Schlumberger

SWTC Flow Loop

Reference Measurement & Calculations

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1 INTRODUCTION

The SWTC multiphase flow loop is operational since April 2016. This state-of-the-art flow loop was designed to serve both the manufacturing and engineering activities of SWTC, Schlumberger's center of excellence in multiphase flow metering. Its main purpose is to evaluate the performance of MPFMs by circulating mixtures of oil, water and gas at various combinations of precise flow rates and desired test pressures.

A set of high precision single phase Coriolis flow meters are used on each single phase line to provide an accurate reference measurement of oil, water and gas mass flow rates, volumetric flow rates and densities. Evaluating the reference measurement uncertainty is of paramount importance if one wants to assess reliably the performance of the MPFMs under test. Besides, all potential sources of error that may arise from the process itself and could eventually alter the reference measurements need to be carefully estimated.

This document aims at demonstrating the flow loop metrological performance by looking closely at the single phase processes and reference measurements. First, the fluids composition is analyzed, considering all the impurities that could be initially present in the gas, oil or water phases. Once the fluid composition is established, a density model is proposed, based on thermodynamic correlations and sample measurements. The uncertainty of the reference meters and their operating ranges are then specified. Finally, quality assurance indicators are introduced. Their purpose is to monitor in real-time the metrological performance of the single phase flow meters and detect potential cross contaminations in the single phase flow lines.

The last part of this document determines the overall uncertainty of the single phase measurements performed on the flow loop, following the guidelines of the GUM **[1]**. The expanded uncertainty is the combination of the reference meters standard uncertainties and a conservative estimation of the potential cross-contamination effects.

1.1 Scope

This document serves the following purposes:

- Describe the reference measurements performed on the SWTC flow loop
- Provide the reference meters measuring ranges and calibration certificates
- Determine the standard uncertainty of the single phase reference measurements
- State the flow loop expanded uncertainty, including the cross-contamination effects
- Propose quality assurance indicators (flowmeters cross-checks and phase contamination)

1.2 Abbreviations

DP	Differential Pressure
DUT	Device Under Test
GIO	Gas-in-Oil ratio
GIW	Gas-in-Water ratio
GVF	Gas Volume Fraction
ID	Inner Diameter
OD	Outer diameter
MPFM	Multiphase Flow Meter
OIG	Oil-in-Gas ratio
OIW	Oil-in-Water ratio
PN	(Supplier) Part Number
SWTC	Singapore Well Testing Center
WIO	Water-In-Oil ratio
WLR	Water Liquid Ratio

1.3 Definitions

Actual conditions	The actual or operating conditions (pressure and temperature) at which fluid properties or volume flow rates are expressed
Compressibility factor (Z)	Ratio of the molar volume of a gas to the molar volume of an ideal gas at the same temperature and pressure.
Equation of state (EoS)	A thermodynamic equation describing the state of matter under a given set of physical conditions such as its temperature, pressure, volume. Equations of state are useful in describing the properties of fluids, mixtures of fluids.
Gas Volume Fraction (GVF)	The gas volume flow rate, relative to the multiphase volume flow rate, at the pressure and temperature prevailing in that section. The GVF is normally expressed as a fraction or percentage.
Homogeneous Multiphase Flow	A multiphase flow in which all phases are evenly distributed over the cross section of a closed conduit; i.e. the composition is the same at all points in the cross section and there the liquid and gas velocities are the same.
Mass flow rate (q)	The mass of a fluid X flowing through the cross-section of a conduit in unit time.
Multiphase flow	Two or more phases flowing simultaneously in a closed conduit. This document deals in particular with multiphase flows of oil, water and gas in the entire region of 0-100% GVF and 0-100% WLR
Multiphase flow meter (MPFM)	A device for measuring the individual oil, water and gas flow rates in a multiphase flow
Phase	In this document, "phase" is used in the sense of one constituent in a mixture of several. In particular, the term refers to oil, gas or water in a mixture of any number of the three.
Standard or Reference conditions	A set of standard (or reference) conditions, in terms of pressure and temperature, at which fluid properties or volume flow rates are expressed, e.g. 101.325 kPa and 15 °C.

Standard Uncertainty, u	Uncertainty of the result of a measurement expressed as a standard deviation
Combined uncertainty	Standard uncertainty of the result of a measurement when that result is obtained from the values of a number of other quantities, equal to the positive square root of the sum of variances of these other quantities weighted according to how the measurement result varies with changes in these quantities
Expanded uncertainty, U	Quantity defining an interval about the result of a measurement that may be expected to encompass a large fraction of the distribution of values that could reasonably be attributed to the measurand
Coverage factor	Numerical factor used as a multiplier of the combined standard uncertainty in order to obtain an expanded uncertainty
Volume flow rate (Q)	The volume of a fluid X flowing through the cross-section of a conduit in unit time at the pressure and temperature prevailing in that section.
Water-in-liquid ratio (WLR)	The water volume flow rate, relative to the total liquid volume flow rate (oil and water), at the pressure and temperature prevailing in that section.
X-in-Y volume ratio (WIO, OIW, GIO, GIW, OIG)	The volume flow rate of X in the Y line, relative to the total volume flow rate measured in the Y line, at the pressure and temperature prevailing in that section
X-in-Y mass ratio (wio, oiw, gio, giw, oig)	The mass flow rate of X in the Y line, relative to the total mass flow rate measured in the Y line

1.4 Symbols and subscripts

Symbol	Quantity	Unit
T_G	Gas reference temperature	°C
P_G	Gas reference pressure	barg
$\rho_G^{P,T}$	Gas reference density at pressure P and temperature T	kg/m^3
q_G^A Q_G^A ρ_G^A	Gas primary flow meter (aggregate) - mass flow rate Gas primary flow meter (aggregate) - volume flow rate Gas primary flow meter (aggregate) - density	kg/h m^3/h kg/m^3
q_G^{A1} Q_G^{A1} ρ_O^{A1}	Gas primary flow meter (large Coriolis flowmeter) - mass flow rate Gas primary flow meter (large Coriolis flowmeter) - volume flow rate Gas primary flow meter (large Coriolis flowmeter) - density	kg/h m^3/h kg/m^3
q_G^{A2} Q_G^{A2} ρ_G^{A2}	Gas primary flow meter (medium Coriolis flowmeter) - mass flow rate Gas primary flow meter (medium Coriolis flowmeter) - volume flow rate Gas primary flow meter (medium Coriolis flowmeter) - density	kg/h m^3/h kg/m^3
q_G^{A3} Q_G^{A3} ρ_G^{A3}	Gas primary flow meter (small Coriolis flowmeter) - mass flow rate Gas primary flow meter (small Coriolis flowmeter) - volume flow rate Gas primary flow meter (small Coriolis flowmeter) - density	kg/h m^3/h kg/m^3
q_G^B	Gas secondary flow meter (aggregate) - volume flow rate	m^3/h
q_G^{B1}	Gas secondary flow meter (large Orifice plate flowmeter) - volume flow rate	m^3/h

Table 1 Symbols and subscripts for the Gas reference measurements

Symbol	Quantity	Unit
T_O	Oil reference temperature	°C
P_O	Oil reference pressure	barg
$\rho_O^{P,T}$	Oil reference density at pressure P and temperature T	kg/m³
q_O^A Q_O^A ρ_O^A	Oil primary flow meter (aggregate) - mass flow rate Oil primary flow meter (aggregate) - volume flow rate Oil primary flow meter (aggregate) - density	kg/h m³/h kg/m³
q_O^{A1} Q_O^{A1} ρ_O^{A1}	Oil primary flow meter (large Coriolis flowmeter) - mass flow rate Oil primary flow meter (large Coriolis flowmeter) - volume flow rate Oil primary flow meter (large Coriolis flowmeter) - density	kg/h m³/h kg/m³
q_O^{A2} Q_O^{A2} ρ_O^{A2}	Oil primary flow meter (small Coriolis flowmeter) - mass flow rate Oil primary flow meter (small Coriolis flowmeter) - volume flow rate Oil primary flow meter (small Coriolis flowmeter) - density	kg/h m³/h kg/m³
Q_O^B	Oil secondary flow meter (aggregate) - volume flow rate	m³/h
Q_O^{B1}	Oil secondary flow meter (large Vortex flowmeter) - volume flow rate	m³/h

Table 2 Symbols and subscripts for the Oil reference measurements

Symbol	Quantity	Unit
T_W	Water reference temperature	°C
P_W	Water reference pressure	barg
$\rho_W^{P,T}$	Water reference density at pressure P and temperature T	kg/m³
q_W^A Q_W^A ρ_W^A	Water primary flow meter (aggregate) - mass flow rate Water primary flow meter (aggregate) - volume flow rate Water primary flow meter (aggregate) - density	kg/h m³/h kg/m³
q_W^{A1} Q_W^{A1} ρ_W^{A1}	Water primary flow meter (large Coriolis flowmeter) - mass flow rate Water primary flow meter (large Coriolis flowmeter) - volume flow rate Water primary flow meter (large Coriolis flowmeter) - density	kg/h m³/h kg/m³
q_W^{A2} Q_W^{A2} ρ_W^{A2}	Water primary flow meter (small Coriolis flowmeter) - mass flow rate Water primary flow meter (small Coriolis flowmeter) - volume flow rate Water primary flow meter (small Coriolis flowmeter) - density	kg/h m³/h kg/m³
Q_W^B	Water secondary flow meter (aggregate) - volume flow rate	m³/h
Q_W^{B1}	Water secondary flow meter (large Magnetic flowmeter) - volume flow rate	m³/h

Table 3 Symbols and subscripts for the Water reference measurements

Symbol	Quantity	Unit
$\boldsymbol{t_{LP}}$	Liquid mixture transit time	s
V_{LP}	Volume of liquid line	m³
$\boldsymbol{t_{MP}^{3,6}}$	Multiphase mixture transit time, 3inch or 6inch	s
$V_{MP}^{3,6}$	Volume of the multiphase line, 3inch or 6inch	m³

Table 4 Symbols and subscripts for the Multiphase section

2 GAS REFERENCE MEASUREMENTS

This section describes the primary reference measurements taken on the gas line (Figure 1) such as the gas density ($\rho_G^{P,T}$), mass flow rate (q_G^A), pressure (P_G) and temperature (T_G). In addition, the quality assurance parameters that are derived from secondary measurements are defined, such as the agreement between the reference flow meters, at low, medium and high flow rates.

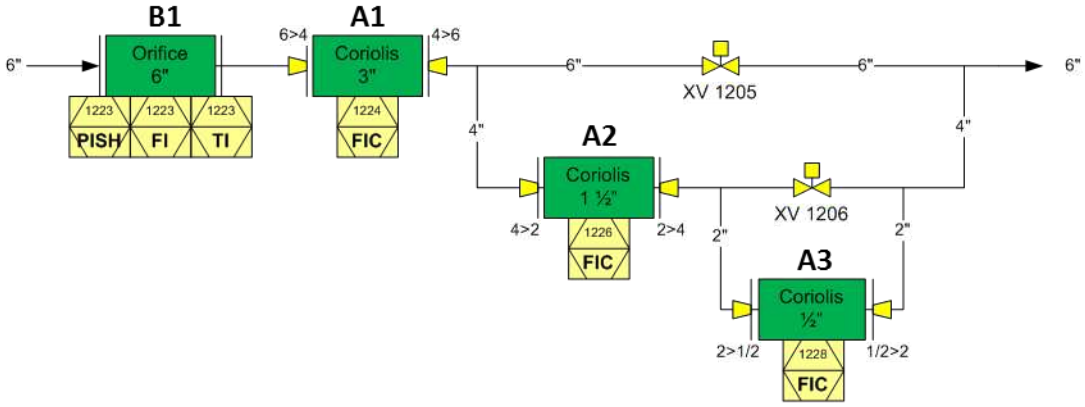

Figure 1 Process flow diagram of the gas reference line

2.1 Composition

The flow loop is pressurized with Nitrogen by default.

2.1.1 Nitrogen purity

The flow loop is pressurized at the desired operating pressure (P_H) using high purity nitrogen cylinders guaranteeing a maximum molar fraction of impurities ($x_{i,inerting}$) of less than 0.01 mol%. In order to further reduce the concentration of impurities in the flow loop, a vacuum is first drawn on the piping and vessels down to 0.05 bara (P_L). This reduces the amount of species contained in the flow loop which is initially under atmospheric air at a standard molar fraction of about 21 mol% ($x_{i,air}$). The final molar fraction of impurities in the gas phase can be achieved using the below equation (see Appendix A for a detailed description of the inerting / purging process):

$$\boldsymbol{x_i = x_{i,air}\left(\frac{P_L}{P_H}\right) + x_{i,inerting}\left(1 - \frac{P_L}{P_H}\right)} \quad \textbf{(1)}$$

The molar fraction of impurities contained in the flow loop can be significantly reduced through the combined effects of vacuum purging and nitrogen inerting, provided that the final pressure is substantially larger than the initial vacuum pressure. In the worst case, when the flow loop is pressurized to the minimum operating pressure (3barg), the concentration of impurities can be as high as 0.27 mol%.

<u>Numerical Application:</u>
Under typical operating conditions,

- $P_H = 10$ barg
- $P_L = 0.05$ bara
- $x_{i,inerting} = 0.01$ mol%
- $x_{i,air} = 21$ mol%
- ➢ $x_i = 0.11$ mol%

2.1.2 Liquid vapors

The gas phase may also contain water and oil vapors originating from the liquid phases. Assuming that the vapors are in thermodynamic equilibrium with their condensed states, the mole fractions of the water and oil vapors can be determined from their equilibrium vapor pressures (P_W^{sv} and P_O^{sv}) for any given pressure (P) and temperature (T).

$$\boldsymbol{x_W = \frac{P_W^{sv}(T)}{P}} \quad (2)$$

$$\boldsymbol{x_O = \frac{P_O^{sv}(T)}{P}} \quad (3)$$

The concentration of water and oil vapors in the gas phase reduces with increasing pressures. In the worst case, when the flow loop is pressurized to the minimum operating pressure (3barg), the mole fraction of water and oil vapors can be as high as 0.6 mol% and 0.0025 mol% respectively.

Numerical Application:
Under typical operating conditions,
- $P = 10\ \mathrm{barg}$
- $T = 50\ °\mathrm{C}$
- $P_W^{sv}(T) = 0.12352\ \mathrm{bar}$ (according to the NIST database **[7]**)
- $P_O^{sv}(T) = 0.0001\ \mathrm{bar}$ (according to the vendor's datasheet **[8]**, see Table 11)
- ➢ $x_W = 0.6\ \mathrm{mol\%}$
- ➢ $x_O = 9.1.10^{-4}\ \mathrm{mol\%}$

2.2 Density

The gas density $\boldsymbol{\rho_G^{P,T}}$ can be calculated at any location on the flow loop from the measured local temperature T and pressure P through the below real gas equation which accounts for the gas compressibility factor:

$$\boldsymbol{\rho_G^{P,T} = \frac{PM_G}{ZRT}} \quad (4)$$

Where:
- P is the absolute gas pressure (Pascal),
- M_G is the molar mass of the gas mixture, including its residual species and vapors (kg/mol)
- Z is the gas compressibility factor,
- R is the ideal gas constant (8.3144621 J/kg.K)
- T is the gas temperature (K).

2.2.1 Molar mass

As discussed in section 2.1, the gas phase may contain a certain amount of residual air impurities (x_i), water vapor (x_W) and oil vapor (x_O). The molar mass of the gas phase can be calculated from the mole fractions of each of its components:

$$M_G = (1 - x_W - x_O - x_i)M_{N_2} + x_W M_W + x_O M_O + x_i M_i$$

This equation can be rearranged as:

$$M_G = M_{N2}\left[1 - x_W\left(1 - \frac{M_W}{M_{N2}}\right) - x_O\left(1 - \frac{M_O}{M_{N2}}\right) - x_i\left(1 - \frac{M_i}{M_{N2}}\right)\right]$$

Numerical Application:
Considering the typical mole fractions of the gas species and vapor as calculated in section 2.1:

- $x_i = 0.11\ \text{mol\%}$
- $x_W = 1.12\ \text{mol\%}$
- $x_O = 5.10^{-4}\ \text{mol\%}$
- $M_{N2} = 28.0134\ \text{g/mol}$
- $M_W = 18.0153\ \text{g/mol}$
- $M_O \approx 170.3348\ \text{g/mol}$ approximating Exxsol D80 to a dodecane molecule
- $M_i \approx M_{O2} = 31.9988\ \text{g/mol}$ assuming oxygen is the most important species left in the gas
- ➢ $M_G \approx 0.996\ M_{N2}$

In view of the negligible contribution of the secondary gas species to the total gas molar mass, the gas composition is assumed to be 100% pure Nitrogen in the rest of the document. Yet, the uncertainty of the gas molar mass is considered and equal to:

$$\frac{\boldsymbol{U(M_G)}}{\boldsymbol{M_G}} = \mathbf{0.4\%} \qquad \textbf{(5)}$$

2.2.2 Compressibility factor

Considering that the gas phase is made of pure Nitrogen, the compressibility factor Z can be calculated from the following formulation, established from R. Span and E.W Lemmon's equation of state for Nitrogen **[4]**:

$$Z = 1 + \pi\left(a_1\tau^{0.75} + \tau(a_2\tau^{0.25} + a_3\tau^2)\right) + \pi\left(a_4\tau^2 + \pi\tau^{1.5}(a_5 + a_6\tau^{0.25})\right)$$

Where:

- $\pi = P/5.10^6$ – non-dimensional pressure (P in Pascal)
- $\tau = 300/T$ – non-dimensional temperature (T in Kelvin)

The constants used in the function are:

- $a_1 = 0.077932180599$
- $a_2 = -0.045130808927$
- $a_3 = -0.041931112693$
- $a_4 = 0.0056646193025$
- $a_5 = -0.0086400452947$
- $a_6 = 0.0087453999129$

This function for the compressibility of Nitrogen is a limited range formulation and is valid over the temperature range of 270 to 320K and the static pressure range from 1 to 90 bara. This formulation can be considered robust for extrapolation up to 330 K, the upper limit of flow loop temperature operating range.

