1.45%
296.28	262.57	0.6840	11.38%	± 1.34%
386.31	338.91	0.7195	12.27%	± 1.26%
502.37	442.93	0.7566	11.83%	± 1.20%

This calibration is traceable to the National Institute of Standards and Technology to an uncertainty of +/-1% of reading +/- .2% of full scale using measurements traceable to NIST Standards in accordance with Mil-Std-45662A.

Prepared By:	Octavio Avila	Cal. Equip. No:	2135
Date:	October 26, 2016		

12/08/11, ALT/CHG

Flow Meter 21776 Certification Documentation, Post-Summer Testing

Micro Motion, Inc.	Mass Flowmeter Calibration Certificate	14267449

Product Code	Serial ID	Order ID	Line	Item	Customer Tag
F100SB21CQBAEZZZZ	14267449	10112352	4	1	

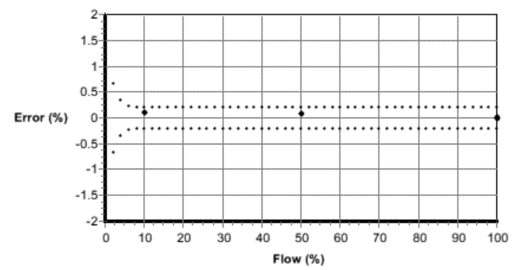
Process

Process ID : 7.19388840
Process Time : 2011.12.13 21:39:32
Process Stand : TSM1D@SSCC
Stand Uncertainty : +/-0.030%
Fluid : H20
100% Rate : 272.1554 KG/MIN
Pickoff : 1
100% P/T : 114.61 PSIG/20.5 C

Results

Status : PASS
D1 : 0
D2 : 1
K1 : 3682.22
K2 : 4355.523
DT : 4.4
FD : 0
DTG : 0
DFQ1 : 0
DFQ2 : 0
FlowCal : 273.854.67
FFQ : 0
FTG : 0
DensCal : 03682043564.40
FCF : 273.85
FT : 4.67

Detail



Flow (%)	Flow Rate (kg/min)	Meter Total (kg)	Reference Total (kg)	Error (%)	Specification (±%)
100.0	272.1554	204.4341	204.432	0.001	0.200
10.0	27.21554	20.37945	20.35603	0.115	0.200
50.0	136.0777	102.3894	102.2937	0.094	0.200
100.0	272.1554	204.3433	204.2831	0.029	0.200

F. CHAPARRO
Technician

Traceable to International Standards. Meter total based on pulse output. Details at www.micromotion.com. 2016.03.30 8:58:54 1 / 1

Coriolis Serial ID 14267449

Micro Motion, Inc.	Mass Flowmeter Calibration Certificate	14430099

Product Code	Serial ID	Order ID	Line	Item	Customer Tag
R100SB21NWBAEZZZZ	14430099	10173854	6.1	5	

Process

Process ID :	7.19664027
Process Time :	2014.07.29 10:17:09
Process Stand :	TSM2D@SSCC
Stand Uncertainty :	+/-0.030%
Fluid :	H20
100% Rate :	272.1554 KG/MIN
Pickoff :	1
100% P/T :	42.14 PSIG/23.4 C

Results

Status :	PASS
D1 :	0
D2 :	1
K1 :	3646.137
K2 :	4320.314
DT :	4.4
FD :	0
DTG :	0
DFQ1 :	0
DFQ2 :	0
FlowCal :	268.644.67
FFQ :	0
FTG :	0
DensCal :	03646043204.40
FCF :	268.64
FT :	4.67

CADENA GABRIEL

Technician

Traceable to International Standards. Meter total based on pulse output. Details at www.micromotion.com. 2016.03.30 8:58:04 1 / 1

Customer: **Noble Energy**
Operator: **Noble Energy**
Location: **Other Noble Locations**
Federal ID:
State ID:

Division:
Area:
County: **Weld**
State: **CO**
Legal Desc: **Bernhardt**

Volumetrics
measurement engineering consulting

Meter Data

Noble Bernhardt J31-32D
NOB_BH_J31-32D

Factor Tracked Meter Factor(MF)
Temp Compensated No
NKF 100000.0000 N/bbl
Manufacturer MicroMotion
Size 1.00 in
Serial No. 14430099
Model No. R100

Master Meter Data

Name VOL Hank
Temp Compensated No
NKF 100000.00 N/bbl
Manufacturer MicroMotion
Size 1.00 in
Serial No. 14428325
Certified
Meter Factor 1.0034

Product Data

Name Crude
Batch No.
Obs. Gravity 42.0 °API
Obs. Temp 60.0 °F
Obs. Press 0.0 psi
API Table Table A - Crude Oil (2004)
Base Density 42.0 °API HYC Y

Tolerances

Tolerance Type: None
Maximum Deviation: 0.029 %

Avg X Prev Meter Factor Deviation:
Enabled? N *Passed?* Y *Prod Dep?* N
Prev X Factor Count Sought: 1
Prev X Factor Count Used: 0
Cut Off History? N *Cutoff Date:*

Prev Meter Factor Deviation: 0.25
Enabled? Y *Passed?* Y *Prod Dep?* N

Proving Mode: Volumetric
Density Mode: Manual
Calc. Method: Avg. Meter Factor
Proving Method: Manual
Passes Per Run 1

Proving Data

	Previous	Current
Task ID		1457129265
Date		03/04/2016
Time		9:07
Product		Crude
Flowrate		10 bbl/hr
Totalizer		86
Throughput		
Base Density		42.0 °API
Avg Prvr Temp		50.2
Avg Prvr Press		5.0
Repeatability		0.042 %
MF		1.0008
MF Variance		

Liquid Properties at Metering Conditions for CMF

Normal Op. Pressure psig
Eq. Vapor Pressure psig
CPL 1.0000

Run	TEMPERATURE Tp	Tm	PRESSURE Pp	Pm	PULSES Np	N	Run Accepted ?		IMF	Flowrate bbl/hr
1	50.1	50.3	5.0	5.0	12022.000	12057.000	1	Yes	1.00059	10.26
2	50.1	50.3	5.0	5.0	12005.000	12036.000	2	Yes	1.00092	10.27
3	50.2	50.4	5.0	5.0	12006.000	12040.000	3	Yes	1.00067	10.27
4	50.2	50.4	5.0	5.0	12015.000	12045.000	4	Yes	1.00101	10.27
5	50.2	50.4	5.0	5.0	12015.000	12046.000	5	Yes	1.00093	10.28
Average	**50.2**	**50.4**	**5.0**	**5.0**	**12012.6000**	**12044.8000**			**1.00082**	**10.270**

(1) GSVp: [N(avg) ÷ NKFp = IVp] * [CTLp * CPLp = CCFp]

Np(avg)	*NKFp*	*IVp*	*CTLp*	*CPLp*	*CCFp*	*GSVp*
12012.6000	100000.0000	0.120126	1.00503	1.00003	1.00848	0.121145

(2) ISVm: [N(avg) ÷ NKF = IVm] * [CTLm * CPLm = CCFm]

N(avg)	*NKF*	*IVm*	*CTLm*	*CPLm*	*CCFm*	*ISVm*
12044.8000	100000.0000	0.120448	1.00493	1.00003	1.00496	0.121045

Status
No previous provings found for prior deviation comparison.