Numerical Application:
Under typical operating conditions,

- $P = 20\ \text{barg}$
- $T = 20\ °\text{C}$
- ➢ $Z = 0.9974$

2.2.3 Uncertainty

As seen from equation **(4)**, the uncertainty of the gas density model is the combination of the pressure and temperature measurement uncertainties, the molar mass uncertainty as well as the uncertainty of the compressibility factor, which is estimated to be $u(Z)/Z = 0.01\ \%$ according to **[4]**.

Numerical Application:
Under typical operating conditions,

- $P_G = 10$ barg
- $U(P_G) = 0.0125\ bar$ (see 2.3.3)
- $U(M_G)/M_G = 0.4\%$ (see 2.2.1)
- $T_G = 50\ °C$
- $U(T_G) = 0.37\ K$ (see 2.3.4)

➢ $U\left(\rho_G^{P_G,T_G}\right)/\rho_G^{P,T} = 0.48\%$ (see table below)

Source	Units	Value	Expanded Uncertainty		Probability	Divisor	Standard	Sensitivity	Uncorr.	Variance
			Abs	(%)					Product	
Pressure	barg	10	0.0125	0.125	Normal(95%)	1.96	0.006	1.045	0.007	4.445E-05
Temperature	degC	50	0.370	0.114	Normal(95%)	1.96	0.189	0.0323	0.006	3.729E-05
molar weight	g/mole	28.014	0.112	0.400	Rectangular	1.73	0.065	0.373	0.024	5.842E-04
Compressibility Z	[-]	0.997	0.0001	0.010	Rectangular	1.73	0.000	10.48	0.001	3.651E-07
Gas Density Uncertainty	**kg/m³**	**10.5**	**0.051 kg/m³**	**0.48 %**	**Normal(95%)**	**1.96**	**0.026**	**1**	**0.026**	**6.663E-04**

2.3 Reference meters

This section describes the single phase reference meters that are used on the gas line. After flowing through the gas scrubber, the gas flow rate is measured by a set of high precision flow meters. As shown in Figure 1, two different technologies are used simultaneously to allow for redundancy. While Coriolis flow meters provide the primary reference measurements (A1, A2 and A3), a conditioning Orifice plate flowmeter is mounted on the gas line as a secondary reference measurement (B1). In addition, local pressure and temperature are measured upstream the reference flow meters.

2.3.1 Primary flow meters

The primary reference flow meters are connected in series (A1, A2 and A3). Two actuated valves allow the control system to automatically select the most accurate flow meter depending on the actual volume flow rate and the flowmeters ranges. The Coriolis flow meters are installed horizontally, flow tubes upward so that they remain full of gas and do not entrap liquid droplets. There are no specific requirements in terms of straight pipe run. Their measuring ranges have been optimized in order that the pressure loss never exceeds 1 bar and they always operate at their optimum accuracy.
Tables 5-7 summarize the output variables and associated uncertainty according to the Coriolis meters flow ranges. Contrary to the oil and water lines, the density measured by the Coriolis flow meters is not used due to the lack of resolution. Volumetric flow rates are not recorded either, because they are not preserved along the pipeline and depend on the local pressure and temperature conditions.

Emerson provides figures for uncertainty in their technical datasheet given in **[10]** (here reported as *specified uncertainty*). Meter performance are periodically verified by calibration check in dedicated facilities, usually at atmospheric pressure. The combined uncertainty accounts for the various sources of uncertainty once installed in the flow loop. The Coriolis flow meters calibration reports and uncertainty tables are available in Appendices E-1, E-2 and E-3.

Flow ranges (FIC 1224) PN: CMF300M426NQBMEZZZ	Output	Specified Uncertainty	Combined Uncertainty
(40 bar) $45\ \mathrm{m^3/h} \leq Q_G^A \leq 805\ \mathrm{m^3/h}$	$q_G^A = q_G^{A1}$	$\frac{u(q_G^{A1})}{q_G^{A1}} = 0.35\%$	$\frac{U(q_G^{A1})}{q_G^{A1}} = \max\left(0.55\%, \frac{Z_{A1}}{q_G^{A1}}\right)$
(30 bar) $60\ \mathrm{m^3/h} \leq Q_G^A \leq 935\ \mathrm{m^3/h}$			
(20 bar) $91\ \mathrm{m^3/h} \leq Q_G^A \leq 1145\ \mathrm{m^3/h}$			
(10 bar) $181\ \mathrm{m^3/h} \leq Q_G^A \leq 1610\ \mathrm{m^3/h}$			
(3 bar) $608\ \mathrm{m^3/h} \leq Q_G^A \leq 2910\ \mathrm{m^3/h}$			

Table 5 Gas large Coriolis flowmeter (A1) measuring range and associated uncertainty at various operating pressures

Flow ranges (FIC 1226) PN: CMFS150M419N2BMEKZZ	Output	Specified Uncertainty	Combined Uncertainty
(40 bar) $9\ \mathrm{m^3/h} \leq Q_G^A \leq 136\ \mathrm{m^3/h}$	$q_G^A = q_G^{A2}$	$\frac{u(q_G^{A2})}{q_G^{A2}} = 0.25\%$	$\frac{U(q_G^{A2})}{q_G^{A2}} = \max\left(0.50\%, \frac{Z_{A2}}{q_G^{A2}}\right)$
(30 bar) $12\ \mathrm{m^3/h} \leq Q_G^A \leq 157\ \mathrm{m^3/h}$			
(20 bar) $19\ \mathrm{m^3/h} \leq Q_G^A \leq 193\ \mathrm{m^3/h}$			
(10 bar) $38\ \mathrm{m^3/h} \leq Q_G^A \leq 270\ \mathrm{m^3/h}$			
(3 bar) $125\ \mathrm{m^3/h} \leq Q_G^A \leq 490\ \mathrm{m^3/h}$			

Table 6 Gas medium Coriolis flowmeter (A2) measuring range and associated uncertainty at various operating pressures

Flow ranges (FIC 1228) PN: CMFS050M314N2BMEKZZ	Output	Specified Uncertainty	Combined Uncertainty
(40 bar) $0.9\ \mathrm{m^3/h} \leq Q_G^A \leq 18\ \mathrm{m^3/h}$	$q_G^A = q_G^{A3}$	$\frac{u(q_G^{A3})}{q_G^{A3}} = 0.25\%$	$\frac{U(q_G^{A3})}{q_G^{A3}} = \max\left(0.50\%, \frac{Z_{A3}}{q_G^{A3}}\right)$
(30 bar) $1.3\ \mathrm{m^3/h} \leq Q_G^A \leq 20\ \mathrm{m^3/h}$			
(20 bar) $1.9\ \mathrm{m^3/h} \leq Q_G^A \leq 25\ \mathrm{m^3/h}$			
(10 bar) $3.8\ \mathrm{m^3/h} \leq Q_G^A \leq 34\ \mathrm{m^3/h}$			
(3 bar) $12.5\ \mathrm{m^3/h} \leq Q_G^A \leq 61\ \mathrm{m^3/h}$			

Table 7 Gas small Coriolis flowmeter (A3) measuring range and associated uncertainty at various operating pressures

Note that the measuring range of the gas Coriolis flow meters varies with the operating pressure due to the change of gas density, as illustrated in Appendix D-1. The flow ranges are updated accordingly in the control system prior a flow loop test to make sure that the Coriolis flow meters always operate within their optimal range.
In addition to the specified uncertainty, the combined uncertainty is defined to calculate the Coriolis meters accuracy below their minimum specified flow. Coriolis flow meters indeed have a wide turndown and can still deliver a precise measurement outside their optimum accuracy range, which can be used for quality assurance purposes. According to the manufacturer, below the minimum (mass) flow rate, the accuracy is governed by the zero stability coefficient:

- CMF300: $Z_{A1} = 6.82\ \mathrm{kg/h}$
- CMFS150: $Z_{A2} = 1.00\ \mathrm{kg/h}$
- CMFS050: $Z_{A3} = 0.101\ \mathrm{kg/h}$

2.3.2 Secondary flow meter

A conditioning orifice plate flowmeter is mounted on the gas line, upstream the larger Coriolis meter, to provide a secondary mass flow measurement (B1). This additional flow meter has been sized to match the large Coriolis measuring range (A1). The orifice plate is installed vertically on a downward flow section and its position complies with the minimum straight run required by the manufacturer (2D upstream and downstream). Table 8 summarizes the output variables of the secondary flowmeter and associated uncertainties according to its measuring ranges.

Flow range (FIC 1223) PN: 3051SFC1CS060N065T33JA1A3Q4M5T1	**Output**	**Specified Uncertainty**
(40 bar) $100\ \mathrm{m^3/h} \le Q_G^B \le 1200\ \mathrm{m^3/h}$	$q_G^B = q_G^{B1}$	$\frac{u(q_G^{B1})}{q_G^{B1}} = 1\%$
(30 bar) $120\ \mathrm{m^3/h} \le Q_G^B \le 1360\ \mathrm{m^3/h}$		
(20 bar) $145\ \mathrm{m^3/h} \le Q_G^B \le 1500\ \mathrm{m^3/h}$		
(10 bar) $200\ \mathrm{m^3/h} \le Q_G^B \le 2000\ \mathrm{m^3/h}$		
(3 bar) $305\ \mathrm{m^3/h} \le Q_G^B \le 3540\ \mathrm{m^3/h}$		

Table 8 Gas Large orifice plate (B1) measuring range and associated uncertainty at various operating pressures

In the same way as the Coriolis flowmeters, the measuring range depends on the operating pressure. The specified uncertainty is calculated as per the methods defined in section 8 of ISO 5167-1:2003 **[2]**. It includes all possible uncertainties, including the DP sensor, pipe ID, gas expansion factor and discharge coefficient uncertainty. The orifice plate calibration report is available in Appendix 0.

2.3.3 Pressure

The gas pressure measurement (P_G) is obtained from the orifice plate multivariable transmitter, offering the below performance. The transmitter calibration report is available in Appendix **Error! Reference source not found.**.

Pressure range (PISH 1223) PN: 3051SFC1CS060N065T33JA1A3Q4M5T1	**Output**	**Specified Uncertainty**
$0\ \mathrm{barg} \le P_G \le 50\ \mathrm{barg}$	P_G	$u(P_G) = 0.025\%\ \text{of span} = 0.0125\ \mathrm{barg}$

Table 9 Gas pressure transmitter range and associated uncertainty

2.3.4 Temperature

The gas temperature measurement (T_G) is obtained from the orifice plate multivariable transmitter, with the measurement range and uncertainty listed in Table 10. The transmitter calibration report is available in Appendix **Error! Reference source not found.**.

Temperature range (TI 1223) PN: 3051SFC1CS060N065T33JA1A3Q4M5T1	**Output**	**Specified Uncertainty**
$0\ °\mathrm{C} \le T_G \le 60\ °\mathrm{C}$	T_G	$u(T_G) = 0.37\ °\mathrm{C}$

Table 10 Gas temperature transmitter range and associated uncertainty

2.4 Quality assurance

All the reference flowmeters are calibrated periodically on a yearly basis. However, to prevent potential measurement drifts that could occur within this period, the three primary flow meters and the secondary flow meter are continuously cross-checked against each other so that any excessive drift triggers a recalibration of the defective flowmeter.
Another source of error in the reference gas flow is the potential liquid carry-over due to an insufficient separation in the scrubber. The lack of resolution on the Coriolis gas density makes it unsuitable for carry-over detection. Instead, an optical spectrometer flow cell is mounted on the reference line offering a much enhanced sensitivity to the presence of liquid droplets in the gas stream.

2.4.1 Low flow cross-check

The small (A3) and medium (A2) Coriolis flow meters are mounted in series, allowing for a continuous cross-check of their readings when flowing through both devices. The agreement between the two flow meters is assessed by comparing the relative difference of two simultaneous mass flow measurements $\left|(q_G^{A2} - q_G^{A3})/q_G^{A3}\right|$ with their combined relative uncertainty $u\big((q_G^{A2} - q_G^{A3})/q_G^{A3}\big)$ and considering a coverage factor of 3. The following condition, when not satisfied is used to trigger an alarm:

For 1.9 m³/h $\leq Q_G^A \leq 25$ m³/h, $$\left|\frac{q_G^{A2} - q_G^{A3}}{q_G^{A3}}\right| < 3\,U\left(\frac{q_G^{A2} - q_G^{A3}}{q_G^{A3}}\right) \quad \textbf{(6)}$$

With $$U\left(\frac{q_G^{A2} - q_G^{A3}}{q_G^{A3}}\right) = \frac{q_G^{A2}}{q_G^{A3}}\sqrt{\left(\frac{U(q_G^{A2})}{q_G^{A2}}\right)^2 + \left(\frac{U(q_G^{A3})}{q_G^{A3}}\right)^2}$$

Note that this condition is only valid for the 20barg operating pressure. For other pressures, the corresponding volume flow range shall be used, as specified in Table 7.
<u>Numerical Application:</u>
For an actual gas volume flow of 10 m^3/h at 20barg and 30°C:
- $q_G^{A2} = 200$ kg/h with $U(q_G^{A2})/q_G^{A2} = 0.5\%$
- $q_G^{A3} = 195.5$ kg/h with $U(q_G^{A3})/q_G^{A3} = 0.5\%$
- ➢ $\left|\frac{q_G^{A2} - q_G^{A3}}{q_G^{A3}}\right| = 2.25\ \% > 3.U\left(\frac{q_G^{A2} - q_G^{A3}}{q_G^{A3}}\right) = 2.07\ \%$, trigger alarm

2.4.2 Medium flow cross-check

Likewise, the medium Coriolis flowmeter (A2) can be cross checked against the larger Coriolis flow meter (A1). The agreement between the two primary flow meters is assessed by comparing the relative difference of two simultaneous mass flow measurements $\left|(q_G^{A1} - q_G^{A2})/q_G^{A2}\right|$ with their combined relative uncertainty $u\big((q_G^{A1} - q_G^{A2})/q_G^{A2}\big)$ and considering a coverage factor of 3. The following condition, when not satisfied is used to trigger an alarm:

For 19 m³/h $\leq Q_G^A \leq 193$ m³/h, $$\left|\frac{q_G^{A1} - q_G^{A2}}{q_G^{A2}}\right| < 3\,U\left(\frac{q_G^{A1} - q_G^{A2}}{q_G^{A2}}\right) \quad \textbf{(7)}$$

With $$U\left(\frac{q_G^{A1} - q_G^{A2}}{q_G^{A2}}\right) = \frac{q_G^{A1}}{q_G^{A2}}\sqrt{\left(\frac{U(q_G^{A1})}{q_G^{A1}}\right)^2 + \left(\frac{U(q_G^{A2})}{q_G^{A2}}\right)^2}$$

Note that this condition is only valid for the 20barg operating pressure. For other pressures, the corresponding volume flow range shall be used, as specified in Table 6.