(3) Proving Factors:

>>>>	(1)	GSVp ÷ ISVm =	1.0008	MF
	(2)	MF * CPL =	1.0008	CMF
	(3)	1 ÷ MF =	0.9992	MA
	(4)	NKF ÷ MF =	99920	KF
	(5)	KF ÷ CPL =	99920	CKF

Repeatability: 0.042 %
Uncertainty: 0.022 %

Trans. Serial No.
Flow Calib Factor
Density Calib Factor
Frequency Set Point
Flowrate Set Point
Zero Verified Zeroed
As Found As Left

Notes
Start Tot= 86.4544
End Tot= 88.7708

noble energy

Checklist

Measurement Maintenance Process:

Witnessing Master Meter Proving

Location: Bernhardt 31-32 **Date:** 3-4-16

Prover Company Name: Volumetrics

Name of Prover Employee Performing Task: TJ Yarbrough

Title of Prover Employee Performing Task: Measurement Tech

Yes/No	Facility Characteristics:
No ✓	Any modifications to upstream facilities since last prove
No ✓	Any modifications to downstream facilities since last prove
Yes ✓	Building condition, heat, and power
Yes/No	**Physical Piping Characteristics:**
No ✓	Proving connections located downstream of meter Closed Loop System
Yes ✓	Meter and prover bypass valves – double-block and bleed
	Coriolis Meter Installations
Yes ✓	Meter installed in free standing position and without bind
	Turbine Meter Installations
N/A	Meter installed with adequate upstream and downstream straight lengths
N/A	Upstream obstructions that could interfere with meter operation or cause flow disturbances
Yes/No	**Flowing Conditions:**
Yes ✓	Stable product temperature and pressure
Yes ✓	Stable flow rate
Yes ✓	System valves and seals checked to ensure there is no leakage
Yes ✓	Trial runs conducted to evacuate any air/gas from system
No ✓	Potential sources of pulsation or vibration
No ✓	Potential sources of liquids and solids contamination

Meter Prove

Base Density:

Base density is 42° at 60 F determined by TJ Yarbrough

Flowing Density: (required only if meter configured to indicate mass)

Flowing Density is 42° at 60° F as determined by TJ Yarbrough

Temperature and Pressure:

Observed Master Meter temperature 50.2°F

Observed Meter temperature 50.4°F

Observed Master Meter pressure 5.0 PSI

Observed Meter pressure 5.0 PSI

Yes/No	
Yes ✓	Meter system (instrumentation/flow computer) CTL and CPL are correct
Yes/No	**Repeatability:**
Yes ✓	Meter proves repeat to <0.05%
Yes/No	**Reproducibility:**
N/A	Meter proof changes by +0.0025 from last prove and historical meter proves vary by +0.25% for similar compositions and flow rates

Totalizer Reading: 86

Meter Factor: 1.0008

Yes/No/NA	Seals in place:
NA ✓	Sample Probe
NA ✓	Sampler volume control
NA ✓	All valves entering or leaving sample pot
NA ✓	Meter assembly(counter head, ATC, ATG)
NA ✓	Temperature recorder (if so equipped)
NA ✓	Back pressure valve
NA ✓	Any drain valves
NA ✓	Proving Legs, valves, etc.

noble energy

Checklist

Measurement Maintenance Process:

Witnessing Master Meter Unit Proving

Witnessed by (Name of Noble Representative): Cody Winberg

Title of Noble Representative: Measurement Tech II

Summary:
- ☑ Pass
- ○ Fail

Provide detailed comments on failed proving/sampling events, including follow-up with Corporate Measurement

Coriolis Serial ID 14430099

FLOW MANAGEMENT DEVICES, LLC

5225 S. 37th St. Phoenix, AZ 85040 · Phone (602)233-9885 · Fax (602)233-9887 · Website: www.FlowMD.com

ISO/IEC 17025:2005 Accredited
Accreditation # 73638

Gravimetric Waterdraw Certificate

Customer :	VOLUMETRICS	Job Number :	002331-0001
P.O. # :	VLMTRCS179	Prover Serial Number :	000480
Model Number :	H44007(RL)1A4S1AAWWCS	Prover Tag Number:	N/A
Test Procedure :	WI 7.5.1-1; 000-100663-DOC	**SECONDARY VOLUME**	
Test Date :	October 16, 2015		

Compressibility factor for water (°F/psig)	3.2E-06	Area Thermal Expansion Coefficient (Ga)	1.92E-05
Elevation (ft)	1125	Detector Thermal Expansion Coefficient (Gl)	9.60E-06
Standard Temperature (°F)	60.0	Modulus of Elasticity (flow tube) (E)	2.80E+07
Standard Pressure (psig)	0.0	Flow Tube Inside Diameter (inches) (ID)	9.650
Field Test Weight Density (gm/cc)	7.84	Flow Tube Wall Thickness (inches) (WT)	0.89
Reference Test Weight density (gm/cc)	7.84	Conductivity Reading (uS)	7

Collected Data	Fill 1	Fill 2	Fill 3	Fill 4	Fill 5
Run Time (sec)	52	86	57	88	56
Apparent Mass of Water (Ww) (gm)	15137.6	15136.6	15137.2	15136.2	15137.1
Air Temperature (°F)	74.7	73.9	73.5	73.5	74.1
Detector Bar Temperature (Td) (°F)	74.5	74.5	74.4	74.4	74.3
Prover Temperature (Tp) (°F)	73.5	73.6	73.6	73.6	73.7
Prover pressure (Pp) (psig)	18.0	18.0	18.0	18.0	18.0
Corrected Encoder Count (3t) [V2-V3]	0.0	0.0	0.0	0.0	0.0
Calculated Densities					
Density of Air (DENa) (gm/cc)	0.001147	0.001148	0.001149	0.001149	0.001148
Water Density (RHOw) (gm/cc)	0.997527	0.997513	0.997513	0.997513	0.997500
Volume Calculation					
True Mass of Water (Mw) (gm)	15152.803	15151.826	15152.438	15151.437	15152.321
Volume of Water (Vw) (ml)	15190.376	15189.597	15190.211	15189.207	15190.295
Correction Factors to Standard Conditions					
Effect of Press. on Water (CPLp)	1.000058	1.000058	1.000058	1.000058	1.000058
Temp. correction CTS for SVP	1.000398	1.000400	1.000399	1.000399	1.000400
Pressure correction CPS for SVP	1.000007	1.000007	1.000007	1.000007	1.000007
Combined Correction Factor (CCF)	1.000463	1.000465	1.000464	1.000464	1.000465
Calculated Volume					
Volume at Standard Conditions (mL)	15183.346	15182.537	15183.166	15182.162	15183.235
Calculated Deviation					
Run percent deviation from average	0.0030%	-0.0023%	0.0018%	-0.0048%	0.0023%

Average Volume at Standard Conditions	15182.889	ml	1.906692	Expanded uncertainty by unit of measure
	15.182889	Liters	0.001907	
	0.0151829	Cubic meters	0.000002	
	4.01089	Gallons	0.000504	
	0.0954975	Barrels	0.000012	
	926.52	Cubic Inches	0.116354	
Repeatability	0.00780%		0.0126%	Expanded uncertainty expressed in percentage
Laboratory Room Temperature	73.9	Ambient (F)		
Laboratory Room Relative Humidity	35.0	% (rh)		
Laboratory Room Barometric Pressure	727.0	mm / Hg		

Combined uncertainty for this calibration is the sum of Calibration Measurement Capability (CMC) and the uncertainty of volume. CMC is based on the accuracy of the measurement equipment used during the prover calibration. Uncertainty of volume is based on the deviation of the five individual runs performed on this prover calibration. This combined uncertainty is then multiplied by K, a coverage factor of 2 to give the expanded uncertainty which defines an interval with an approximate 95% confidence level. Calibration standards used are traceable to NIST through approved accredited laboratories (reports on file). The purchase order number, sales order number and serial number on this report is the unique traceability used in referencing measurement traceability for artifacts identified in this report. Prover volume calibrated in accordance with FMD document 000-100663-DOC and API 4.9.4.

Performed By: [signature]
Witnessed: [signature]
Quality: [signature]

Date: 10/16-15
For: Volumetrics

NIST TRACEABLE INSTRUMENTS USED

Air Temperature Thermometer :	1024
Switch Bar Temperature Thermometer :	1077
Prover Temperature Thermometer :	1097
Mechanical Pressure Gauge :	E196203
PI Tape :	101410128
I.D. Gauge :	946368018683
Conductivity Meter Test Fluid :	CDSA-45
Encoder :	N/A

Test Weights :	80437
Test Weights :	80438
Test Weights :	80439
Test Weights :	80440
Test Weights :	0
Test Weights :	0
Test Weights :	0
Test Weights :	0

F 7.5.1-1; 000-101790-DOC REV E

F 7.5.1-7 Water Draw Data Collection

Gravimetric Water Draw Data Collection Form

Customer Name Volumetrics
Sales order # 002331 - 0001
Serial # 000480
Model # H44007(RL)1AYS1AAWWCS

Test Date 10/16/2015
Witness Name CRAIG COOK
Technician Name Scott Paladini
Barometric Pressure 727

Rel. Humidity 35%
Elevation 1125
Conductivity Calibration CDSA-45

Primary Volume

Conductivity 7

	Run 1 Fast		Run 2 Slow		Run 3 Fast		Run 4 Slow		Run 5 Fast	
Run Time	64	98	65	104	68					
Apparent Mass of Water	18870.8	18869.5	18870.7	18869.4	18870.4					
Air temperature	74.0	73.3	73.6	74.1	74.6					
Detector Bar Temperature	74.5	74.4	74.4	74.4	74.4					
Prover Temperature	73.2	73.2	73.3	73.3	73.4					
Prover Pressure	18	18	18	18	18					
Encoder Counts										

Secondary Volume

Conductivity 7

	Run 1 Fast		Run 2 Slow		Run 3 Fast		Run 4 Slow		Run 5 Fast	
Run Time	52	86	57	88	56					
Apparent Mass of Water	15137.6	15136.6	15137.2	15136.2	15137.8					
Air temperature	74.7	73.9	73.5	73.5	74.1					
Detector Bar Temperature	74.5	74.5	74.4	74.4	74.3					
Prover Temperature	73.5	73.6	73.6	73.6	73.7					
Prover Pressure	18	18	18	18	18					
Encoder Counts										

Witness Signature [illegible] Date 10/16/15 Thermometers SWB 1077 Prover 1097 Ambient 1024

Technician Signature [illegible] Date 10/16/2015 Pressure Gage E196203 Hygrometer 122161022 Barometer 111576215

Quality Signature [illegible] Date 10/16/15 Conductivity Meter 484642

Test Weights 80437 80438 80439 80440

F 7.5.1-7 Water Draw Data Collection	

API 4.9.4 Water Draw Checklist

API SECTION NUMBER	API SECTION TITLE	FMD SECTION NUMBER	DESCRIPTION	Verified	Customer Initials	Lab Tech Initials	Comments
5.2.2	Calibration Records	7.2.1	Verify hand written records match data entered	(B)	CRR	JP	
			Verify Data on Water Draw Cert				
5.2.6.2	Weigh Scale	6.2.3	Level Empty				
			Level Full				
			Protected from Elements				
			Container is large enough to hold volume				
			Weigh Scale verification with in +/-0.0025%				
5.2.6.3	Test Weights	5.1.3	Verify that they have been certified in the past 3 years				
			Are ASTM Class 1, 2, 3, or 4				
			Test Weight Tolerance +/- 0.002%				
5.2.6.5	Weight Scale Verification	6.2.3	Two Calibration verification				
			Test weights within +/- 20% of Total Mass				
			Mass Indication 0.005%				
5.2.6.6	Draining the Container	7.11 & 7.13	The container is completely drained				
5.2.6.7	Taring/Zeroing	7.18	The scale has been Tared/Zeroed				
5.2.7.2	Water Quality	6.2.2	Water conductivity is <50 microseimens				
5.2.8	Bleed Air	7.4	Verify there is no air in system				
5.2.9	Flow Rate	4.2	Verify that flow rate changed by 25% between runs				
5.2.10	Calibration Runs	7.20	5 consecutive runs pass				
6.2	Calibration Preparation	5.1.2	Thermometer are calibrated within 0.2 F (0.1 C)				
		5.1.1	Pressure Gage calibrated accurate to 1psig				
		4.2	All piping, flanges and closed valves are leak free	(B)	CRR	JP	

Witness Signature [signature] Date 10-16-15

Technician Signature [signature] Date 10/16/2015

Doc # 000-104614-DOC	Rev D	Release Date 09/11/2015

5225 S. 37th St. Phoenix, AZ 85040- Tel: 602-233-9885 Fax: 602-233-9887

Volumetrics Water Draw Volumetrics Water Draw

FLOW MANAGEMENT DEVICES, LLC

5225 S. 37th St. Phoenix, AZ 85040 · Phone (602)233-9885 · Fax (602)233-9887 · Website: www.FlowMD.com

ISO/IEC 17025:2005 Accredited
Accreditation # 73638

PJLA Calibration and Testing

Gravimetric Waterdraw Certificate

Customer :	VOLUMETRICS	Job Number :	002331-0001
P.O. # :	VLMTRCS179	Prover Serial Number :	000480
Model Number :	H44007(RL)1A4S1AAWWCS	Prover Tag Number:	N/A
Test Procedure :	WI 7.5.1-1; 000-100663-DOC	PRIMARY VOLUME	
Test Date :	October 16, 2015		

Compressibility factor for water (°F/psig)	3.2E-06	Area Thermal Expansion Coefficient (Ga)	1.92E-05
Elevation (ft)	1125	Detector Thermal Expansion Coefficient (Gl)	9.60E-06
Standard Temperature (°F)	60.0	Modulus of Elasticity (flow tube) (E)	2.80E+07
Standard Pressure (psig)	0.0	Flow Tube Inside Diameter (inches) (ID)	9.650
Field Test Weight Density (gm/cc)	7.84	Flow Tube Wall Thickness (inches) (WT)	0.89
Reference Test Weight density (gm/cc)	7.84	Conductivity Reading (uS)	7

Collected Data	Fill 1	Fill 2	Fill 3	Fill 4	Fill 5
Run Time (sec)	64	98	65	104	68
Apparent Mass of Water (Ww) (gm)	18870.8	18869.5	18870.7	18869.4	18870.4
Air Temperature (°F)	74.0	73.3	73.6	74.1	74.6
Detector Bar Temperature (Td) (°F)	74.5	74.4	74.4	74.4	74.4
Prover Temperature (Tp) (°F)	73.2	73.2	73.3	73.3	73.4
Prover pressure (Pp) (psig)	18.0	18.0	18.0	18.0	18.0
Corrected Encoder Count (It) [V1-V3]	0.0	0.0	0.0	0.0	0.0
Calculated Densities					
Density of Air (DENa) (gm/cc)	0.001148	0.001150	0.001149	0.001148	0.001147
Water Density (RHOw) (gm/cc)	0.997566	0.997566	0.997553	0.997553	0.997540
Volume Calculation					
True Mass of Water (Mw) (gm)	18889.777	18888.501	18889.691	18888.372	18889.356
Volume of Water (Vw) (ml)	18935.867	18934.587	18936.030	18934.708	18935.943
Correction Factors to Standard Conditions					
Effect of Press. on Water (CPLp)	1.000058	1.000058	1.000058	1.000058	1.000058
Temp. correction CTS for SVP	1.000393	1.000392	1.000394	1.000394	1.000396
Pressure correction CPS for SVP	1.000007	1.000007	1.000007	1.000007	1.000007
Combined Correction Factor (CCF)	1.000458	1.000457	1.000459	1.000459	1.000461
Calculated Volume					
Volume at Standard Conditions (mL)	18927.198	18925.938	18927.342	18926.021	18927.218
Calculated Deviation					
Run percent deviation from average	0.0024%	-0.0043%	0.0032%	-0.0038%	0.0025%

Average Volume at Standard Conditions	18926.743	ml	2.269543	Expanded uncertainty by unit of measure
	18.926743	Liters	0.002270	
	0.0189267	Cubic meters	0.000002	
	4.99992	Gallons	0.000600	
	0.1190456	Barrels	0.000014	
	1154.98	Cubic Inches	0.138496	
Repeatability	0.00742%		0.0120%	Expanded uncertainty expressed in percentage
Laboratory Room Temperature	73.9	Ambient (F)		
Laboratory Room Relative Humidity	35.0	% (rh)		
Laboratory Room Barometric Pressure	727.0	mm / Hg		

Combined uncertainty for this calibration is the sum of Calibration Measurement Capability (CMC) and the uncertainty of volume. CMC is based on the accuracy of the measurement equipment used during the prover calibration. Uncertainty of volume is based on the deviation of the five individual runs performed on this prover calibration. This combined uncertainty is then multiplied by K, a coverage factor of 2 to give the expanded uncertainty which defines an interval with an approximate 95% confidence level. Calibration standards used are traceable to NIST through approved accredited laboratories (reports on file). The purchase order number, sales order number and serial number on this report is the unique traceability used in referencing measurement traceability for artifacts identified in this report. Prover volume calibrated in accordance with FMD document 000-100663-DOC and API 4.9.4.