Numerical Application:
For an actual gas volume flow of 50 m^3/h at 20barg and 30°C:

- $q_G^{A1} = 1200$ kg/h with $U(q_G^{A1})/q_G^{A1} = 0.55\%$
- $q_G^{A2} = 1170$ kg/h with $U(q_G^{A2})/q_G^{A2} = 0.5\%$

➢ $\left|\frac{q_G^{A1} - q_G^{A2}}{q_G^{A2}}\right| = 2.5\% > 3.U\left(\frac{q_G^{A1} - q_G^{A2}}{q_G^{A2}}\right) = 2.06\%$, trigger alarm

2.4.3 Large flow cross-check

The secondary reference meter (B1) is mounted in series with the larger Coriolis flow meter (A1). Quality check of the higher flow rates is performed by comparing the mass flow rates measured by the Orifice plate and Coriolis flow meters. The agreement between the primary and secondary flow meters is assessed by comparing the relative difference of two simultaneous measurements $\left|(q_G^{B1} - q_G^{A1})/q_G^{A1}\right|$ with the meters' combined relative uncertainty, $u\left((q_G^{B1} - q_G^{A1})/q_G^{A1}\right)$ and considering a coverage factor of 3. The following condition, when not satisfied, is used to trigger an alarm:

For 145 m³/h ≤ Q_G^A ≤ 1000 m³/h, $$\left|\frac{q_G^{B1} - q_G^{A1}}{q_G^{A1}}\right| < 3\,U\left(\frac{q_G^{B1} - q_G^{A1}}{q_G^{A1}}\right) \quad \textbf{(8)}$$

With $$U\left(\frac{q_G^{B1} - q_G^{A1}}{q_G^{A1}}\right) = \frac{q_G^{B1}}{q_G^{A1}}\sqrt{\left(\frac{U(q_G^{A1})}{q_G^{A1}}\right)^2 + \left(\frac{U(q_G^{B1})}{q_G^{B1}}\right)^2}$$

Note that this condition is only valid for the 20barg operating pressure. For other pressures, the corresponding volume flow range shall be used, as specified in Table 8.

Numerical Application:
For an actual gas volume flow of 200 m^3/h at 20barg and 30°C:

- $q_G^{A1} = 4800$ kg/h with $U(q_G^{A1})/q_G^{A1} = 0.55\%$
- $q_G^{B1} = 4630$ kg/h with $U(q_G^{B1})/q_G^{B1} = 1\%$

➢ $\left|\frac{q_G^{B1} - q_G^{A1}}{q_G^{A1}}\right| = 3.67\ \% > 3.U\left(\frac{q_G^{B1} - q_G^{A1}}{q_G^{A1}}\right) = 3.54\%$ trigger alarm

2.4.4 Oil in gas

The recirculation liquid used in the compressor section is the same oil (EXXSOL D80) as in the rest of the flow loop. In the event of an incomplete separation in the wet gas scrubber, some oil droplets may possibly be entrained in the output gas stream and induce a significant error in the gas reference flow meters.
In this regard, an in-line optical liquid scattering sensor flow cell is inserted between the secondary and primary reference meters to detect potential liquid carry-over. This device is capable of detecting the presence of liquid droplets at very high gas-cuts (GVF > 99%). The optical system consists of a light source and spectrometer(s) operating in the NIR (Near infrared) and/or the UV (Ultraviolet) range. The level of the measured optical-density baseline shift due to added attenuation caused by scattering of liquid droplets in the gas stream is indicative of the level of liquid entrainment. Experimental tests can be used to correlate optical (scattering) attenuation measurement to the liquid volume concentration in gas.

$$\boldsymbol{OIG} = \quad \textbf{(9)}$$

To be completed (meter not commissioned yet)

A secondary ultrasound transit-time gas reference flowmeter may provide alternative detection of liquid carry-over in gas from the change in the detected speed of sound, in addition to providing gas velocity (volume flow rate) measurement.

3 OIL REFERENCE MEASUREMENTS

This section summarizes the primary reference measurements acquired on the oil line (Figure 2) such as the oil density (ρ_O^T), the oil mass flow rate (q_O^A), the oil pressure (P_O) and temperature (T_O). It also defines the quality assurance parameters that are calculated such as the fraction of water in oil (WIO), gas in oil (GIO) and the agreement between the oil reference flow meters, at low and high flow rates.

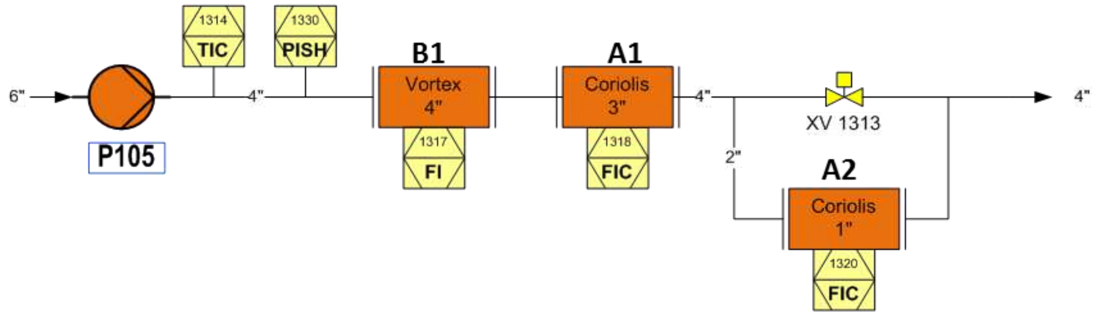

Figure 2 Process flow diagram of the oil reference flow line.

3.1 Composition

3.1.1 Oil type

The default oil used in the flow loop is EXXSOL D80, hereafter denoted as the “light oil”, a de-aromatized hydrocarbon liquid which offers advantageous safety, health and environmental properties. The typical properties of the oil are summarized in Table 11:

Characteristic	Typical value	Test method
Appearance	Clear / Transparent	-
Initial Boiling Point	208°C	ASTM D86
Flash Point	82 °C	ASTM D93 (Method A)
Aromatic content	0.2 wt%	ExxsonMobil Method
Total sulphur	1 wppm max	ASTM D5453
Density (15.6°C)	0.795 g/ml	ASTM D4052
Kinematic viscosity (25°C)	2.18 mm²/s	ASTM D445
Vapor Pressure (20°C)	0.01 kPa	ExxsonMobil Method

Table 11 Main chemical and physical properties of EXXSOL D80 **[8]**

For more information refer to the sample analysis report provided in Appendix E-5.

For specific tests under higher viscosities, the flow loop may be filled with a higher viscosity oil (up to 300 cSt), hereafter defined as the “viscous oil”. The liquid pumps, heat exchangers and reference flowmeters have been sized accordingly.

3.1.2 Dissolved Nitrogen

The solubility of Nitrogen in the oil phase is assumed to be negligible. Indeed, according to the comparative study of Nitrogen solubility in various liquids given in reference **[5]**, the mole fraction of dissolved Nitrogen is around 100 times smaller in oil (Dodecane) compared to water (Fresh water).

3.2 Density

Even if the Coriolis flowmeters can provide a fairly accurate estimate of the oil density, their measurement can be subject to potential cross-contaminations occurring in the oil line, such as WIO or GIO. Instead, a true oil density model is achieved from a pure oil sample collected prior each flow loop test and through standard correlations that account for the temperature effects.
Alternative: P, T tabulated density

3.2.1 Model

The oil density $\rho_O^{T_s}$ is measured with a reference densitometer (Anton Paar DMA 35) on a centrifuged sample collected at atmospheric pressure and at ambient temperature T_s. According to the ASTM D1250-80 Petroleum measurement tables **[3]**, the following correlation can be used to correct for the oil thermal expansion:

$$\boldsymbol{\rho_O^{P,T} = \rho_O^{15} \exp[-\alpha_{15} \times \Delta T \times (1 + 0.8 \times \alpha_{15} \times \Delta T)]} \qquad \textbf{(10)}$$

$$\text{with} \quad \alpha_{15} = \frac{K_0 + K_1 \rho_O^{15}}{\left(\rho_O^{15}\right)^2}$$

Where

- Where $\rho_O^{P,T}$ and ρ_O^{15} are the oil densities at temperature T and 15°C, expressed in kg/m^3.
- With $K_0 = 594.5418$ and $K_1 = 0$ for the Jet Group (densities ranging from 788 to 838.5kg/m^3)
- And $\Delta T = T - 15$ with T in °C

The oil density at standard conditions ρ_O^{15} can be derived from the sample measurement $\rho_O^{T_s}$ by inverting equation **(10)** using a zero-finding algorithm such as the Newton-Raphson method. Note that this model does not account for the oil compressibility which is considered to be negligible under the specified operating pressure range.

3.2.2 Uncertainty

The uncertainty of the reference oil density $u(\rho_O^{P,T})$ is assumed to be essentially driven by the sample measurement uncertainty $u(\rho_O^{T_s})$ determined by the handheld densitometer accuracy and impossibility to evaluate compressibility effect of oil between atmospheric and line pressure:

$$\boldsymbol{U\left(\rho_O^{P,T}\right) = 2\ \mathrm{kg/m^3}} \qquad \textbf{(11)}$$

The calibration certificate of the DMA 35 handheld densitometer is available in Appendix E-6. We arbitrarily estimate uncertainty for compressibility of the oil to same order of magnitude as the densitometer uncertainty (1 kg/m^3).

Table 3 gives the reference oil density measurement expanded uncertainty.

			Expanded Uncertainty				

Source	Units	Value	Abs	(%)	Probability	Divisor	Standard	Variance
DMA uncertainty	kg/m³	800	1.040	0.130	Normal(95%)	1.96	0.066	4.339E-03
ASTM formula	Kg/m³	800	1.360	0.170	Normal(95%)	1.96	0.087	7.523E-03
Pressure effect	Kg/m³	800	1.040	0.130	Normal(95%)	1.96	0.066	4.399E-03
Oil Density Uncertainty	**kg/m³**	**800**	**2.00**	**0.25**	**Normal(95%)**	**1.96**	**0.128**	**1.632E-02**

Table 12: Oil density measurement expanded uncertainty table

3.3 Reference meters

This section describes the single phase reference meters installed on the oil line. After flowing through the oil pump, the oil flow rate is measured by a set of high precision flow meters. Two different technologies are used simultaneously to allow for redundancy: Coriolis flowmeters are used as primary references ($A1, A2$) whereas a Vortex shedding flowmeter is mounted in series to provide a secondary reference measurement ($B1$). In addition, local pressure and temperature are measured upstream the reference flow meters.

3.3.1 Primary flow meters

The two Coriolis flow meters are connected in series (A1 and A2 in Figure 2). An actuated valve allows the control system to automatically select the appropriate flow meter by comparing the actual volume flow rate with the flow meters measuring ranges. Tables 13 and 14 summarize the output variables and associated uncertainty according to the Coriolis meters flow ranges.

Emerson provides figures for the uncertainty in their technical datasheet **[10]** (reported here as *specified uncertainty*). Meter performance are periodically verified by calibration check in dedicated facilities, usually at atmospheric pressure. The Combined uncertainty accounts for other sources of uncertainty related to the operating conditions. The Coriolis flow meters calibration reports and detailed uncertainty calculation tables are available in Appendix E-7 and E-8.

Flow range (FIC 1318) PN: CMFS100M419N2BMEKZZ	**Output**	**Specified Uncertainty**	**Combined Uncertainty**
(Light oil) $8.5\ \mathrm{m^3/h} \leq Q_O^A \leq 174\ \mathrm{m^3/h}$ (Viscous oil at 300 cSt) $7.8\ \mathrm{m^3/h} \leq Q_O^A \leq 120\ \mathrm{m^3/h}$	$q_O^A = q_O^{A1}$	$\frac{u(q_O^{A1})}{q_O^{A1}} = 0.1\%$	$\frac{U(q_O^{A1})}{q_O^{A1}} = \max\left(0.24\%, \frac{Z_{A1}}{q_O^{A1}}\right)$
	$Q_O^A = \frac{q_O^{A1}}{\rho_O^{A1}}$	$\frac{u(Q_O^A)}{Q_O^A} = 0.12\%$	$\frac{U(Q_O^{A1})}{Q_O^{A1}} = \max\left(0.27\%, \frac{Z_{A1}}{q_O^{A1}}\right)$
	$\rho_O^A = \rho_O^{A1}$	$u(\rho_O^{A1}) = 0.5\ \mathrm{kg/m^3}$	$U(\rho_O^{A1}) = 1\ \mathrm{kg/m^3}$

Table 13 Oil large Coriolis flowmeter (A1) measuring range and associated uncertainty for the light and viscous oils

Flow range (FIC 1320) PN: CMFS100M419N2BMEKZZ	Output	Specified Uncertainty	Combined Uncertainty
(Light oil) $0.6\ \mathrm{m^3/h} \le Q_O^A \le 14\ \mathrm{m^3/h}$ (Viscous oil at 300 cSt) $0.5\ \mathrm{m^3/h} \le Q_O^A \le 6.2\ \mathrm{m^3/h}$	$q_O^A = q_O^{A2}$	$\frac{u(q_O^{A2})}{q_O^{A2}} = 0.1\%$	$\frac{U(q_O^{A2})}{q_O^{A2}} = \max\left(0.36\%, \frac{Z_{A2}}{q_O^{A2}}\right)$
	$Q_O^A = \frac{q_O^{A2}}{\rho_O^{A2}}$	$\frac{u(Q_O^{A2})}{Q_O^{A2}} = 0.12\%$	$\frac{U(Q_O^{A2})}{Q_O^{A2}} = \max\left(0.38\%, \frac{Z_{A2}}{q_O^{A2}}\right)$
	$\rho_O^A = \rho_O^{A2}$	$u(\rho_O^{A2}) = 0.5\ \mathrm{kg/m^3}$	$U(\rho_O^{A2}) = 1\ \mathrm{kg/m^3}$

Table 14 Oil small Coriolis flowmeter (A2) measuring range and associated uncertainty for the light and viscous oils

In addition to the specified uncertainty, the combined uncertainty is defined to calculate the Coriolis meters accuracy below their specified range. Coriolis flow meters indeed have a wide turndown and can still deliver a precise measurement outside their optimum accuracy range that can be used for quality assurance purposes. According to the manufacturer, below the minimum (mass) flow rate, the accuracy is governed by the zero stability coefficient:

- CMF300: $Z_{A1} = 6.82\ \mathrm{kg/h}$
- CMFS100: $Z_{A2} = 0.461\ \mathrm{kg/h}$

3.3.2 Secondary flow meters

A Vortex shedding flow meter is inserted downstream the large Coriolis flow meter to provide a redundant flow measurement (B1). This additional flowmeter has been sized so that its measuring range matches with the larger Coriolis flow meter. The Vortex flow meter is installed on a horizontal portion and its position complies with the minimum straight pipe length required by the manufacturer (10D upstream and 5D downstream). Table 15 summarizes the output variables measured from the secondary flowmeter and their associated uncertainty. Note that the vortex flowmeter is not suitable for higher viscosity oils. The calibration report is available in Appendix E-9.

Flow range (FI 1317) PN: 8800DF040SA3N1P1M5T1Q4	Output	Specified Uncertainty
(Light oil) $12\ \mathrm{m^3/h} \le Q_O^B \le 212\ \mathrm{m^3/h}$	$Q_O^B = Q_O^{B1}$	$u(Q_O^{B1})/Q_O^{B1} = 0.65\%$

Table 15 Oil Large Vortex flowmeter (B1) measuring range and associated uncertainty for the light oil

3.3.3 Pressure

The oil line pressure transmitter is located upstream the reference flow meters; its measurement range and uncertainty are listed in Table 16. The calibration report is available in Appendix E-10.

Pressure range (PISH 1330) PN: PMC51-AA22IA1SGJRKJA	Output	Specified Uncertainty
$-1\ \mathrm{barg} \le P_O \le 40\ \mathrm{barg}$	P_O	$u(P_O)/P_O = 0.20\ \%$

Table 16 Oil line pressure transmitter range and associated uncertainty

3.3.4 Temperature

The oil line temperature transmitter is located upstream the reference flow meters; its measurement range and uncertainty are listed in Table 17. The configuration report is available in Appendix E-11.

Temperature range (TIC 1314) PN: TR10-AFA3CDSAK3000	Output	Specified Uncertainty
$0°\text{C} \leq T_O \leq 100°\text{C}$	T_O	$u(T_O) = 0.1°\text{C} + 0.0017\,.T_O(°\text{C})$

Table 17 Oil line temperature transmitter range and associated uncertainty

3.4 Quality assurance

Thanks to the oil density model defined in Section 3.2, the comfortable overlap between primary flow meters at low flow rates (3.3.1) and the use of a secondary reference flowmeter at higher flow rates for light oil (3.3.2), it is possible to achieve robust quality indicators to verify the accuracy of the oil reference measurements and anticipate a recalibration whenever necessary.