Performed By:
Witnessed:
Quality:

Date: 10·16·15
For: Volumetrics

NIST TRACEABLE INSTRUMENTS USED

Air Temperature Thermometer :	1024
Switch Bar Temperature Thermometer :	1077
Prover Temperature Thermometer :	1097
Mechanical Pressure Gauge :	E196203
Pi Tape :	101410128
I.D. Gauge :	946368018683
Conductivity Meter Test Fluid :	CDSA-45
Encoder :	N/A

Test Weights :	80437
Test Weights :	80438
Test Weights :	80439
Test Weights :	80440
Test Weights :	0
Test Weights :	0
Test Weights :	0
Test Weights :	0

F 7.5.1-1; 000-101790-DOC REV E

Volumetrics Water Draw Volumetrics Water Draw

Customer: **Volumetrics, Inc**
Operator: **Volumetrics, Inc**
Location: **Volumetrics, Inc**
Federal ID:
State ID:

Division:
Area:
County:
State: **CO**
Legal Desc:

Volumetrics
measurement engineering consulting

Meter Data

VOL Hank
MASTER_7

Factor Tracked **Meter Factor(MF)**
Temp Compensated **No**
NKF **100000.0000** **N/bbl**
Manufacturer **MicroMotion**
Size **1.00** **in**
Serial No. **14428325**
Model No. **F100**

Prover Data

BPV **0.119046** **bbl**
I.D. **9.650** **in**
W.T. **0.890** **in**
Manufacturer **Flow MD**
Type **Displacement-Piston**
Serial No. **480**
Elasticity **2.8E7** **1/psi**

Pipe Ga **1.92E-5** **1/°F**
External Shaft Gl **9.6E-6** **1/°F**
Certified

Product Data

Name **Crude**
Batch No.
Obs. Gravity **45.2 °API**
Obs. Temp **60.0 °F**
Obs. Press **0.0 psi**
API Table **Table A - Crude Oil (2004)**
Base Density **45.2 °API** HYC **Y**

Tolerances

Tolerance Type: **Repeatability**
Maximum Deviation: **0.050 %**
Enabled? **Y** *Passed?* **Y** *Min # of Runs:* **5**
Criteria: **5** *out of* **5** *consecutive runs*

Avg X Prev Meter Factor Deviation:
Enabled? **N** *Passed?* **Y** *Prod Dep?* **N**
Prev X Factor Count Sought: **1**
Prev X Factor Count Used: **0**
Cut Off History? **N** *Cutoff Date:*

Prev Meter Factor Deviation:
Enabled? **N** *Passed?* **Y** *Prod Dep?* **N**

Proving Mode: **Volumetric**
Density Mode: **Manual**
Calc. Method: **Avg. Data Factor**
Proving Method: **PIU**
Passes Per Run **1**

Proving Data

	Previous	*Current*
Task ID	**1456968163**	**1456969017**
Date	**03/02/2016**	**03/02/2016**
Time	**12:22**	**12:36**
Product	**Crude**	**Crude**
Flowrate	**8 bbl/hr**	**5 bbl/hr**
Totalizer	**5745**	**5747**
Throughput	**-998**	**2**
Base Density	**45.2°API**	**45.2 °API**
Switch Bar Temp	**62.2**	**63.1**
Avg Prvr Temp	**70.4**	**71.8**
Avg Prvr Press	**20.9**	**21.2**
Repeatability	**0.035 %**	**0.019 %**
MF	**1.0034**	**1.0045**
MF Variance	**0.0004**	**0.0011**

Liquid Properties at Metering Conditions for CMF

Normal Op. Pressure **psig**
Eq. Vapor Pressure **psig**
CPL **1.0000**

Run	TEMPERATURE Tp	Tm	PRESSURE Pp	Pm	PULSES N	Run Accepted ?		IMF	Flowrate bbl/hr
1	71.7	73.6	21.2	21.2	11864.630	1	Yes	1.00466	5.173
2	71.6	73.6	21.2	21.2	11865.044	2	Yes	1.00468	5.167
3	71.7	73.6	21.2	21.2	11866.888	3	Yes	1.00446	5.168
4	71.8	73.6	21.2	21.2	11866.642	4	Yes	1.00446	5.166
5	72.1	73.6	21.1	21.1	11864.698	5	Yes	1.00446	5.157
Average	**71.8**	**73.6**	**21.2**	**21.2**	**11865.5804**			**1.00454**	**5.166**

(1) GSVp: BPV * [CTSp * CPSp * CTLp * CPLp = CCFp]

BPV	*CTSp*	*CPSp*	*CTLp*	*CPLp*	*CCFp*	*GSVp*
0.119046	1.00026	1.00001	0.99370	1.00013	0.99410	0.118344

(2) ISVm: [N(avg) ÷ NKF = IVm] * [CTLm * CPLm = CCFm]

N(avg)	*NKF*	*IVm*	*CTLm*	*CPLm*	*CCFm*	*ISVm*
11865.5804	100000.0000	0.118656	0.99273	1.00013	0.99286	0.117809

(3) Proving Factors:

>>>> (1)	GSVp ÷ ISVm =	***1.0045***	MF
(2)	MF * CPL =	1.0045	CMF
(3)	1 ÷ MF =	0.9955	MA
(4)	NKF ÷ MF =	99552	KF
(5)	KF ÷ CPL =	99552	CKF

Repeatability: **0.019 %**
Uncertainty: **0.012 %**

Trans. Serial No.
Flow Calib Factor
Density Calib Factor

Frequency Set Point
Flowrate Set Point
Zero Verified Zeroed
As Found As Left

Customer: **Volumetrics, Inc**
Operator: **Volumetrics, Inc**
Location: **Volumetrics, Inc**
Federal ID:
State ID:

Division:
Area:
County:
State: **CO**
Legal Desc:

Volumetrics
measurement engineering consulting

Meter Data

VOL Hank
MASTER_7

Factor Tracked	**Meter Factor(MF)**
Temp Compensated	**No**
NKF	**100000.0000 N/bbl**
Manufacturer	**MicroMotion**
Size	**1.00 in**
Serial No.	**14428325**
Model No.	**F100**

Prover Data

BPV	**0.119046 bbl**
I.D.	**9.650 in**
W.T.	**0.890 in**
Manufacturer	**Flow MD**
Type	**Displacement-Piston**
Serial No.	**480**
Elasticity	**2.8E7 1/psi**
Pipe Ga	**1.92E-5 1/°F**
External Shaft Gl	**9.6E-6 1/°F**
Certified	

Product Data

Name	**Crude**
Batch No.	
Obs. Gravity	**45.2 °API**
Obs. Temp	**60.0 °F**
Obs. Press	**0.0 psi**
API Table	**Table A - Crude Oil (2004)**
Base Density	**45.2 °API** HYC **Y**

Tolerances

Tolerance Type: **Repeatability**
Maximum Deviation: **0.050 %**
Enabled? **Y** *Passed?* **Y** *Min # of Runs:* **5**
Criteria: **5** *out of* **5** *consecutive runs*

Avg X Prev Meter Factor Deviation:
Enabled? **N** *Passed?* **Y** *Prod Dep?* **N**
Prev X Factor Count Sought: **1**
Prev X Factor Count Used: **0**
Cut Off History? **N** *Cutoff Date:*

Prev Meter Factor Deviation:
Enabled? **N** *Passed?* **Y** *Prod Dep?* **N**

Proving Mode:	**Volumetric**
Density Mode:	**Manual**
Calc. Method:	**Avg. Data Factor**
Proving Method:	**PIU**
Passes Per Run	**1**

Proving Data

	Previous	*Current*
Task ID	**1456967615**	**1456968163**
Date	**03/02/2016**	**03/02/2016**
Time	**12:13**	**12:22**
Product	**Crude**	**Crude**
Flowrate	**13 bbl/hr**	**8 bbl/hr**
Totalizer	**6743**	**5745**
Throughput	**1002**	**-998**
Base Density	**45.2°API**	**45.2 °API**
Switch Bar Temp	**61.6**	**62.2**
Avg Prvr Temp	**69.7**	**70.4**
Avg Prvr Press	**20.0**	**20.9**
Repeatability	**0.020 %**	**0.035 %**
MF	**1.0030**	**1.0034**
MF Variance	**0.0008**	**0.0004**

Liquid Properties at Metering Conditions for CMF

Normal Op. Pressure **psig**
Eq. Vapor Pressure **psig**
CPL **1.0000**

Run	TEMPERATURE Tp	Tm	PRESSURE Pp	Pm	PULSES N	Run Accepted ?		IMF	Flowrate bbl/hr
1	70.3	71.8	20.8	20.8	11874.452	1	Yes	1.00358	8.231
2	70.3	71.8	20.9	20.9	11877.143	2	Yes	1.00335	8.234
3	70.3	71.8	20.9	20.9	11877.823	3	Yes	1.00330	8.224
4	70.5	71.8	20.9	20.9	11876.083	4	Yes	1.00333	8.225
5	70.7	71.8	20.9	20.9	11873.681	5	Yes	1.00344	8.221
Average	**70.4**	**71.8**	**20.9**	**20.9**	**11875.8364**			**1.00340**	**8.227**

(1) GSVp: BPV * [CTSp * CPSp * CTLp * CPLp = CCFp]

BPV	*CTSp*	*CPSp*	*CTLp*	*CPLp*	*CCFp*	*GSVp*
0.119046	1.00022	1.00001	0.99445	1.00013	0.99481	0.118428

(2) ISVm: [N(avg) ÷ NKF = IVm] * [CTLm * CPLm = CCFm]

N(avg)	*NKF*	*IVm*	*CTLm*	*CPLm*	*CCFm*	*ISVm*
11875.8364	100000.0000	0.118758	0.99370	1.00013	0.99383	0.118025

(3) Proving Factors:

>>>>	(1)	GSVp ÷ ISVm =	***1.0034***	MF
	(2)	MF * CPL =	1.0034	CMF
	(3)	1 ÷ MF =	0.9966	MA
	(4)	NKF ÷ MF =	99661	KF
	(5)	KF ÷ CPL =	99661	CKF

Repeatability: **0.035 %**
Uncertainty: **0.015 %**

Trans. Serial No.
Flow Calib Factor
Density Calib Factor
Frequency Set Point
Flowrate Set Point
Zero Verified Zeroed
As Found As Left

Customer: **Volumetrics, Inc**
Operator: **Volumetrics, Inc**
Location: **Volumetrics, Inc**
Federal ID:
State ID:

Division:
Area:
County:
State: **CO**
Legal Desc:

Meter Data	Product Data	Proving Data
VOL Hank MASTER_7 *Factor Tracked* Meter Factor(MF) *Temp Compensated* No *NKF* 100000.0000 N/bbl *Manufacturer* MicroMotion *Size* 1.00 in *Serial No.* 14428325 *Model No.* F100	*Name* Crude *Batch No.* *Obs. Gravity* 45.2 °API *Obs. Temp* 60.0 °F *Obs. Press* 0.0 psi *API Table* Table A - Crude Oil (2004) *Base Density* 45.2 °API HYC Y	*Previous* / *Current* *Task ID* 1456967370 / 1456967615 *Date* 03/02/2016 / 03/02/2016 *Time* 12:09 / 12:13 *Product* Crude / Crude *Flowrate* 26 bbl/hr / 13 bbl/hr *Totalizer* 5741 / 6743 *Throughput* 8 / 1002 *Base Density* 45.2°API / 45.2 °API *Switch Bar Temp* 61.1 / 61.6 *Avg Prvr Temp* 69.1 / 69.7 *Avg Prvr Press* 44.6 / 20.0 *Repeatability* 0.042 % / 0.020 % *MF* 1.0022 / 1.0030 *MF Variance* 0.0007 / 0.0008
Prover Data *BPV* 0.119046 bbl *I.D.* 9.650 in *W.T.* 0.890 in *Manufacturer* Flow MD *Type* Displacement-Piston *Serial No.* 480 *Elasticity* 2.8E7 1/psi *Pipe Ga* 1.92E-5 1/°F *External Shaft Gl* 9.6E-6 1/°F *Certified*	**Tolerances** *Tolerance Type:* Repeatability *Maximum Deviation:* 0.050 % *Enabled?* Y *Passed?* Y *Min # of Runs:* 5 *Criteria:* 5 *out of* 5 *consecutive runs* *Avg X Prev Meter Factor Deviation:* *Enabled?* N *Passed?* Y *Prod Dep?* N *Prev X Factor Count Sought:* 1 *Prev X Factor Count Used:* 0 *Cut Off History?* N *Cutoff Date:* *Prev Meter Factor Deviation:* *Enabled?* N *Passed?* Y *Prod Dep?* N *Proving Mode:* Volumetric *Density Mode:* Manual *Calc. Method:* Avg. Data Factor *Proving Method:* PIU *Passes Per Run* 1	**Liquid Properties at Metering Conditions for CMF** *Normal Op. Pressure* psig *Eq. Vapor Pressure* psig CPL 1.0000

Run	TEMPERATURE Tp	Tm	PRESSURE Pp	Pm	PULSES N	Run Accepted ?		IMF	Flowrate bbl/hr
1	69.3	71.9	20.0	20.0	11884.020	1	Yes	1.00334	12.953
2	69.5	71.9	20.0	20.0	11884.639	2	Yes	1.00320	12.923
3	69.8	71.6	20.0	20.0	11885.286	3	Yes	1.00282	12.925
4	69.9	71.6	19.9	19.9	11884.154	4	Yes	1.00286	12.870
5	70.0	71.6	20.0	20.0	11882.897	5	Yes	1.00291	12.858
Average	**69.7**	**71.7**	**20.0**	**20.0**	**11884.1992**			**1.00303**	**12.906**

(1) GSVp: BPV * [CTSp * CPSp * CTLp * CPLp = CCFp]

BPV	CTSp	CPSp	CTLp	CPLp	CCFp	GSVp
0.119046	1.00020	1.00001	0.99482	1.00012	0.99515	0.118469

(2) ISVm: [N(avg) ÷ NKF = IVm] * [CTLm * CPLm = CCFm]

N(avg)	NKF	IVm	CTLm	CPLm	CCFm	ISVm
11884.1992	100000.0000	0.118842	0.99375	1.00012	0.99387	0.118113

(3) Proving Factors:

>>>>	(1)	GSVp ÷ ISVm =	***1.0030***	MF
	(2)	MF * CPL =	1.0030	CMF
	(3)	1 ÷ MF =	0.9970	MA
	(4)	NKF ÷ MF =	99701	KF
	(5)	KF ÷ CPL =	99701	CKF

Repeatability: **0.020 %**
Uncertainty: **0.028 %**

Trans. Serial No.
Flow Calib Factor
Density Calib Factor
Frequency Set Point
Flowrate Set Point
Zero Verified Zeroed
As Found As Left

Customer: **Volumetrics, Inc**	Division:	
Operator: **Volumetrics, Inc**	Area:	
Location: **Volumetrics, Inc**	County:	
Federal ID:	State: **CO**	
State ID:	Legal Desc:	

Volumetrics — measurement engineering consulting

Meter Data

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MASTER_7

Factor Tracked **Meter Factor(MF)**
Temp Compensated **No**
NKF **100000.0000 N/bbl**
Manufacturer **MicroMotion**
Size **1.00 in**
Serial No. **14428325**
Model No. **F100**

Prover Data

BPV **0.119046 bbl**
I.D. **9.650 in**
W.T. **0.890 in**
Manufacturer **Flow MD**
Type **Displacement-Piston**
Serial No. **480**
Elasticity **2.8E7 1/psi**
Pipe Ga **1.92E-5 1/°F**
External Shaft Gl **9.6E-6 1/°F**
Certified

Product Data

Name **Crude**
Batch No.
Obs. Gravity **45.2 °API**
Obs. Temp **60.0 °F**
Obs. Press **0.0 psi**
API Table **Table A - Crude Oil (2004)**
Base Density **45.2 °API** HYC **Y**

Tolerances

Tolerance Type: **Repeatability**
Maximum Deviation: **0.050 %**
Enabled? **Y** *Passed?* **Y** *Min # of Runs:* **5**
Criteria: **5** *out of* **5** *consecutive runs*

Avg X Prev Meter Factor Deviation:
Enabled? **N** *Passed?* **Y** *Prod Dep?* **N**
Prev X Factor Count Sought: **1**
Prev X Factor Count Used: **0**
Cut Off History? **N** *Cutoff Date:*