3.4.1 Low flow cross-check

The small and large Coriolis flow meters are mounted in series, allowing for a continuous cross-check of their measurements when flowing through both devices. The agreement between the two primary flow meters is assessed by comparing the relative difference of two simultaneous measurements $\left|(Q_O^{A1} - Q_O^{A2})/Q_O^{A2}\right|$ with their combined relative uncertainty $u\left((Q_O^{A1} - Q_O^{A2})/Q_O^{A2}\right)$ and considering a coverage factor of 3. The following condition, when not satisfied is used to trigger an alarm:

For $0.6\ \mathrm{m^3/h} \leq Q_O^A \leq 14\ \mathrm{m^3/h}$, $$\left|\frac{Q_O^{A1} - Q_O^{A2}}{Q_O^{A2}}\right| < 3\,U\left(\frac{Q_O^{A1} - Q_O^{A2}}{Q_O^{A2}}\right) \quad \textbf{(12)}$$

With $$U\left(\frac{Q_O^{A1} - Q_O^{A2}}{Q_O^{A2}}\right) = \frac{Q_O^{A1}}{Q_O^{A2}}\sqrt{\left(\frac{U(Q_O^{A1})}{Q_O^{A1}}\right)^2 + \left(\frac{U(Q_O^{A2})}{Q_O^{A2}}\right)^2}$$

Note that this condition is only valid for the light oil. For the viscous oil, the corresponding volume flow range shall be considered, as specified in Table 14.

<u>Numerical Application:</u>
Considering an actual oil volume flow rate of 4m^3/h,

- $Q_O^{A1} = 4.06\ \mathrm{m^3/h}$ with $U(Q_O^{A1})/Q_O^{A1} = 0.27\%$
- $Q_O^{A2} = 4.00\ \mathrm{m^3/h}$ with $U(Q_O^{A2})/Q_O^{A2} = 0.38\%$
- ➢ $\left|\frac{Q_O^{A1}-Q_O^{A2}}{Q_O^{A2}}\right| = 1.5\ \% > 3\,U\left(\frac{Q_O^{A1}-Q_O^{A2}}{Q_O^{A2}}\right) = 1.37\ \%$, trigger alarm

3.4.2 Large flow cross-check

The secondary reference flowmeter is mounted in series with the larger primary flowmeter. Quality check of the higher flow rates is performed by comparing the volumetric flow rates of light oil measured by the Vortex and Coriolis flow meters. The agreement between the primary and secondary flow meters is assessed by comparing the relative difference of two simultaneous measurements $\left|(Q_O^{B1} - Q_O^{A1})/Q_O^{A1}\right|$ with the meters' combined relative uncertainty, $u\left((Q_O^{B1} - Q_O^{A1})/Q_O^{A1}\right)$ and considering a coverage factor of 3. The following condition, when not satisfied, is used to trigger an alarm:

$$\textbf{For 12 m}^3\textbf{/h} \leq Q_O^A \leq \textbf{212 m}^3\textbf{/h,} \qquad \left|\frac{Q_O^{B1} - Q_O^{A1}}{Q_O^{A1}}\right| < 3\, U\left(\frac{Q_O^{B1} - Q_O^{A1}}{Q_O^{A1}}\right) \tag{13}$$

With $$U\left(\frac{Q_O^{B1} - Q_O^{A1}}{Q_O^{A1}}\right) = \frac{Q_O^{B1}}{Q_O^{A1}}\sqrt{\left(\frac{U(Q_O^{A1})}{Q_O^{A1}}\right)^2 + \left(\frac{U(Q_O^{B1})}{Q_O^{B1}}\right)^2}$$

Note that this condition is largely valid for the light oil since Vortex flowmeters require flow with Reynolds number > ~250 and can therefore not work on higher viscosity liquids.

Numerical Application:
Assuming an actual oil volume flow of 120 m³/h,

- $Q_O^{A1} = 120\ \mathrm{m^3/h}$ with $U(Q_O^{A1})/Q_O^{A1} = 0.27\%$
- $Q_O^{B1} = 123\ \mathrm{m^3/h}$ with $U(Q_O^{B1})/Q_O^{B1} = 0.65\%$

➢ $\left|\frac{Q_O^{B1}-Q_O^{A1}}{Q_O^{A1}}\right| = 2.50\ \% > 3\ U\left(\frac{Q_O^{B1}-Q_O^{A1}}{Q_O^{A1}}\right) = 2.16\ \%$, trigger alarm

3.4.3 Water-in-oil

Traces of water could possibly be present in the oil phase due to an incomplete oil-water separation in the separator. As explained in Appendix B, it is possible to derive the water-in-oil (WIO) ratio from the measured density in the oil line (ρ_O^A) and the theoretical oil ($\rho_O^{P_O,T_O}$) and water densities ($\rho_W^{P_O,T_O}$) calculated at the oil line conditions (P_O, T_O).

$$\boldsymbol{WIO = \frac{\rho_O^A - \rho_O^{P_O,T_O}}{\rho_W^{P_O,T_O} - \rho_O^{P_O,T_O}}} \tag{14}$$

The following condition, when not satisfied, is used to trigger an alarm:

$$\boldsymbol{WIO < 3\,.\,U(WIO)} \tag{15}$$

The uncertainty on the WIO measurement can be determined from the combined uncertainty of the reference water $U(\rho_W^{P_O,T_O})$ and oil $U(\rho_O^{P_O,T_O})$ densities and Coriolis measured density $U(\rho_O^A)$:

$$U^2(WIO) = \frac{1}{\left(\rho_W^{P_O,T_O} - \rho_O^{P_O,T_O}\right)^2} U^2\left(\rho_O^A\right) + \frac{(\rho_O^A - \rho_W^{P_O,T_O})^2}{\left(\rho_W^{P_O,T_O} - \rho_O^{P_O,T_O}\right)^4} U^2\left(\rho_O^{P_O,T_O}\right) + \frac{\left(\rho_O^{P_O,T_O} - \rho_O^A\right)^2}{\left(\rho_W^{P_O,T_O} - \rho_O^{P_O,T_O}\right)^4} U^2\left(\rho_W^{P_O,T_O}\right)$$

Numerical Application:
Considering a deviation of 4 kg/m³ from the true oil density,

- $\rho_O^A = 806.7\ \mathrm{kg/m^3}$ with $U(\rho_O^A) = 1.0\ \mathrm{kg/m^3}$
- $\rho_O^{P_O,T_O} = 800\ \mathrm{kg/m^3}$ with $U(\rho_O^{T_O}) = 2\ \mathrm{kg/m^3}$
- $\rho_W^{P_O,T_O} = 996\ \mathrm{kg/m^3}$ with $U(\rho_W^{P_O,T_O}) = 1.8\ \mathrm{kg/m^3}$ (see Eq.19)

➢ $WIO = 3.42\ \% > 3\,.\,U(WIO) = 3.33\ \%$, trigger alarm

3.4.4 Gas-in-oil

Gas may also be entrained in the oil phase due to an incomplete separation of the gas and liquid streams in the separator (as known as gas carry-under). Just as the water-in-oil contamination, the gas-in-oil content (GIO) can be derived from the oil Coriolis density (ρ_O^A), the expected oil density ($\rho_O^{T_O}$) and the expected gas density ($\rho_G^{P_O,T_O}$) at the oil line pressure and temperature conditions (P_O, T_O):

$$\boldsymbol{GIO = \frac{\rho_O^A - \rho_O^{P_O,T_O}}{\rho_G^{P_O,T_O} - \rho_O^{P_O,T_O}}} \quad \textbf{(16)}$$

The uncertainty on the GIO measurement can be determined from the combined uncertainty of the gas density $u(\rho_G^{P_O,T_O})$, the oil density $u(\rho_O^{P_O,T_O})$ and the measured Coriolis density $u(\rho_O^A)$:

$$U^2(GIO) = \frac{1}{\left(\rho_G^{P_O,T_O} - \rho_O^{P_O,T_O}\right)^2} U^2(\rho_O^A) + \frac{(\rho_O^A - \rho_G^{P_O,T_O})^2}{\left(\rho_G^{P_O,T_O} - \rho_O^{P_O,T_O}\right)^4} U^2\left(\rho_O^{P_O,T_O}\right) + \frac{\left(\rho_O^{P_O,T_O} - \rho_O^A\right)^2}{\left(\rho_G^{P_O,T_O} - \rho_O^{P_O,T_O}\right)^4} U^2\left(\rho_G^{P_O,T_O}\right)$$

Numerical Application:
Assuming a deviation of 4 kg/m³ from the true oil density,

- $\rho_O^A = 796\ \mathrm{kg/m^3}$ with $U(\rho_O^A) = 1\ \mathrm{kg/m^3}$
- $\rho_O^{P_O,T_O} = 800\ \mathrm{kg/m^3}$ with $U(\rho_O^{P_O,T_O}) = 1\ \mathrm{kg/m^3}$
- $\rho_G^{P_O,T_O} = 23.38\ \mathrm{kg/m^3}$ with $U\left(\rho_G^{P_O,T_O}\right) = 0.217\mathrm{kg/m^3}$
- ➢ $GIO = 0.52\% > 3\,.\,U(GIO) = 0.43\%$, trigger alarm

Thanks to the gas density being significantly lower than the oil density, this method can detect gas-in-oil contents as low as 0.5%.

4 WATER REFERENCE MEASUREMENTS

This section summarizes the primary reference measurements acquired on the water line (Figure 3) such as the water density ($\rho_W^{P,T}$), the water mass flow rate (q_W^A), the water pressure (P_W) and temperature (T_W). It also defines the quality assurance parameters that are calculated such as the fraction of oil in water (OIW), gas in water (GIW) and the agreement between the reference flow meters, at low and high flow rates.

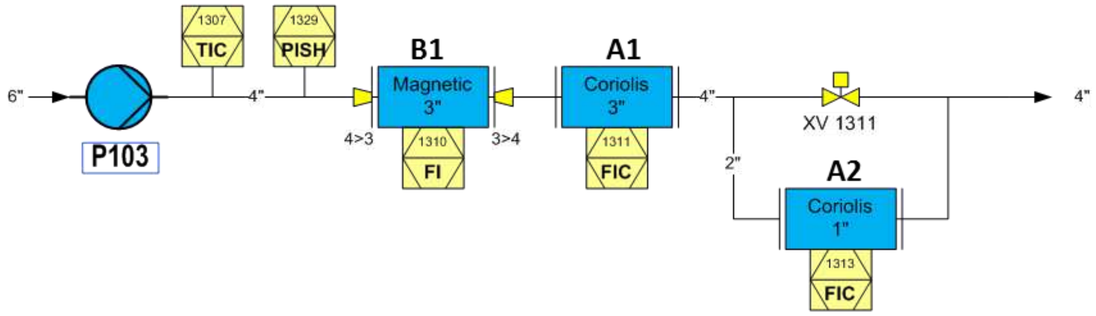

Figure 3 Process flow diagram of the water reference line

4.1 Composition

4.1.1 Water solution

The separator is filled with fresh water by default. However, since the pipework is entirely manufactured from stainless steel, the facility can also utilize brine as water phase. Pure Sodium Chloride (NaCl) can be diluted in the separator at various concentrations ranging from fresh water up to 200g/kg.

4.1.2 Dissolved Nitrogen

The aqueous NaCl solution in the flow loop is equilibrated with the Nitrogen gas phase, meaning that a certain amount of the gas is dissolved in water. The influence of the dissolved Nitrogen on the water density can be predicted by using the thermodynamic model of the N_2-H_2O-NaCl solution proposed by Shide Mao and Zhenhao Duan **[9]**:

$$\boldsymbol{\rho_{H2O-NaCl-N2} = \frac{m_{H2O-NaCl-N2}}{V_{H2O-NaCl-N2}}} \qquad \textbf{(17)}$$

With:

$$m_{H2O-NaCl-N2} = 1000 + m_{NaCl}M_{NaCl} + m_{N2}M_{N2}$$

$$V_{H2O-NaCl-N2} = \frac{1000 + m_{NaCl}M_{NaCl}}{\rho_{H2O-NaCl}} + m_{N2}V_{N2}$$

Where:

- $m_{H2O-NaCl-N2}$ is the molality of the H_2O-NaCl-N_2 solution in mol/kg
- $m_{H2O-NaCl}$ is the molality of the H_2O-NaCl solution in mol/kg
- m_{NaCl} is the molality of the $NaCl$ in mol/kg
- m_{N2} is the molality of the N_2 in mol/kg
- V_{N2} is the partial molar volume of N_2 in the aqueous $NaCl$ solution in cm^3/mol
- $M_{N2} = 28.0134$ g/mol is the molar mass of Nitrogen
- $M_{NaCl} = 58.4428$ g/mol is the molar mass of $NaCl$

Numerical Application
Considering a gas pressure $P_G = 20$ bar, a temperature $T_G = 30°$C, the thermodynamic model predicts the following solubility factors for Nitrogen in a 1 g/mol (equivalent to 58 g/kg) aqueous NaCl solution:

- $V_{N2} = 39.32\ \mathrm{cm^3/mol}$
- $m_{N2} = 0.00824\ \mathrm{mol/kg}$
- $m_{NaCl} = 1\ \mathrm{mol/kg}$

When applied to an estimated brine density $\rho_{H2O-NaCl} = 1037.795\ \mathrm{kg/m^3}$ (using the Rowe and Chou model presented in section 4.2), equation **(17)** gives a density of the liquid phase solution of $\rho_{H2O-NaCl-N2} = 1037.690\ \mathrm{kg/m^3}$. The effect of dissolved Nitrogen on the water density is in the order of 0.01% and will hence be neglected in the rest of this document.

4.2 Density

Just as the oil line, the density measured by the Coriolis flowmeters is not used as a reference because of potential cross-contaminations. Instead, a water density model is achieved from a pure water/brine sample collected prior each flow loop test and through standard correlations that account for the temperature and pressure effects.

4.2.1 Model

According to Rowe and Chou **[6]**, the density of the aqueous NaCl solution at a given temperature T and pressure P can be estimated from experimental correlations by the following formula:

$$\boldsymbol{\rho_W^{P,T} = \frac{1000}{A(T) + sD(T) + s^2E(T) - P\left(B(T) + P\,C(T) + s\left(F(T) + sG(T) + \frac{1}{2}P\,H(T)\right)\right)}} \quad \textbf{(18)}$$

Where:
- $\rho_W^{P,T}$ is the brine density in kg/m^3
- s is the water salinity in kg of NaCl per kg of solution (from 0 to 250,000 ppm)
- T is the absolute temperature in Kelvin (from 273.15K to 448.15K)
- P is the water absolute pressure in kg/cm^2

The brine density $\rho_W^{P_0,T_0}$ is measured with a handheld densitometer (Anton Paar DMA 35) on a centrifuged sample at atmospheric pressure ($P_0 \approx 0$ barg) and at ambient temperature T_0. The water salinity can then be calculated by inverting equation **(18)** using the sample measurement taken at atmospheric pressure:

$$s = \frac{-D(T_0) - \sqrt{D^2(T_0) - 4 \times E(T_0) \times \left(A(T_0) - \frac{1000}{\rho_W^{P_0,T_0}}\right)}}{2 \times E(T_0)}$$

Below is the Table of parameters used in the Rowe-Chou correlation:

Par.	Formula
A(T)	5.916365 – (0.01035794 x T) + (0.9270048e-5 x T^2) – (1127.552 / T) + (100674.1 / T^2)
B(T)	0.5204914e-2 – (0.10482101e-4 x T) + (0.8328532e-8 x T^2) – (1.1702939 / T) + (102.2783 / T^2)
C(T)	0.1185470e-7 – (0.65991430e-10 x T)

D(T)	- 2.5166 + (0.0111766 x T) – (0.170552e-4 x T^2)
E(T)	2.84851 – (0.0154305 x T) + (0.223982e-4 x T^2)
F(T)	-0.0014814 + (0.82969e-5 * T) – (0.12469e-7 * T^2)
G(T)	0.0027141 – (0.153910e-4 * T) + (0.22655e-7 * T^2)
H(T)	0.62158e-6 – (0.40075e-8 * T) + (0.65972e-11 * T^2)

4.2.2 Uncertainty

Rowe and Chou claim that their correlation reproduces the brine density with an accuracy of 0.15%, i.e. around 1.5 kg/m^3 over the range of temperatures from 0 to 150°C, NaCl concentrations from 0 to 25wt% and pressures from 1 to 343 bar. However, because the sample density is used in the first place to calculate the water salinity, the resulting uncertainty (Table 18) is assumed to be the combination of both the correlation uncertainty (1.5 kg/m^3) and the sample measurement uncertainty (1 kg/m^3):

$$u\left(\rho_W^{P,T}\right) = 1.8\ \mathrm{kg/m^3} \tag{19}$$

Source	Units	Value	Expanded Uncertainty Abs	Expanded Uncertainty (%)	Probability	Divisor	Standard	Variance
Rowe and Chou uncertainty	kg/m^3	1,000	1.500	0.150	Normal(95%)	1.96	0.077	5.857E-03
Sampling uncertainty	kg/m^3	1,000	1.000	0.100	Normal(95%)	1.96	0.051	2.603E-03
Water Density Uncertainty	**kg/m^3**	**1,000**	**1.80**	**0.1800**	**Normal(95%)**	**1.96**	**0.092**	**8.460E-03**

Table 18 : Water density calculation uncertainty table

The calibration certificate of the DMA 35 handheld densitometer and the uncertainty table are available in Appendix E-6.

4.3 Reference meters

This section describes the single phase reference meters used on the water line. The water line arrangement is similar to the oil line in that two different technologies are used simultaneously to allow for redundancy and cross check: Coriolis flowmeters are used as primary references $(A1, A2)$ whereas a Magnetic flowmeter is installed to provide a secondary reference measurement $(B1)$, Figure 3. In addition, local pressure and temperature are measured upstream the reference flow meters.

4.3.1 Primary flow meters

The two Coriolis flow meters are connected in series (A1 and A2). An actuated valve allows the control system to automatically select the most suitable flow meter by comparing the actual flow rate with the flowmeters' range. Tables 19-20 summarize the output flow variables measured from the primary flowmeters and their associated uncertainty.
Emerson provides figures for uncertainty in their technical datasheet **[10]**. Meter performance are periodically verified by calibration check in dedicated facilities, usually at atmospheric pressure. The combined uncertainty accounts for external source of uncertainty related to the operating conditions. The Coriolis flowmeters calibration reports and associated uncertainty tables are available in Appendix E-12 and E-13.

Flow range (FIC 1311) PN: CMF300M426N2BMEZZZ	Output	Specified Uncertainty	Combined Uncertainty
(Fresh water) $7\ \mathrm{m^3/h} \leq Q_W^A \leq 162\ \mathrm{m^3/h}$ (20% salinity Brine) $5\ \mathrm{m^3/h} \leq Q_W^A \leq 141\ \mathrm{m^3/h}$	$q_W^A = q_W^{A1}$	$\frac{u(q_W^{A1})}{q_W^{A1}} = 0.1\%$	$\frac{U(q_W^{A1})}{q_W^{A1}} = \max\left(0.24\%, \frac{Z_{A1}}{q_W^{A1}}\right)$
	$Q_W^A = \frac{q_W^{A1}}{\rho_W^{A1}}$	$\frac{u(Q_W^A)}{Q_W^A} = 0.11\%$	$\frac{U(Q_W^{A1})}{Q_W^{A1}} = \max\left(0.27\%, \frac{Z_{A1}}{q_W^{A1}}\right)$
	$\rho_W^A = \rho_W^{A1}$	$u(\rho_W^{A1}) = 0.5\ \mathrm{kg/m^3}$	$U(\rho_W^{A1}) = 1\ \mathrm{kg/m^3}$

Table 19 Water large Coriolis flowmeter (A1) measuring range and associated uncertainty for fresh water and 20% salinity brine

Flow range (FIC 1313) PN: CMFS100M419N2BMEKZZ	Output	Specified Uncertainty	Combined Uncertainty
(Fresh Water) $0.5\ \mathrm{m^3/h} \leq Q_W^A \leq 13\ \mathrm{m^3/h}$ (20% salinity Brine) $0.4\ \mathrm{m^3/h} \leq Q_W^A \leq 11.5\ \mathrm{m^3/h}$	$q_W^A = q_W^{A2}$	$\frac{u(q_W^{A2})}{q_W^{A2}} = 0.1\%$	$\frac{U(q_W^{A2})}{q_W^{A2}} = \max\left(0.36\%, \frac{Z_{A2}}{q_W^{A2}}\right)$
	$Q_W^A = \frac{q_W^{A2}}{\rho_W^{A2}}$	$\frac{u(Q_W^{A2})}{Q_W^{A2}} = 0.11\%$	$\frac{U(Q_W^{A2})}{Q_W^{A2}} = \max\left(0.37\%, \frac{Z_{A2}}{q_W^{A2}}\right)$
	$\rho_W^A = \rho_W^{A2}$	$u(\rho_W^{A2}) = 0.5\ \mathrm{kg/m^3}$	$U(\rho_W^{A2}) = 1\ \mathrm{kg/m^3}$

Table 20 Water small Coriolis flowmeter (A2) measuring range and associated uncertainty for fresh water and 20% salinity brine

Just as on the oil line, in addition to the specified uncertainty, the combined uncertainty is defined to calculate the Coriolis meters accuracy below their specified range. According to the manufacturer, below the minimum (mass) flow rate, the accuracy is governed by the zero stability coefficient:

- CMF300: $Z_{A1} = 6.82\ \mathrm{kg/h}$
- CMFS100: $Z_{A2} = 0.461\ \mathrm{kg/h}$

4.3.2 Secondary flow meters

An electromagnetic flow meter is inserted in series with the large Coriolis flow meter to provide a redundant flow measurement (B1). This additional flowmeter has been sized to match with the larger Coriolis flow meter's measuring range. The flow meter is installed on a horizontal portion and its position complies with the minimum straight pipe length required by the manufacturer (5D upstream and 2D downstream). Table 21 summarizes the output variables measured from the Magnetic flowmeter and their associated uncertainty. The Magnetic flowmeter calibration report is available in Appendix E-14.

Flow range (FI 1310) PN: 8732EST1A1E5M4	Output	Specified Uncertainty
(Fresh water) $17\ \text{m}^3/\text{h} \leq Q_W^B \leq 206\ \text{m}^3/\text{h}$ (20% salinity brine) $17\ \text{m}^3/\text{h} \leq Q_W^B \leq 206\ \text{m}^3/\text{h}$	$Q_W^B = Q_W^{B1}$	$u(Q_W^{B1})/Q_W^{B1} = 0.25\%$

Table 21 Water Large electromagnetic flowmeter (B1) measuring range and associated uncertainty for fresh water and 20% brine

4.3.3 Pressure

The water line pressure transmitter is located upstream the reference flow meters; its measurement range and uncertainty are listed in Table 22. The calibration report is available in Appendix E-15.

Pressure range (PISH 1329) PN: PMC51-AA22IA1SGJRKJA	Output	Specified Uncertainty
$-1\ \text{barg} \leq P_W \leq 40\ \text{barg}$	P_W	$u(P_W)/P_W = 0.20\ \%$

Table 22 Water line pressure transmitter range and associated uncertainty

Insert example of table of pressure budget table

4.3.4 Temperature

The water line temperature transmitter is located upstream the reference flow meters; its measurement range and uncertainty are listed in Table 23. The configuration report is available in Appendix E-16.

Temperature range (TIC 1307) PN: TR10-AFA3CDSAK3000	Output	Specified Uncertainty
$0°\text{C} \leq T_W \leq 100°\text{C}$	T_W	$u(T_W) = 0.1°\text{C} + 0.0017\,.T_W\ (°\text{C})$

Table 23 Water line temperature transmitter range and associated uncertainty

4.4 Quality assurance

Thanks to the water density model defined in Section (4.2), the comfortable overlap between primary flow meters at low flow rates (4.3.1) and the use of a secondary reference flowmeter at higher flow rates (4.3.2), it is possible to achieve reliable quality indicators to verify the accuracy of the water reference measurements.

4.4.1 Low flow cross-check

The small and large Coriolis flow meters are mounted in series, allowing for a continuous cross-check of their measurements when flowing through both devices. The agreement between the two primary flow meters is assessed by comparing the relative difference of two simultaneous measurements $\left|(Q_W^{A1} - Q_W^{A2})/Q_W^{A2}\right|$ with their combined relative uncertainty $u\left((Q_W^{A1} - Q_W^{A2})/Q_W^{A2}\right)$ and considering a coverage factor of 3. The following condition, when not satisfied is used to trigger an alarm:

$$\text{For } 0.5\ \text{m}^3/\text{h} \leq Q_W^A \leq 14\ \text{m}^3/\text{h}, \quad \left|\frac{Q_W^{A1} - Q_W^{A2}}{Q_W^{A2}}\right| < 3\ U\left(\frac{Q_W^{A1} - Q_W^{A2}}{Q_W^{A2}}\right) \qquad (20)$$

With $$U\left(\frac{Q_W^{A1}-Q_W^{A2}}{Q_W^{A2}}\right)=\frac{Q_W^{A1}}{Q_W^{A2}}\sqrt{\left(\frac{U(Q_W^{A1})}{Q_W^{A1}}\right)^2+\left(\frac{U(Q_W^{A2})}{Q_W^{A2}}\right)^2}$$

Note that this condition is only valid for fresh water. For brine with high salt concentrations, the corresponding volume flow range shall be used, as specified in Table 20.

Numerical Application:
Considering an actual volume flow of fresh water of 6 m³/h,
- $Q_W^{A1}=6.00\ \mathrm{m^3/h}$ with $U(Q_W^{A1})/Q_W^{A1}=0.27\%$
- $Q_W^{A2}=6.1\ \mathrm{m^3/h}$ with $U(Q_W^{A2})/Q_W^{A2}=0.37\%$
- ➢ $\left|\frac{Q_W^{A1}-Q_W^{A2}}{Q_W^{A2}}\right|=1.67\%>3.U\left(\frac{Q_W^{A1}-Q_W^{A2}}{Q_W^{A2}}\right)=1.39\%$, trigger alarm

4.4.2 Large flow cross-check

The Magnetic flowmeter is mounted in series with the larger Coriolis flow meter. At higher flow rates, it is hence possible to continuously check the primary and secondary flowmeters against each other. The agreement between the primary and secondary flowmeters is assessed by comparing the relative difference of two simultaneous measurements $\left|(Q_W^{B1}-Q_W^{A1})/Q_W^{A1}\right|$ with their combined relative uncertainty, $u\left((Q_W^{B1}-Q_W^{A1})/Q_W^{A1}\right)$ and considering a coverage factor of 3. The following condition, when not satisfied, is used to trigger an alarm:

For 17 m³/h ≤ Q_W^A ≤ 150 m³/h, $$\left|\frac{Q_W^{B1}-Q_W^{A1}}{Q_W^{A1}}\right|<3\,U\left(\frac{Q_W^{B1}-Q_W^{A1}}{Q_W^{A1}}\right) \quad \textbf{(21)}$$

With $$U\left(\frac{Q_W^{B1}-Q_W^{A1}}{Q_W^{A1}}\right)=\frac{Q_W^{B1}}{Q_W^{A1}}\sqrt{\left(\frac{U(Q_W^{A1})}{Q_W^{A1}}\right)^2+\left(\frac{U(Q_W^{B1})}{Q_W^{B1}}\right)^2}$$

Note that this condition is only valid for fresh water. For brine with high salt concentrations, the corresponding volume flow range shall be used, as specified in Table 21.

Numerical Application:
Considering an actual volume flow of fresh water of 30 m³/h,
- $Q_W^{A1}=30.0\ \mathrm{m^3/h}$ with $U(Q_W^{A1})/Q_W^{A1}=0.27\%$
- $Q_W^{B1}=30.4\ \mathrm{m^3/h}$ with $U(Q_W^{B1})/Q_W^{B1}=0.25\%$
- ➢ $\left|\frac{Q_W^{B1}-Q_W^{A1}}{Q_W^{A1}}\right|=1.33\%>3.U\left(\frac{Q_W^{B1}-Q_W^{A1}}{Q_W^{A1}}\right)=1.12\%$, trigger alarm

4.4.3 Oil-in-water

Traces of oil can possibly be present in the water phase due to an incomplete separation in the upstream oil-water separator. As explained in Appendix B, it is possible to derive the oil-in-water (OIW) ratio from the measured density in the water line (ρ_W^A) and the theoretical water ($\rho_W^{P_W,T_W}$) and oil densities ($\rho_O^{P_W,T_W}$) calculated at the water line conditions (P_W,T_W).

$$\boldsymbol{OIW=\frac{\rho_W^A-\rho_W^{P_W,T_W}}{\rho_O^{P_W,T_W}-\rho_W^{P_W,T_W}}} \quad \textbf{(22)}$$

The following condition, when not satisfied, is used to trigger an alarm:

$$\boldsymbol{OIW < 3\,.\,U(OIW)} \tag{23}$$

The uncertainty on the OIW measurement can be determined from the combined uncertainty of the reference water $U(\rho_W^{P_W,T_W})$ and oil $U(\rho_O^{P_W,T_W})$ densities and Coriolis measured density $U(\rho_W^A)$:

$$U^2(OIW) = \frac{1}{\left(\rho_O^{P_W,T_W} - \rho_W^{P_W,T_W}\right)^2} U^2\left(\rho_W^A\right) + \frac{(\rho_W^A - \rho_O^{P_W,T_W})^2}{\left(\rho_O^{P_W,T_W} - \rho_W^{P_W,T_W}\right)^4} U^2\left(\rho_W^{P_W,T_W}\right) + \frac{\left(\rho_W^{P_W,T_W} - \rho_W^A\right)^2}{\left(\rho_O^{P_W,T_W} - \rho_W^{P_W,T_W}\right)^4} U^2\left(\rho_O^{P_W,T_W}\right)$$

<u>Numerical application:</u>
Considering a deviation of 6 kg/m³ from the true water density,

- $\rho_W^A = 993 \text{ kg/m}^3$ with $U(\rho_W^A) = 1.0 \text{ kg/m}^3$
- $\rho_W^{P_W,T_W} = 1000 \text{ kg/m}^3$ with $U(\rho_W^{P_W,T_W}) = 1.8 \text{ kg/m}^3$
- $\rho_O^{P_W,T_W} = 800 \text{ kg/m}^3$ with $U(\rho_O^{P_W,T_W}) = 2 \text{ kg/m}^3$

➢ $OIW = 3.5\% > 3\,.\,U(OIW) = 3.0\%$, trigger alarm

4.4.4 Gas-in-water

Gas may also be entrained in the water phase due to an incomplete separation of the gas and liquid streams in the separator (known as gas carry-under). Similar to the oil-in-water contamination, the gas-in-water content (GIW) can be derived from the water Coriolis density (ρ_W^A), the expected water density $(\rho_W^{P_W,T_W})$ and the expected gas density $(\rho_G^{P_W,T_W})$ at the water line pressure and temperature conditions (P_W, T_W):

$$\boldsymbol{GIW = \frac{\rho_W^A - \rho_W^{P_W,T_W}}{\rho_G^{P_W,T_W} - \rho_W^{P_W,T_W}}} \tag{24}$$

The uncertainty on the GIW measurement can be determined from the combined uncertainty of the gas density $U(\rho_G^{P_W,T_W})$, the water density $U(\rho_W^{P_W,T_W})$ and the measured Coriolis density $U(\rho_W^A)$:

$$U^2(GIW) = \frac{1}{\left(\rho_G^{P_W,T_W} - \rho_W^{P_W,T_W}\right)^2} U^2\left(\rho_W^A\right) + \frac{(\rho_W^A - \rho_G^{P_W,T_W})^2}{\left(\rho_G^{P_W,T_W} - \rho_W^{P_W,T_W}\right)^4} U^2\left(\rho_W^{P_W,T_W}\right) + \frac{\left(\rho_W^{P_W,T_W} - \rho_W^A\right)^2}{\left(\rho_G^{P_W,T_W} - \rho_W^{P_W,T_W}\right)^4} U^2\left(\rho_G^{P_W,T_W}\right)$$

<u>Numerical application:</u>
Considering a deviation of 3.5 kg/m³ from the true water density,

- $\rho_W^A = 993 \text{ kg/m}^3$ with $U(\rho_W^A) = 1 \text{ kg/m}^3$
- $\rho_W^{P_W,T_W} = 999.5 \text{ kg/m}^3$ with $U(\rho_W^{P_W,T_W}) = 1.8 \text{ kg/m}^3$
- $\rho_G^{P_W,T_W} = 23.38 \text{ kg/m}^3$ with $U\left(\rho_G^{P_W,T_W}\right) = 0.11 \text{ kg/m}^3$

➢ $GIW = 0.67\% > 3\,.\,U(GIW) = 0.63\%$, trigger alarm

Thanks to the gas density being significantly lower than the water density, this method can detect gas-in-water contents as low as 0.3%. In addition to the GIW indicator, two visualization sight flow sections are provided on the test line, allowing the operator to periodically check for gas bubbles that would be entrained in the liquid phases.

5 MULTIPHASE REFERENCE MEASUREMENTS

The single phase flows are mixed in two consecutive steps. First, oil and water are mixed together using a standard Y-branch configuration. Then, the resulting liquid mixture is mixed with the gas stream through the mixing section, which offers multiple mixing configurations (Y-branch, mixing venturi, either 3inch or 6inch in line size). From this point, the multiphase mixture can travel either through one of the three test stations available (parallel configuration) or simultaneously through 2 or 3 of them (series configuration) before returning to the separator by the vertical return lines.