Prev Meter Factor Deviation:
Enabled? **N** *Passed?* **Y** *Prod Dep?* **N**

Proving Mode: **Volumetric**
Density Mode: **Manual**
Calc. Method: **Avg. Data Factor**
Proving Method: **PIU**
Passes Per Run **1**

Proving Data

	Previous	*Current*
Task ID	**1456966575**	**1456967370**
Date	**03/02/2016**	**03/02/2016**
Time	**11:56**	**12:09**
Product	**Crude**	**Crude**
Flowrate	**37 bbl/hr**	**26 bbl/hr**
Totalizer	**5733**	**5741**
Throughput	**5**	**8**
Base Density	**45.2°API**	**45.2 °API**
Switch Bar Temp	**60.6**	**61.1**
Avg Prvr Temp	**68.4**	**69.1**
Avg Prvr Press	**46.8**	**44.6**
Repeatability	**0.012 %**	**0.042 %**
MF	**1.0015**	**1.0022**
MF Variance	**-0.0003**	**0.0007**

Liquid Properties at Metering Conditions for CMF

Normal Op. Pressure **psig**
Eq. Vapor Pressure **psig**
CPL **1.0000**

Run	TEMPERATURE Tp	Tm	PRESSURE Pp	Pm	PULSES N	Run Accepted ?		IMF	Flowrate bbl/hr
1	68.9	70.4	44.6	44.6	11888.432	1	Yes	1.00237	26.268
2	69.0	70.4	44.5	44.5	11888.064	2	Yes	1.00235	26.241
3	69.1	70.4	44.5	44.5	11887.330	3	Yes	1.00237	26.247
4	69.1	70.4	44.6	44.6	11892.303	4	Yes	1.00194	26.258
5	69.2	70.4	44.5	44.5	11892.329	5	Yes	1.00189	26.244
Average	**69.1**	**70.4**	**44.6**	**44.6**	**11889.6916**			**1.00218**	**26.252**

(1) GSVp: BPV * [CTSp * CPSp * CTLp * CPLp = CCFp]

BPV	*CTSp*	*CPSp*	*CTLp*	*CPLp*	*CCFp*	*GSVp*
0.119046	1.00019	1.00002	0.99514	1.00027	0.99562	0.118525

(2) ISVm: [N(avg) ÷ NKF = IVm] * [CTLm * CPLm = CCFm]

N(avg)	*NKF*	*IVm*	*CTLm*	*CPLm*	*CCFm*	*ISVm*
11889.6916	100000.0000	0.118897	0.99445	1.00027	0.99472	0.118269

(3) Proving Factors:

>>>>	(1)	GSVp ÷ ISVm =	***1.0022***	MF
	(2)	MF * CPL =	1.0022	CMF
	(3)	1 ÷ MF =	0.9978	MA
	(4)	NKF ÷ MF =	99780	KF
	(5)	KF ÷ CPL =	99780	CKF

Repeatability: **0.042 %**
Uncertainty: **0.026 %**

Trans. Serial No.
Flow Calib Factor
Density Calib Factor

Frequency Set Point
Flowrate Set Point
Zero Verified Zeroed
As Found As Left

Notes

sixth run 11894.887

Customer: **Volumetrics, Inc**
Operator: **Volumetrics, Inc**
Location: **Volumetrics, Inc**
Federal ID:
State ID:

Division:
Area:
County:
State: **CO**
Legal Desc:

Meter Data

VOL Hank
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Factor Tracked **Meter Factor(MF)**
Temp Compensated **No**
NKF **100000.0000** **N/bbl**
Manufacturer **MicroMotion**
Size **1.00** **in**
Serial No. **14428325**
Model No. **F100**

Prover Data

BPV **0.119046** **bbl**
I.D. **9.650** **in**
W.T. **0.890** **in**
Manufacturer **Flow MD**
Type **Displacement-Piston**
Serial No. **480**
Elasticity **2.8E7** **1/psi**
Pipe Ga **1.92E-5** **1/°F**
External Shaft Gl **9.6E-6** **1/°F**
Certified

Product Data

Name **Crude**
Batch No.
Obs. Gravity **45.2 °API**
Obs. Temp **60.0 °F**
Obs. Press **0.0 psi**
API Table **Table A - Crude Oil (2004)**
Base Density **45.2 °API** HYC **Y**

Tolerances

Tolerance Type: **Repeatability**
Maximum Deviation: **0.050 %**
Enabled? **Y** *Passed?* **Y** *Min # of Runs:* **5**
Criteria: **5** *out of* **5** *consecutive runs*

Avg X Prev Meter Factor Deviation:
Enabled? **N** *Passed?* **Y** *Prod Dep?* **N**
Prev X Factor Count Sought: **1**
Prev X Factor Count Used: **0**
Cut Off History? **N** *Cutoff Date:*

Prev Meter Factor Deviation:
Enabled? **N** *Passed?* **Y** *Prod Dep?* **N**

Proving Mode: **Volumetric**
Density Mode: **Manual**
Calc. Method: **Avg. Data Factor**
Proving Method: **PIU**
Passes Per Run **1**

Proving Data

	Previous	*Current*
Task ID	**1456966128**	**1456966575**
Date	**03/02/2016**	**03/02/2016**
Time	**11:48**	**11:56**
Product	**Crude**	**Crude**
Flowrate	**50 bbl/hr**	**37 bbl/hr**
Totalizer	**5728**	**5733**
Throughput	**21**	**5**
Base Density	**42.5°API**	**45.2 °API**
Switch Bar Temp	**59.5**	**60.6**
Avg Prvr Temp	**66.7**	**68.4**
Avg Prvr Press	**39.5**	**46.8**
Repeatability	**0.026 %**	**0.012 %**
MF	**1.0018**	**1.0015**
MF Variance	**0.0002**	**-0.0003**

Liquid Properties at Metering Conditions for CMF

Normal Op. Pressure **psig**
Eq. Vapor Pressure **psig**
CPL **1.0000**

Run	TEMPERATURE Tp	Tm	PRESSURE Pp	Pm	PULSES N	Run Accepted ?		IMF	Flowrate bbl/hr
1	68.3	68.7	46.7	46.7	11891.311	1	Yes	1.00150	37.202
2	68.3	68.7	46.8	46.8	11890.852	2	Yes	1.00153	37.205
3	68.4	68.7	46.9	46.9	11892.309	3	Yes	1.00139	37.231
4	68.4	68.7	46.8	46.8	11891.237	4	Yes	1.00147	37.202
5	68.4	68.7	46.8	46.8	11891.384	5	Yes	1.00145	37.182
Average	**68.4**	**68.7**	**46.8**	**46.8**	**11891.4186**			**1.00147**	**37.204**

(1) GSVp: BPV * [CTSp * CPSp * CTLp * CPLp = CCFp]

BPV	*CTSp*	*CPSp*	*CTLp*	*CPLp*	*CCFp*	*GSVp*
0.119046	1.00017	1.00002	0.99552	1.00028	0.99599	0.118569

(2) ISVm: [N(avg) ÷ NKF = IVm] * [CTLm * CPLm = CCFm]

N(avg)	*NKF*	*IVm*	*CTLm*	*CPLm*	*CCFm*	*ISVm*
11891.4186	100000.0000	0.118914	0.99536	1.00029	0.99565	0.118397

(3) Proving Factors:

>>>>	(1)	GSVp ÷ ISVm =	***1.0015***	MF
	(2)	MF * CPL =	1.0015	CMF
	(3)	1 ÷ MF =	0.9985	MA
	(4)	NKF ÷ MF =	99850	KF
	(5)	KF ÷ CPL =	99850	CKF

Repeatability: **0.012 %**
Uncertainty: **0.007 %**

Trans. Serial No.
Flow Calib Factor
Density Calib Factor
Frequency Set Point
Flowrate Set Point
Zero Verified Zeroed
As Found As Left

Notes

sixth run 11894.887

Customer: **Volumetrics, Inc**
Operator: **Volumetrics, Inc**
Location: **Volumetrics, Inc**
Federal ID:
State ID:

Division:
Area:
County:
State: **CO**
Legal Desc:

Meter Data

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Factor Tracked **Meter Factor(MF)**
Temp Compensated **No**
NKF **100000.0000** **N/bbl**
Manufacturer **MicroMotion**
Size **1.00** **in**
Serial No. **14428325**
Model No. **F100**