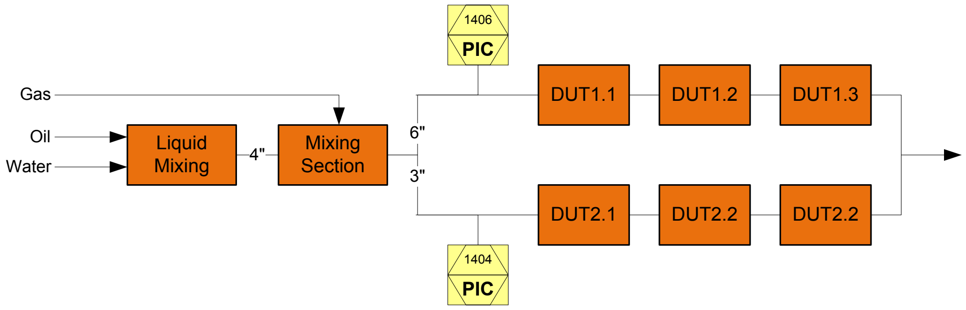

Figure 4 Simplified process flow diagram of the multiphase line

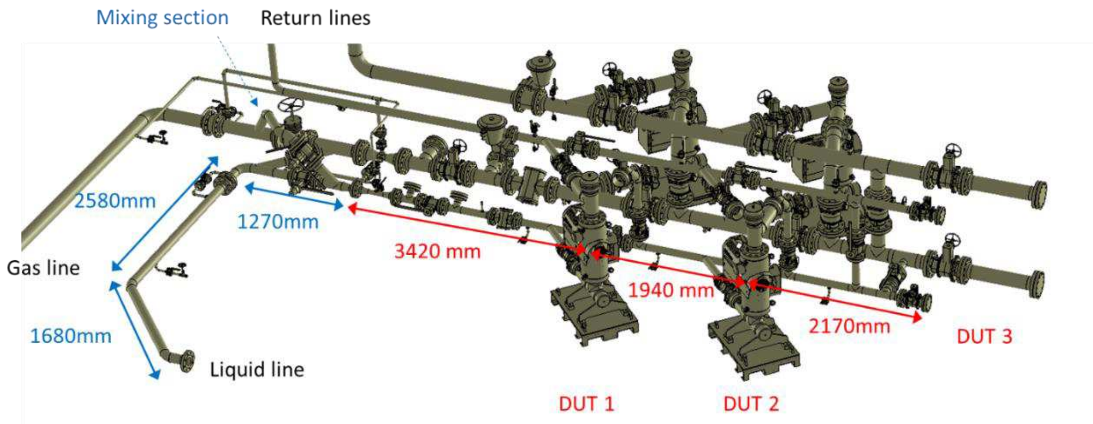

Figure 5 General arrangement of the test section, showing the Gas line, Liquid line, Mixing section, DUTs and main dimensions: in blue color, the distance from the liquid mixing point to the mixing section; in red color, the distance from the mixing section to the respective DUTs

5.1 Transit times

From the moment the single phases are measured by the reference flow meters in the gas, oil and water lines and the moment they are measured by the DUT, some delay may occur, depending on the phases' velocity in the pipes. Since the mixing is done in two consecutive steps, two transit times need to be accounted for: the liquid mixture transit time (t_{LP}) and the multiphase mixture transit time (t_{MP}).

5.1.1 Liquid mixture

We assume no delay in the single phase oil and water lines since they are fully packed with pure oil or pure water. The time it takes for a newly generated oil-water mixture to travel from the Y-branch mixing point up to the multiphase mixing section can be calculated as follows:

$$\boldsymbol{t_{LP}} = \frac{\boldsymbol{V_{LP}}}{\boldsymbol{Q_W^A + Q_O^A}} \qquad \textbf{(25)}$$

Where

- V_{LP} denotes the inner volume of the liquid mixture line (m^3)
- Q_W^A and Q_O^A are the measured water and oil volume flow rates (m^3/h)

The liquid line is made of a 4inch pipe diameter, schedule 40, which translates to a 102mm ID. Its total length is 5530mm according to the distances measured on Figure 5. This gives a total line volume of:

$$V_{LP} = 0.0452 \text{ m}^3$$

From equation **(25)** it can be understood that the longest transit time is reached at the lowest oil and water flow rates. For instance, assuming $Q_W^A = 0.5$ m^3/h and $Q_O^A = 0.5$ m^3/h, the transit time for the multiphase mixture to reach the mixing section can be as high as 160 seconds.

5.1.2 Multiphase mixture

The time required for the multiphase mixture to reach the DUT from the mixing section ($t_{MP}^{3,6}$) can be approximated by assuming that all 3 phases are travelling at the same velocity (homogeneous multiphase flow) defined by the total volume flow rate:

$$\boldsymbol{t_{MP}^{3,6}} = \frac{\boldsymbol{V_{MP}^{3,6}}}{\boldsymbol{Q_G^A + Q_W^A + Q_O^A}} \qquad \textbf{(26)}$$

Where

- $V_{MP}^{3,6}$ denotes the inner volume of the multiphase mixture line, either 3 or 6 inch (m^3)
- Q_W^A and Q_O^A are the measured water and oil volume flow rates (m^3/h)
- $Q_G^A = \frac{q_G^A}{\rho_G^{P_M,T_M}}$ is the gas volumetric flow rate (m^3/h) given at the test section pressure (P_M)

If the 3 inch test line is selected, the line ID is 78mm and its total length is 7530mm according to the distances measured on Figure 5 and assuming the worst case location, i.e. when the DUT is mounted on the last test station. This gives a total line volume of:

$$V_{MP}^3 = 0.0360 \text{ m}^3$$

In case the test is carried out on the 6-inch test line, the line ID is 154mm and its total length 7530mm, leading to a total line volume of:

$$V_{MP}^6 = 0.1403 \text{ m}^3$$

At the minimum expected flow rates, i.e. $Q_O^A = 0.5$ m^3/h, $Q_W^A = 0.5$ m^3/h and $Q_G^A = 5$ m^3/h, the transit time required for the multiphase mixture to reach the DUT is around 20 seconds on the 3 inch test line and 80 seconds on the 6 inch line.

5.2 Quality assurance

The total transit time ($t_{MP} + t_{LP}$) is around 240s in the worst case, i.e. at the minimum gas, oil and water flow rates and when circulating through the 6 inch test line. To avoid any transient effect when switching to a new flow period, the data logger only starts recording the flow loop reference data and DUT data 300s after the new flow rates have been set. Besides, the stability of the DUT outputs, such as the oil, water and gas flow rates but also the differential pressure readings is also checked before starting to log a new flow period.

6 UNCERTAINTY STATEMENT

The reference measurements performed on the single phase lines have been detailed in the previous sections as well as the quality assurance capabilities enabled by the use of secondary reference meters and accurate fluid density models. This section establishes the flow loop overall uncertainty against which the DUT can be tested reliably. It also specifies the remedial actions that shall be taken in response to the quality indicators so as to guarantee a consistent metrology over time.

6.1 Uncertainty statement

The main outputs delivered by the flow loop acquisition system are the single phase mass flow rates (q_G^A, q_O^A, q_W^A) measured by the Coriolis flowmeters. In addition, the reference densities ($\rho_G^{P_M,T_M}, \rho_O^{P_M,T_M}, \rho_W^{P_M,T_M}$) can be provided to calculate the volume flow rates at the DUT location as long as a local temperature (T_M) and pressure (P_M) measurements are made available on the DUT. This is usually the case when testing MPFMs such as the Vx Spectra meters.

6.1.1 Contamination correction factors

Let's assume that a small portion of oil and gas are entrained in the water reference line and respectively a small amount of water and gas are present in the oil reference line. The net mass flow rates flowing through the DUT can be calculated as follows:

$$\boldsymbol{q_O^{NET} = q_O^A \,.\, (1 - wio - gio) + q_W^A \,.\, oiw + q_G^A \,.\, oig} \qquad \textbf{(27)}$$
$$\boldsymbol{q_W^{NET} = q_W^A \,.\, (1 - oiw - giw) + q_O^A \,.\, wio} \qquad \textbf{(28)}$$
$$\boldsymbol{q_G^{NET} = q_G^A \,.\, (1 - oig) + q_W^A \,.\, giw + q_O^A \,.\, gio} \qquad \textbf{(29)}$$

Note that the mass contamination ratios are used here instead of the previously introduced volume contamination ratios since these equations are based on mass flow rates. These equations can also be arranged as follows:

$$\boldsymbol{q_O^{NET} = \varepsilon_O . q_O^A} \quad \text{with} \quad \boldsymbol{\varepsilon_O = 1 - wio - gio + q_W^A/q_O^A \ oiw + q_G^A/q_O^A \ oig} \qquad \textbf{(30)}$$
$$\boldsymbol{q_W^{NET} = \varepsilon_W . q_W^A} \quad \text{with} \quad \boldsymbol{\varepsilon_W = 1 - oiw - giw + q_O^A/q_W^A \ wio} \qquad \textbf{(31)}$$
$$\boldsymbol{q_G^{NET} = \varepsilon_G . q_G^A} \quad \text{with} \quad \boldsymbol{\varepsilon_G = 1 - oig + q_W^A/q_G^A \ giw + q_O^A/q_G^A \ gio} \qquad \textbf{(32)}$$

The coefficients ε_O, ε_W and ε_G can be interpreted as mass-flow correction factors that shall be applied to the primary reference flow rates to compensate for the cross-contamination effects. Their amplitudes depend on the contamination levels but also on the ratio between the single phase mass flow rates. Based on oil and water samples analysis and liquid carry-over measurements, no visible traces of contamination have been detected in the flow loop reference lines over the whole range of oil, water and gas flow rates. The following contamination ratios are therefore considered conservative:

- $wio = oiw = 10^{-3}$ kg/kg
- $oig = 10^{-4}$ kg/kg
- $gio = giw = 10^{-5}$ kg/kg

The mass-flow correction factors depend on the ratios of single phase mass flow rates. It is hence possible to rewrite equations **(30)**, **(31)** and **(32)** by using the volumetric-flow-rate based Water-Liquid-

Ratio (WLR) and Gas-Volume-Fraction (GVF) notations, regardless of the oil, water or gas absolute flow rates:

$$\varepsilon_O = 1 - wio - gio + \left(\frac{WLR}{1-WLR}\right)\left(\frac{\rho_W^A}{\rho_O^A}\right) oiw + \frac{GVF}{(1-WLR).(1-GVF)}\left(\frac{\rho_G^A}{\rho_O^A}\right) oig$$
$$\varepsilon_W = 1 - oiw - giw + \left(\frac{1-WLR}{WLR}\right)\left(\frac{\rho_O^A}{\rho_W^A}\right) wio$$
$$\varepsilon_G = 1 - oig + WLR\left(\frac{1-GVF}{GVF}\right)\left(\frac{\rho_W^A}{\rho_G^A}\right) giw + (1-WLR)\left(\frac{1-GVF}{GVF}\right)\left(\frac{\rho_O^A}{\rho_G^A}\right) gio$$

The correction factors deviate significantly from 1 when either the WLR or GVF tends to 0% or 100%, in other words for heterogeneous mixtures of oil, water and gas where the contaminants in the main phase are more likely to affect the minor phase composition. However, in practice, except when running single phase tests where the WLR and GVF are naturally either 0% or 100%, the flow loop operates over a reduced range of WLR and GVF, which lessens the impact of potential cross-contamination, as shown in the following numerical application:

- $25\% \leq WLR \leq 75\%$
- $10\% \leq GVF \leq 99\%$

<u>Numerical application:</u>
Considering the following fluid densities,
- $\rho_O^A = 800$ kg/m³
- $\rho_W^A = 1000$ kg/m³
- $\rho_G^A = 23.4$ kg/m³ (estimated Nitrogen density at 20barg and 30°C)

The largest expected mass-flow correction factors are:
- $\varepsilon_O = 1.0039$ for $WLR = 75\%$ and $GVF = 99\%$
- $\varepsilon_W = 1.0014$ for $WLR = 25\%$ and any GVF
- $\varepsilon_G = 1.0036$ for $WLR = 75\%$ and $GVF = 10\%$

6.1.2 Expanded uncertainty

In principle and according to the GUM **[1]**, all sources of bias should be identified and corrected before evaluating measurement uncertainties. However, cross-contamination errors are not practical to assess over such a wide range of flow rates and pressures. As a result, instead of correcting the measurements for all these recognized potential effects, the uncertainty assigned to the results is enlarged in proportion, as per the F.2.4.5 recommendations of the GUM.

The uncertainty of the mass flow rates is the root-mean square combination of the Coriolis mass flow measurement expanded uncertainties at 95% confidence, $U(q_G^A)$, $U(q_O^A)$ and $U(q_W^A)$, as specified in Sections 2.3.1, 3.3.1 and 4.3.1, and the worst case mass-flow correction factors, ε_G, ε_O and ε_W, as estimated in Section 6.1.1:

$$\boldsymbol{U\,(q_G)/q_G = 0.65\%} \quad \textbf{(33)}$$
$$\boldsymbol{U\,(q_O)/q_O = 0.53\%} \quad \textbf{(34)}$$
$$\boldsymbol{U\,(q_W)/q_W = 0.38\%} \quad \textbf{(35)}$$

Densities are calculated from pure samples and thermodynamic models. They are therefore not subject to any correction factor due to cross-contamination effects. As calculated in Sections 2.2.3, 3.2.2 and 4.2.2, their expanded uncertainties at 95% confidence are:

$$U(\rho_G)/\rho_G = 0.48\% \tag{36}$$

$$U(\rho_O)/\rho_O = 0.26\% \tag{37}$$

$$U(\rho_W)/\rho_W = 0.18\% \tag{38}$$

Finally, the uncertainties of the volumetric flow rates can be derived from the uncertainties of the mass flow rates and corresponding densities at 95% confidence:

$$U(Q_G)/Q_G = 0.81\% \tag{39}$$

$$U(Q_O)/Q_O = 0.59\% \tag{40}$$

$$U(Q_W)/Q_W = 0.42\% \tag{41}$$

6.2 Quality assurance

The quality indicators defined in the previous sections are meant to monitor the agreement between the reference flow meters as well as the purity of the single phases. These indicators are not only a safeguard for the flow loop metrological performance but they also act as a decision-making support for the operator to trigger an anticipated maintenance of the devices which would start drifting from their rated performance.

6.2.1 Flow cross-checks

Three flow cross-checks indicators are available on the gas line at low **(6)**, medium **(7)** and large **(8)** flow rates, covering the whole range of gas flow rates. Likewise, on the oil and water lines, 2 flow indicators for low (**12** and **20**) and large (**13** and **21**) flow rates are defined, covering the whole range of oil and water flow rates. When any of these quality checks is not passed, the corresponding flowmeters shall be verified and eventually sent back for re-calibration.

6.2.2 Contamination checks

The single phase flow lines are continuously checked for cross-contaminations. The contamination indicators defined in **(9)**, **(14)**, **(16)**, **(22)** and **(24)** are used to detect potential separation issues. When any of these parameters deviate from its nominal value, the process conditions shall be checked and this operating point eventually discarded. On top of these contamination indicators, periodic sampling is performed on the single phase lines to verify the separation efficiency.

7 REFERENCES

Consult the latest valid version of each document referenced.

7.1 Normative References

Title	Document Number
1. Evaluation of measurement data — Guide to the expression of uncertainty in measurement	JCGM 100:2008
2. Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full - Part 1: General principles and requirements	ISO 5167-1:2003
3. The Petroleum Measurement Tables Volume Correction Factors Volume X	ASTM D 1250-80

7.2 Informative References

Title

4. R. Span, E.W. Lemnon, R.T. Jacobsen, and W. Wagner. ‘A reference quality equation of state for Nitrogen’ *International Journal of Thermophysics, 1998, 19(4) 1121-1132*
5. R. Battino, T.R. Rettich, T. Tominaga. ‘The solubility of Nitrogen and Air in Liquids’. *Journal of Physical and Chemical Reference Data, Vol 13, No. 2, 1984*
6. A.M. Rowe and J.C.S. Chou. ‘Pressure-Volume-Temperature-Concentration Relation of Aqueous NaCl solutions’. *Journal of Chemical and Engineering Data*, Vol 15, No. 1, 1970
7. The IAPWS formulation 1995 for the thermodynamics properties of ordinary water substance for general and scientific use. *J. Phys. Chem. Ref. Data, 2002,31,2,387-535*
8. Exxsol D80 datasheet
9. Shide Mao, Zhenhao Duan, ‘A thermodynamic model for calculating nitrogen solubility, gas phase composition and density of the N_2–H_2O–NaCl system’ . *Fluid Phase Equilibria 248 (2006) 103-114* http://models.kl-edi.ac.cn/models/h2o_n2_nacl/
10. Emerson MicroMotion ELITE Coriolis flowmeters datasheet http://www2.emersonprocess.com/siteadmincenter/PM%20Micro%20Motion%20Documents/ELITE-PDS-PS-00374.pdf

8 REVISION RECORD SUMMARY

Table 24: Document revision record summary table

Revision	Date	Remarks	Prepared By	Reviewed By	Approved By
AA	20-June-2016	First issue	D. CHAZAL		
AB	13-July-2016	Included CG.XIE comments	D.CHAZAL	CG.XIE	C.TOUSSAINT
AC	10-Oct-2016	Included NEL comments	C.TOUSSAINT	D.CHAZAL	D.CHAZAL
AD	10-Mar-2017	Included NEL audit findings	C.TOUSSAINT	D.CHAZAL	D.CHAZAL
AF	31-Aug-2017	Updated calibration certificates and revised flow loop uncertainty figures	C.TOUSSAINT	CG.XIE	G.JOLIVET

A INERTING AND PURGING PROCESS

To ensure the purest gas composition in the flow loop for metrology and safety purposes, a low vacuum is first drawn on the piping and vessels which are then filled with a high purity purge gas, typically Nitrogen. This purging / inerting process reduces the amount of unwanted chemical species that are initially contained in air, such as oxygen:

$$x_{i,air} = 21 \text{ mol\%}$$

However, the inerting gas which is essentially composed of Nitrogen (99.99%) also brings a small amount of impurities into the flow loop, at the below molar fraction:

$$x_{i,inerting} = 0.01 \text{ mol\%}$$

The molar fraction of species diluted in the flow loop in the final state is calculated assuming that the ideal gas law holds throughout the inerting / purging process. Besides, the internal volume (V) and temperature (T) of the flow loop are assumed to be constant.

<u>In the first state</u>, the internal volume of the piping and vessels contains air at atmospheric pressure and with a standard concentration of species of 21 mol%.

$$P(t_1) = 1 \text{ bara}$$

$$x_i(t_1) = x_{i,air} = 21 \text{ mol\%}$$

<u>In the second state</u>, after vacuum has been drawn by the vacuum pump, the pressure in the flow loop can be as low as 50 mbara, depending on the water temperature (lower temperatures result in lower vapor pressures). Assuming that the composition of air is uniform throughout the flow loop as the vacuum is drawn, then, the composition of the gas at state 2 is the same as at the initial state:

$$P(t_2) = P_L = 50 \text{ mbara}$$

$$x_i(t_2) = x_i(t_1) = \frac{n_i(t_2)}{n(t_2)} = \frac{n_i(t_2)RT}{P_L V}$$

Solving for the moles of the species present in the gas at the vacuum state:

$$n_i(t_2) = \frac{x_{i,air}\, P_L V}{RT} \tag{A1}$$

<u>In the third state</u>, the flow loop is filled with the inerting gas up to the final pressure, leading to the following total amount of gas in the flow loop:

$$P(t_3) = P_H$$

$$n(t_3) = \frac{P_H V}{RT} \tag{A2}$$

The total moles of purge gas added to the flow loop is simply:

$$\Delta n_{inerting} = n(t_3) - n(t_2) = \frac{(P_H - P_L)V}{RT}$$

Assuming that the composition of the inerting gas is constant during the filling process, the moles of species that are added to the flow loop via the inerting gas during the filling process is:

$$\Delta n_{i,inerting} = x_{i,inerting}.\Delta n_{inerting} \tag{A3}$$

Combining (A1), (A2) and (A3) yields the mole fraction of species present in the gas at the final state:

$$x_i(t_3) = \frac{n_i(t_3)}{n(t_3)} = \frac{n_i(t_2) + \Delta n_{i,inerting}}{n(t_3)}$$

i.e.

$$\boldsymbol{x_i(t_3) = x_{i,air}\left(\frac{P_L}{P_H}\right) + x_{i,inerting}\left(1 - \frac{P_L}{P_H}\right)}$$

Assuming a vacuum pressure of 50 mbara and a final pressure of 20bara, the mole fraction of impurities in the flow loop is around 0.06 mol%.

B CROSS-CONTAMINATION CALCULATIONS

This calculation note shows how to determine the water-in-oil (WIO), oil-in-water (OIW) or gas-in-oil (GIO) quantities from the measured and expected densities of the respective phases. Note that the oil-in-gas (OIG) or water-in-gas (WIG) contents cannot be estimated using this technique due to the lack of resolution of the gas density measurement.

Let M be the suffix of the main phase and C denote the contaminant phase. A small amount of C is assumed to be present in M due to an incomplete separation. The main phase Coriolis flow meter (q_M^A) measures the total amount of M and C flowing through the main phase line. We can therefore write the following conservation equations:

$$q_M^A = q_{M/M} + q_{C/M} \quad \text{for the mass flow rates}$$

$$\frac{q_M^A}{\rho_M^A} = \frac{q_{M/M}}{\rho_M^{P_M,T_M}} + \frac{q_{C/M}}{\rho_C^{P_M,T_M}} \quad \text{for the volume flow rates}$$

They can be solved for $q_{M/M}$ and $q_{C/M}$:

$$q_{M/M} = q_M^A \frac{\frac{1}{\rho_C^{P_M,T_M}} - \frac{1}{\rho_M^A}}{\frac{1}{\rho_C^{P_M,T_M}} - \frac{1}{\rho_M^{P_M,T_M}}} \quad \text{and} \quad q_{C/M} = q_M^A \frac{\frac{1}{\rho_M^A} - \frac{1}{\rho_M^{P_M,T_M}}}{\frac{1}{\rho_C^{P_M,T_M}} - \frac{1}{\rho_M^{P_M,T_M}}}$$

The contaminant-in-main phase (cim) **mass** ratio is determined by the ratio of contaminant mass flow in the main line $(q_{C/M})$ relative to the total liquid mass flow measured in the main line (q_M^A):

$$\boldsymbol{cim = \frac{\frac{1}{\rho_M^A} - \frac{1}{\rho_M^{P_M,T_M}}}{\frac{1}{\rho_C^{P_M,T_M}} - \frac{1}{\rho_M^{P_M,T_M}}}}$$

The respective volume flow rates $Q_{M/M}$ and $Q_{C/M}$ can also be derived:

$$Q_{M/M} = Q_M^A \frac{\rho_C^{P_M,T_M} - \rho_M^A}{\rho_C^{P_M,T_M} - \rho_M^{P_M,T_M}} \quad \text{and} \quad Q_{C/M} = Q_M^A \frac{\rho_M^A - \rho_M^{P_M,T_M}}{\rho_C^{P_M,T_M} - \rho_M^{P_M,T_M}}$$

The contaminant-in-main phase (CIM) **volume** ratio is determined by the ratio of contaminant volume flow in the main line $(Q_{C/M})$ relative to the total liquid flow measured in the main line (Q_M^A):

$$\boldsymbol{CIM = \frac{\rho_M^A - \rho_M^{P_M,T_M}}{\rho_C^{P_M,T_M} - \rho_M^{P_M,T_M}}}$$

C REFERENCE DATA LOGGING

The following table lists all the variables recorded by the flow loop historian and their corresponding sensor and software tags.

Variable	Tag name	Sensor Tag	Line	Description	Quantity	Unit
P_G	**P_gas**	FI1223	Gas	Reference pressure	Pressure	barg
q_G^A	**Qm_gas_A**	-	Gas	Primary reference flow - Aggregate	Mass flow rate	kg/h
q_G^{A1}	**Qm_gas_A1**	FIC1224	Gas	Primary reference flow meter - Large	Mass flow rate	kg/h
q_G^{A2}	**Qm_gas_A2**	FIC1226	Gas	Primary reference flow meter - Medium	Mass flow rate	kg/h
q_G^{A3}	**Qm_gas_A3**	FIC1228	Gas	Primary reference flow meter - Small	Mass flow rate	kg/h
q_G^B	**Qm_gas_B**	FI1223	Gas	Secondary reference flow meter - Large	Mass flow rate	kg/h
ρ_G^A	**Rho_gas_A**	-	Gas	Primary reference density - Aggregate	Fluid density	kg/m³
ρ_G^{A1}	**Rho_gas_A1**	FIC1224	Gas	Primary reference flow meter - Large	Fluid density	kg/m³
ρ_G^{A2}	**Rho_gas_A2**	FIC1226	Gas	Primary reference flow meter - Medium	Fluid density	kg/m³
ρ_G^{A3}	**Rho_gas_A3**	FIC1228	Gas	Primary reference flow meter - Small	Fluid density	kg/m³
$\rho_G^{P,T}$	**Rho_gas_PT**	-	Gas	Calculated density - from N2 EoS	Fluid density	kg/m³
T_G	**T_gas**	FI1223	Gas	Reference temperature	Temperature	°C
P_O	**P_oil**	PISH1330	Oil	Reference Pressure	Pressure	Barg
q_O^A	**Qm_oil_A**	-	Oil	Primary reference flow - Aggregate	Mass flow rate	kg/h
q_O^{A1}	**Qm_oil_A1**	FIC1318	Oil	Primary reference flow meter - Large	Mass flow rate	kg/h
q_O^{A2}	**Qm_oil_A2**	FIC1320	Oil	Primary reference flow meter - Small	Mass flow rate	kg/h
Q_O^B	**Qv_oil_B**	FI1317	Oil	Secondary reference flow meter - Large	Volume flow rate	m³/h
ρ_O^A	**Rho_oil_A**	-	Oil	Primary reference density - Aggregate	Fluid density	kg/m³
ρ_O^{A1}	**Rho_oil_A1**	FIC1318	Oil	Primary reference flow meter - Large	Fluid density	kg/m³
ρ_O^{A2}	**Rho_oil_A2**	FIC1320	Oil	Primary reference flow meter - Small	Fluid density	kg/m³
$\rho_O^{P,T}$	**Rho_oil_PT**	-	Oil	Calculated density - from model & sample	Fluid density	kg/m³
T_O	**T_oil**	TIC1314	Oil	Reference temperature	Temperature	°C
P_W	**P_water**	PISH1329	Water	Reference pressure	Pressure	Barg
q_W^A	**Qm_water_A**	-	Water	Primary reference flow - Aggregate	Mass flow rate	kg/h
q_W^{A1}	**Qm_water_A1**	FIC1311	Water	Primary reference flow meter - Large	Mass flow rate	kg/h
q_W^{A2}	**Qm_water_A2**	FIC1313	Water	Primary reference flow meter - Small	Mass flow rate	kg/h
Q_W^B	**Qv_water_B**	FI1310	Water	Secondary reference flow meter - Large	Volume flow rate	m³/h
ρ_W^A	**Rho_water_A**	-	Water	Primary reference density - Aggregate	Fluid density	kg/m³
ρ_W^{A1}	**Rho_water_A1**	FIC1311	Water	Primary reference flow meter - Large	Fluid density	kg/m³
ρ_W^{A2}	**Rho_water_A2**	FIC1313	Water	Primary reference flow meter - Small	Fluid density	kg/m³
$\rho_W^{P,T}$	**Rho_water_PT**	-	Water	Calculated density - from model & sample	Fluid density	kg/m³
T_W	**T_water**	TIC1307	Water	Reference Temperature	Temperature	°C
dP_{MP}^3	**dP_mix_3**	dP1403	MP	3 inch reference differential pressure	Diff. pressure	mbar
P_{MP}^3	**P_mix_3**	PIC1404	MP	3 inch reference pressure	Pressure	Barg
dP_{MP}^6	**dP_mix_6**	dP1405	MP	6 inch reference differential pressure	Diff. pressure	mbar
P_{MP}^6	**P_mix_6**	PIC1406	MP	6 inch reference pressure	Pressure	barg
P_{Sep}	**P_separator**	PISH1111	MP	Separator reference pressure	Pressure	barg
T_{Sep}	**T_separator**	TI1110	MP	Separator reference temperature	Temperature	°C

D REFERENCE FLOW METERS OPERATING RANGES

The below bar charts show the operating envelopes of the primary and secondary reference flow meters for each single phase line. The colour coding is the following:

- Green: accuracy within specified tolerances and low pressure drop (< 0.5bar)
- Orange: moderately degraded accuracy (between 1 and 2 times the specified accuracy) or moderate pressure drop (between 0.5 and 1 bar)
- Red: degraded accuracy (between 2 to 5 times the specified accuracy) or excessive pressure drop (between 1 and 2 bar)

In addition, for each single phase fluid, the most important characteristic of the fluid with respect to the flow meter's performance is varied in order to verify the operating envelope over all possible operating conditions.

Data extracted from Rosemount's Instrument Toolkit, Version 3.0.
Fluid temperature: 30 °C, Ambient temperature: 30 °C

D-1 Gas line

The gas reference flow meters envelopes are mostly sensitive to the operating pressure. The following envelopes are determined at different operating pressures ranging from the maximum (40bar) to the minimum (3bar) expected operating pressures.

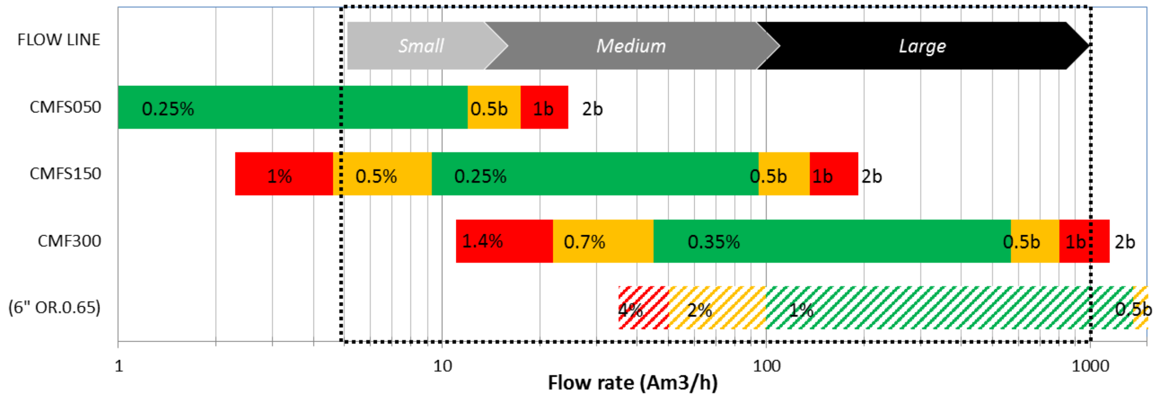

Figure 6 Gas flow meters measuring ranges for a **40 bar** operating pressure.

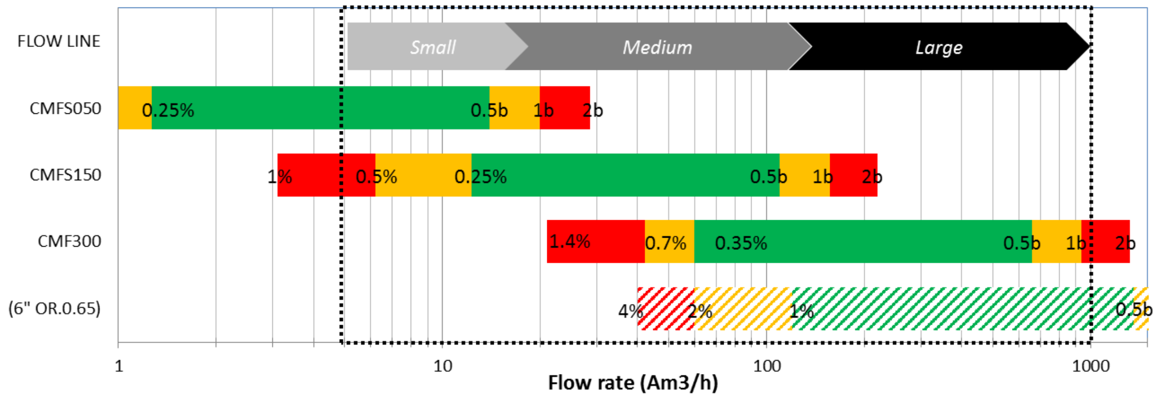

Figure 7 Gas flow meters measuring ranges for a **30 bar** operating pressure.