Prover Data

BPV **0.119046** **bbl**
I.D. **9.650** **in**
W.T. **0.890** **in**
Manufacturer **Flow MD**
Type **Displacement-Piston**
Serial No. **480**
Elasticity **2.8E7** **1/psi**
Pipe Ga **1.92E-5** **1/°F**
External Shaft Gl **9.6E-6** **1/°F**
Certified

Product Data

Name **Crude**
Batch No.
Obs. Gravity **42.5 °API**
Obs. Temp **60.0 °F**
Obs. Press **0.0 psi**
API Table **Table A - Crude Oil (2004)**
Base Density **42.5 °API** HYC **Y**

Tolerances

Tolerance Type: **Repeatability**
Maximum Deviation: **0.050 %**
Enabled? **Y** *Passed?* **Y** *Min # of Runs:* **5**
Criteria: **5** *out of* **5** *consecutive runs*

Avg X Prev Meter Factor Deviation:
Enabled? **N** *Passed?* **Y** *Prod Dep?* **N**
Prev X Factor Count Sought: **1**
Prev X Factor Count Used: **0**
Cut Off History? **N** *Cutoff Date:*

Prev Meter Factor Deviation:
Enabled? **N** *Passed?* **Y** *Prod Dep?* **N**

Proving Mode: **Volumetric**
Density Mode: **Manual**
Calc. Method: **Avg. Data Factor**
Proving Method: **PIU**
Passes Per Run **1**

Proving Data

	Previous	*Current*
Task ID	1456962172	1456966128
Date	03/02/2016	03/02/2016
Time	10:42	11:48
Product	Crude	Crude
Flowrate	62 bbl/hr	50 bbl/hr
Totalizer	5707	5728
Throughput	121	21
Base Density	42.5°API	42.5 °API
Switch Bar Temp	58.7	59.5
Avg Prvr Temp	65.5	66.7
Avg Prvr Press	47.9	39.5
Repeatability	0.036 %	0.026 %
MF	1.0016	1.0018
MF Variance	0.0013	0.0002

Liquid Properties at Metering Conditions for CMF

Normal Op. Pressure psig
Eq. Vapor Pressure psig
CPL **1.0000**

Run	TEMPERATURE Tp	Tm	PRESSURE Pp	Pm	PULSES N	Run Accepted ?		IMF	Flowrate bbl/hr
1	66.6	67.9	39.5	39.5	11890.749	1	Yes	1.00198	50.095
2	66.7	67.9	39.5	39.5	11891.499	2	Yes	1.00187	50.066
3	66.7	67.9	39.5	39.5	11892.312	3	Yes	1.00180	50.043
4	66.7	67.9	39.6	39.6	11892.830	4	Yes	1.00176	49.926
5	66.7	67.9	39.6	39.6	11893.809	5	Yes	1.00167	49.903
Average	**66.7**	**67.9**	**39.5**	**39.5**	**11892.2398**			**1.00182**	**50.006**

(1) GSVp: BPV * [CTSp * CPSp * CTLp * CPLp = CCFp]

BPV	*CTSp*	*CPSp*	*CTLp*	*CPLp*	*CCFp*	*GSVp*
0.119046	1.00012	1.00002	0.99653	1.00023	0.99690	0.118677

(2) ISVm: [N(avg) ÷ NKF = IVm] * [CTLm * CPLm = CCFm]

N(avg)	*NKF*	*IVm*	*CTLm*	*CPLm*	*CCFm*	*ISVm*
11892.2398	100000.0000	0.118922	0.99591	1.00023	0.99614	0.118463

(3) Proving Factors:

>>>>	(1)	GSVp ÷ ISVm =	***1.0018***	MF
	(2)	MF * CPL =	1.0018	CMF
	(3)	1 ÷ MF =	0.9982	MA
	(4)	NKF ÷ MF =	99820	KF
	(5)	KF ÷ CPL =	99820	CKF

Repeatability: **0.026 %**
Uncertainty: **0.017 %**

Trans. Serial No.
Flow Calib Factor
Density Calib Factor
Frequency Set Point
Flowrate Set Point
Zero Verified Zeroed
As Found As Left

Notes

sixth run 11894.887

Customer: **Volumetrics, Inc** | Division:
Operator: **Volumetrics, Inc** | Area:
Location: **Volumetrics, Inc** | County:
Federal ID: | State: **CO**
State ID: | Legal Desc:

Meter Data

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MASTER_7

Factor Tracked Meter Factor(MF)
Temp Compensated No
NKF 100000.0000 N/bbl
Manufacturer MicroMotion
Size 1.00 in
Serial No. 14428325
Model No. F100

Prover Data

BPV 0.119046 bbl
I.D. 9.650 in
W.T. 0.890 in
Manufacturer Flow MD
Type Displacement-Piston
Serial No. 480
Elasticity 2.8E7 1/psi
Pipe Ga 1.92E-5 1/°F
External Shaft Gl 9.6E-6 1/°F
Certified

Product Data

Name Crude
Batch No.
Obs. Gravity 42.5 °API
Obs. Temp 60.0 °F
Obs. Press 0.0 psi
API Table Table A - Crude Oil (2004)
Base Density 42.5 °API HYC Y

Tolerances

Tolerance Type: Repeatability
Maximum Deviation: 0.050 %
Enabled? Y *Passed?* Y *Min # of Runs:* 5
Criteria: 5 *out of* 5 *consecutive runs*

Avg X Prev Meter Factor Deviation:
Enabled? N *Passed?* Y *Prod Dep?* N
Prev X Factor Count Sought: 1
Prev X Factor Count Used: 0
Cut Off History? N *Cutoff Date:*

Prev Meter Factor Deviation:
Enabled? N *Passed?* Y *Prod Dep?* N

Proving Mode: Volumetric
Density Mode: Manual
Calc. Method: Avg. Data Factor
Proving Method: PIU
Passes Per Run 1

Proving Data

	Previous	Current
Task ID	1455176870	1456962172
Date	02/10/2016	03/02/2016
Time	18:47	10:42
Product	Crude	Crude
Flowrate	16 bbl/hr	62 bbl/hr
Totalizer	5586	5707
Throughput	3	121
Base Density	43.3°API	42.5 °API
Switch Bar Temp	64.9	58.7
Avg Prvr Temp	69.6	65.5
Avg Prvr Press	38.9	47.9
Repeatability	0.027 %	0.036 %
MF	1.0003	1.0016
MF Variance	-0.0012	0.0013

Liquid Properties at Metering Conditions for CMF

Normal Op. Pressure psig
Eq. Vapor Pressure psig
CPL 1.0000

Run	TEMPERATURE Tp	Tm	PRESSURE Pp	Pm	PULSES N	Run Accepted ?		IMF	Flowrate bbl/hr
1	65.4	66.1	47.8	47.8	11888.075	1	Yes	1.00186	61.779
2	65.5	66.1	48.0	48.0	11890.689	2	Yes	1.00159	61.682
3	65.5	66.1	48.0	48.0	11892.342	3	Yes	1.00145	61.815
4	65.6	66.1	47.7	47.7	11891.720	4	Yes	1.00145	61.833
5	65.7	66.1	47.8	47.8	11888.429	5	Yes	1.00169	61.887
Average	**65.5**	**66.1**	**47.9**	**47.9**	**11890.2510**			**1.00161**	**61.799**

(1) GSVp: BPV * [CTSp * CPSp * CTLp * CPLp = CCFp]

BPV	CTSp	CPSp	CTLp	CPLp	CCFp	GSVp
0.119046	1.00009	1.00002	0.99715	1.00028	0.99754	0.118753

(2) ISVm: [N(avg) ÷ NKF = IVm] * [CTLm * CPLm = CCFm]

N(avg)	NKF	IVm	CTLm	CPLm	CCFm	ISVm
11890.2510	100000.0000	0.118903	0.99684	1.00028	0.99712	0.118561

(3) Proving Factors:

>>>>	(1)	GSVp ÷ ISVm =	***1.0016***	MF
	(2)	MF * CPL =	1.0016	CMF
	(3)	1 ÷ MF =	0.9984	MA
	(4)	NKF ÷ MF =	99840	KF
	(5)	KF ÷ CPL =	99840	CKF

Repeatability: **0.036 %**
Uncertainty: **0.022 %**

Trans. Serial No.
Flow Calib Factor
Density Calib Factor

Frequency Set Point
Flowrate Set Point
Zero Verified Zeroed
As Found As Left

Notes

sixth run 11894.887

Volumetrics Hank

hontzsch
flow measuring technology

m/s | m³/h | l/min | Calibration

WVP	Water flow rate in test bench with closed test section
Reference	electromagnetic flow rate meter
Measuring uncertainty	0.5 %
Calibration range	**0.5 ... 125 m^3/h (equal to 0.018 ... 4.42 m/s (at Di 100 mm))**
Calibration medium	water

Calibration / Measuring uncertainty / Recalibration

Höntzsch is able to carry out an optimally tailored calibration for every type of operation. As close an approximation as possible to the real conditions is achieved using a variation of pressure, temperature and type of calibration medium.

This ideal choice of calibration conditions means that measuring uncertainties in practical applications are reduced to a minimum. Höntzsch calibration certificates document the set value and actual value and provide the user with proof and reliabilty that faultless and accurate measuring equipment is in use for solving measuring problems.

The measuring uncertainties for the references are relative values.

The measuring uncertainties shown on the calibration certificate are determined according to the "GUIDE OF EXPRESSION OF UNCERTAINTY IN MEASUREMENT". The expanded measurement uncertainties result from the standard measurement uncertainties being multiplied with the coverage factor k = 2. The value of the measurable variable lies as a rule with a probability of approx. 95 % within the respective value interval.

It must be pointed out that additional measuring uncertainties can arise from modified application conditions. Influencing factors are, for example, pressure, temperature, flow profile and the degree of turbulence of the flow to be measured. Details regarding measuring uncertainty of each measuring system can be found in the relevant data specification.

It is the responsibility of the user to determine the re-calibration interval. The intervals should be chosen so that the re-calibration takes place before a significant change in the medium for the measurement problem. Please take into account the specific application conditions, environmental influences and the extent of potential secondary damage caused by values outside the specified tolerance.

Standards, directives or legal requirements can also determine the right time for a re-calibration.

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Internet www.hoentzsch.com

Subject to alteration

zertifiziert nach
ISO 9001 : 2008
certified quality

Calibration	m/s	m³/h	l/min

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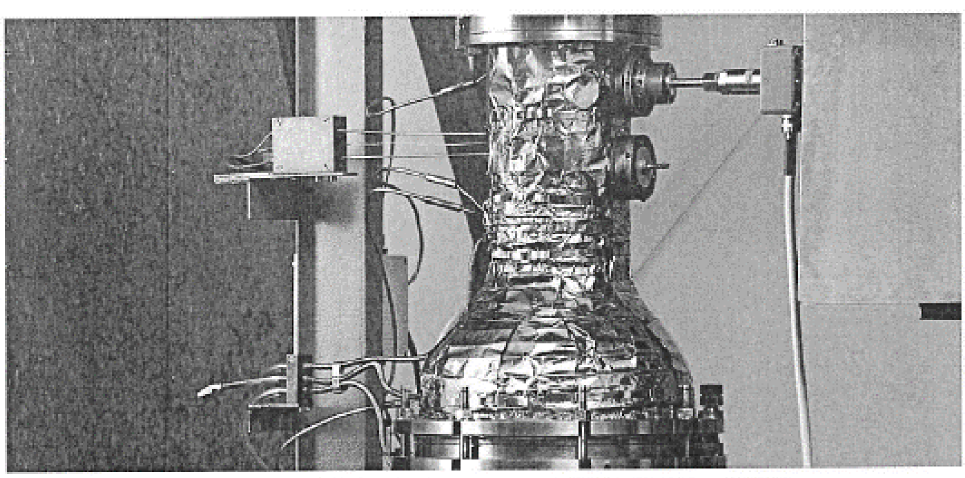
HDVP	High pressure flow rate test bench in closed construction
Reference	DKD calibrated transfer measurement standards
Measuring uncertainty	1 %
Calibration range	**0.22 ... 4000 m^3/h** *(0.10 ... 220 Nm/s)
Pressure range	**1000 ... 10000 hPa**
Temperature range	+20 ... +45 °C
Calibration medium	air
* calculated from flow rate and average flow velocity with the respective profile factor	

RVP	Real gas flow rate test bench
Reference	LDA calibrated transfer measurement standards
Measuring uncertainty	0.8 %
Calibration range	**0.06 ... 100 m^3/h** *(0.08 ... 150 Nm/s)
Pressure range	**1000 ... 10000 hPa**
Calibration medium	numerous gases
* calculated from flow rate and average flow velocity	

FVP	Liquid flow rate test bench
Reference	calibrated measuring volume / precision timing
Measuring uncertainty	1 %
Calibration range	**0.02 ... 9 l/min**
Calibration medium	numerous liquids



High temperature flow test facility HTP in closed construction 'University of Stuttgart'

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m/s | m³/h | l/min | Calibration

WK320	Göttinger free jet wind tunnel
Reference	laser Doppler anemometer (LDA)
Measuring uncertainty	0.3 %
Calibration range	**0.18 ... 70 m/s**
Calibration medium	air

WK320 / Transfer	Göttinger free jet wind tunnel
Reference	LDA calibrated transfer measurement standards
Measuring uncertainty	0.6 %
Calibration range	**0.18 ... 70 m/s**
Calibration medium	air

WK130 / Transfer	Free jet wind tunnel
Reference	LDA calibrated transfer measurement standards
Measuring uncertainty	0.6 %
Calibration range	**0.35 ... 30 m/s**
Calibration medium	air

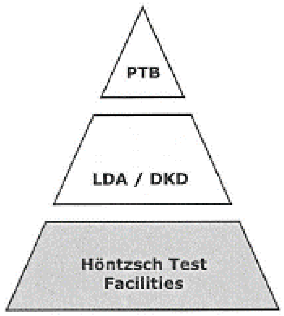
NWK	Low velocity wind tunnel with closed test section
Reference	LDA calibrated transfer measurement standards
Measuring uncertainty	0.6 %
Calibration range	**0.10 ... 5.0 m/s**
Calibration medium	air

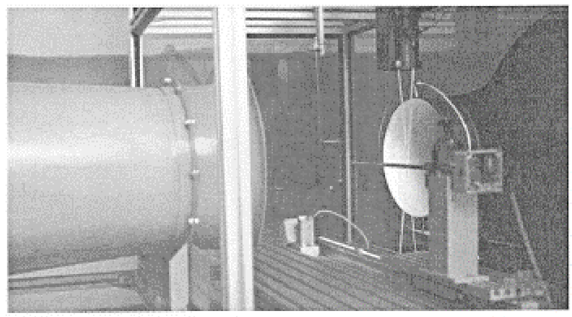
HTP	High temperature flow test bench in closed construction 'University of Stuttgart'
Reference	LDA calibrated transfer measurement standards
Measuring uncertainty	3 % (0.18 ... 2.0 m/s); 2 % (> 2.0 m/s)
Calibration range	**0.18 ... 70 m/s**
Temperature range	**+20 ... +400 °C**
Calibration medium	air

Calibration | m/s | m³/h | l/min

höntzsch
flow measuring technology

Calibration of flow velocity and flow rate





Free jet wind tunnel WK320 with laser Doppler anemometer (LDA)

The Höntzsch calibration system

The Höntzsch calibration process is incorporated in the Quality Management Systems QMS DIN EN ISO 9001:2008 and is carried out in close compliance with ISO/IEC/EN 17025. All Höntzsch calibrations can be attributed to national measurement standards.

Ensuring global uniformity of dimensions, Höntzsch GmbH works closely with other national and international metrological institutes. Exchange of research findings and extensive international comparisons have proved successful.

Höntzsch works resolutely and in close collaboration with national and international accredited laboratories to further develop calibration methods and reduce measuring uncertainties.

Calibration equipment

Description	Abbreviation
Free jet wind tunnel	WK320 / LDA
Free jet wind tunnel	WK320 / Transfer
Free jet wind tunnel	WK130 / Transfer
Low velocity wind tunnel	NWK
High temperature flow test bench	HTP
High pressure flow rate test bench	HDVP
Real gas flow rate test bench	RVP
Liquid flow rate test bench	FVP
Water flow rate test bench	WVP

Hoentzsch Certificate