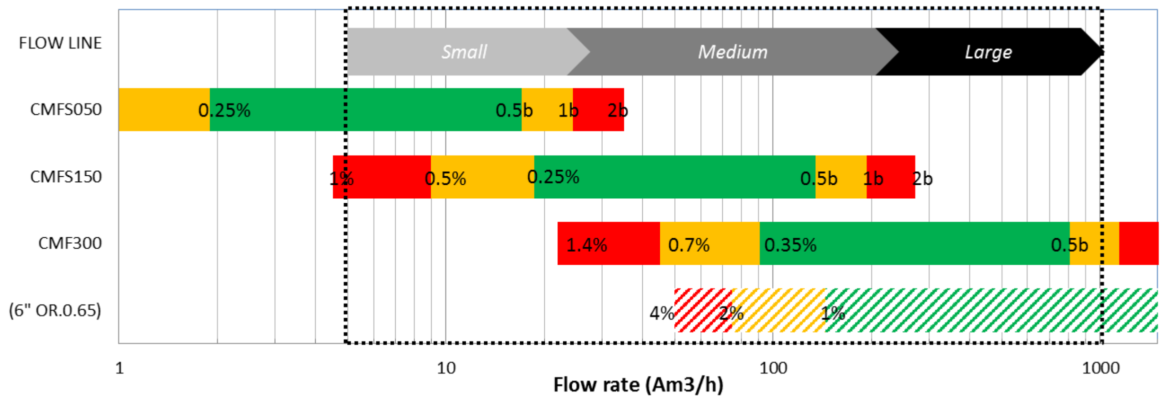

Figure 8 Gas flow meters measuring ranges for a **20 bar** operating pressure.

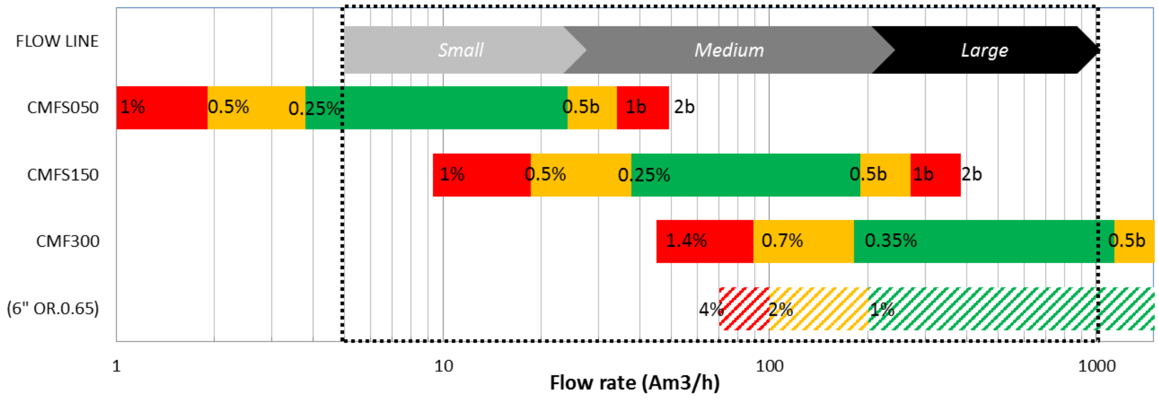

Figure 9 Gas flow meters measuring ranges for a **10 bar** operating pressure.

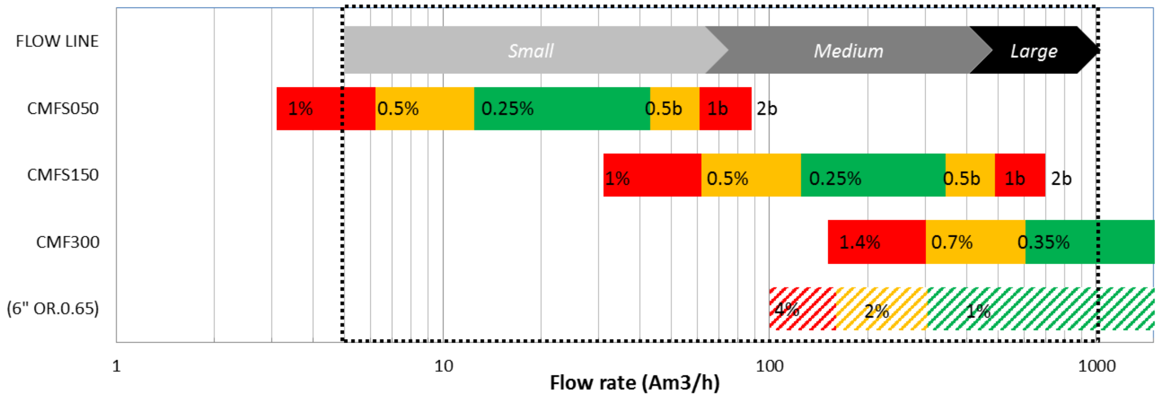

Figure 10 Gas flow meters measuring ranges for a **3 bar** operating pressure.

D-2 Oil line

The oil flow meters performance will essentially be affected by the oil viscosity. The following Figures show the flow meters envelopes in the light oil case (default) and highest viscosity case. It must be noted that the Vortex flow meter can only be used in the first case.

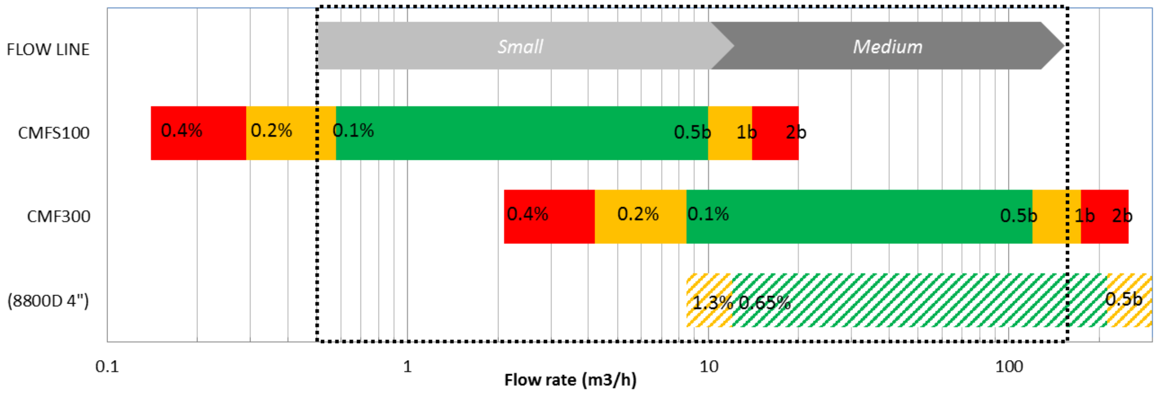

Figure 11 Oil flow meters ranges for EXXSOL D80 (795 kg/m^3, 2 cSt)

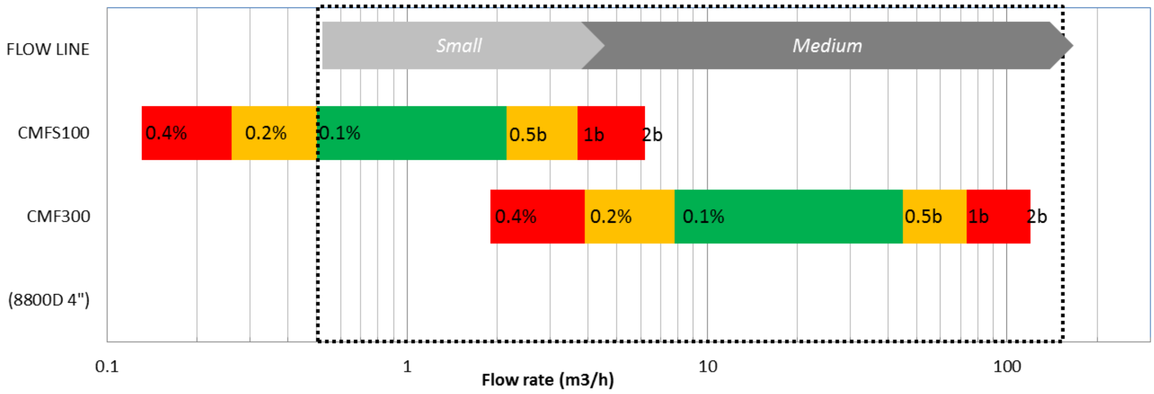

Figure 12 Oil flow meters ranges for a Viscous oil (875 kg/m^3, 300 cSt)

D-3 Water line

The parameter of interest for the water phase is the water salinity. The following envelopes are therefore calculated in the Fresh water case and saturated brine case.

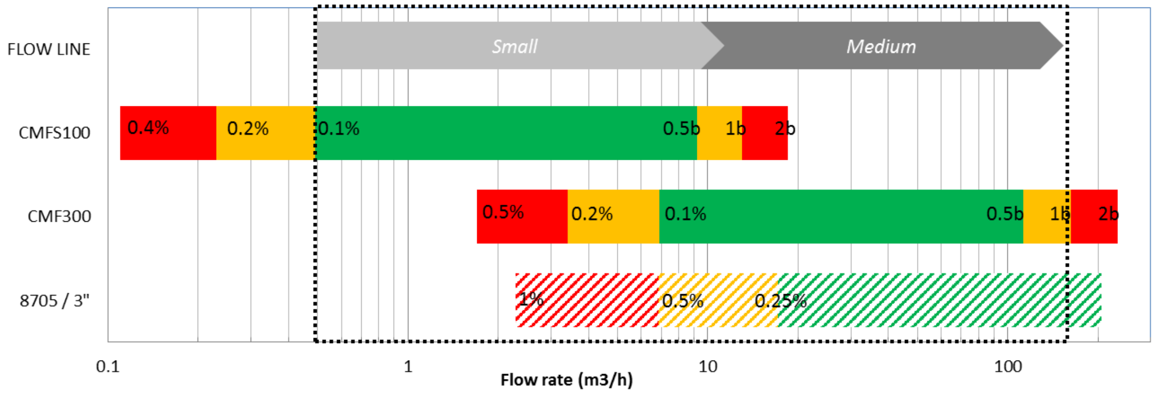

Figure 13 Water flow meters envelopes for Fresh water (997 kg/m^3)

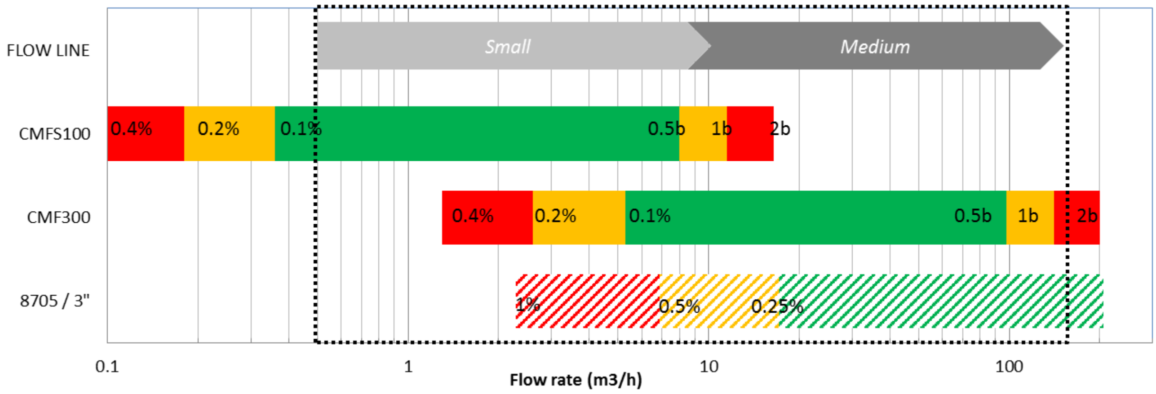

Figure 14 Water flow meters envelopes for saturated brine (1280 kg/m^3)

E CALIBRATION CERTIFICATES

E-1 FIC 1224 Gas Coriolis flowmeter (A1) – 4 Jan 2017

FIC 1224 Source	Units	Value	Expanded Uncertainty Abs	(%)	Probability	Divisor	Std	Sens.	Variance	Ref.
Calibration	kg/s	3	0.0105	0.350	Normal(95%)	1.96	0.005	1	2.870E-05	[1]
Repeatability	kg/s	3	0.0053	0.175	Normal(95%)	1.96	0.003	1	7.175E-06	[1]
Zero Stability	kg/s	3	0.0015	0.050	Rectangular	1.73	0.001	1	7.518E-07	[1]
Drift	kg/s	3	0.0100	0.333	Rectangular	1.73	0.006	1	3.341E-05	[2]
Installation effect	kg/s	3	0.0011	0.035	Rectangular	1.73	0.001	1	3.684E-07	[3]
RFI	Kg/s	3	0.0011	0.035	Rectangular	1.73	0.001	1	3.684E-07	[3]
Line pressure variation	kg/s	3	0.0003	0.009	Normal(95%)	1.93	0.000	1	1.957E-08	[1]
Mass Flow Uncertainty	**kg/s**	**3**	**0.55**	**0.55**	**Normal(95%)**	**1.96**	**0.008**	**1**	**7.0791E-05**	

Ref:
[1]: MicroMotion Product Datasheet PS-00374 Rev AD, www.emerson.com
[2]: NEL data, based on return of experience
[3]: NEL data, based on return of experience

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ilac-MRA   SAC-SINGLAS ACCREDITED LABORATORY

ISO\IEC 17025 Accredited Calibration Certificate: 8.00001994

Model Code	Serial ID	Order ID	Line	Item	Customer Tag
CMF300M426NQBMEZZZ	13082787	31031233	12.1	1	FIC-1224
CP 700	30091355	31031233	2.1	-	FIC-1224
Comments:	Calibration done using stand transmitter				

Calibration Information	
Date / Time:	2016.12.25 12:46:00
Calibration Stand:	FLC2A
Fluid:	H2O
Mass Uncertainty (%):	0.050
Density Uncertainty (kg/m³):	0.15
Volume Uncertainty (%):	0.053
Max Rate P/T (kPa/°C)	168.91 / 21.54
	CORIOLIS ISO/IEC 17025 VERIFY

The reported expanded uncertainties (U_{95}) are based on the combined uncertainty multiplied by a coverage factor k =2, which provides a confidence level of approximately 95%. All uncertainties have been determined in accordance with the GUM and EA 04/2.

Calibration Constants			
D1:	0.00000	FCF:	710.18
D2:	1.00000	FT:	4.45
K1:	10521.54	Flow Cal:	710.184.45
K2:	12470.14	Mass MF:	1.00000
DT:	4.45	Zero (µsec):	0.066
FD:	219.2517	DTG:	0.00
Dens Cal:	10522124704.45	DFQ1:	0.00
Dens MF:	1.00000	DFQ2:	0.00
		FFQ:	0.00
Vol MF:	1.00000	FTG:	0.00
	Mass Flow cut-off (kg/min):		1.0000

This calibration was performed by comparison to a reference meter,(dynamic start/stop reference meter method) as described in ISO 10790:1999(E) "Measurement of fluid flow in closed conduits – Guidance to the selection, installation and use of Coriolis meters (mass flow, density and volume flow measurements)", Annex A "Calibration techniques", and the internal accredited product calibration procedure LWI S-21.

The results reported herein have been performed in accordance with the laboratory's term of accreditation under the Singapore Accreditation Council.

These measurements have been made using the calibration stand listed above, which is traceable to one or more of the following National Metrology Institutes: NIM-China, NIST-USA, and VSL-The Netherlands.

The processes used to obtain these calibration results comply with the requirements of ISO/IEC 17025:2005.

UUT Avg Results - Mass ☑ AS FOUND ☑ AS LEFT

Mass Rate (kg/min)	Fluid Pressure (kPa)	Fluid Temp (°C)	Mass Total (kg)	Mass Diff (%)	Rpts (n)	u_A Mean (%)	U_{95} (%)	Spec. (%)
226.361	80.93	21.62	226.796	0.0058	3	0.0036	0.051	0.100
1127.64	180.6	21.47	1127.89	-0.0028	3	0.0040	0.051	0.100
2243.24	168.9	21.54	2243.21	-0.0053	3	0.0048	0.051	0.100

UUT Avg Results - Density

Mass Rate (kg/min)	Fluid Pressure (kPa)	Fluid Temp (°C)	Density (kg/m³)	Density Diff (kg/m³)	Rpts (n)	u_A Mean (kg/m³)	U_{95} (kg/m³)	Spec. (kg/m³)
226.361	80.93	21.62	997.948	-0.12	3	0.0061	0.16	0.500
1127.64	180.6	21.47	997.983	-0.16	3	0.0091	0.16	0.500
2243.24	168.9	21.54	998.043	-0.082	3	0.022	0.16	0.500

UUT Avg Results - Volume

Volume Rate (l/min)	Fluid Pressure (kPa)	Fluid Temp (°C)	Volume Total (l)	Volume Diff (%)	Rpts (n)	u_A Mean (%)	U_{95} (%)	Spec. (%)
226.826	80.93	21.62	227.236	0.0058	3	0.0036	0.054	0.112
1129.92	180.6	21.47	1129.99	-0.0028	3	0.0040	0.054	0.112
2247.64	168.9	21.54	2247.43	-0.0053	3	0.0048	0.054	0.112

EMERSON PROCESS MANAGEMENT FLOW TECHNOLOGIES CO., LTD. Quality Assurance Approved

Calibration Operator 2017.1.4
Aravind Date

Cal & Quality Manager
Gui Wenhao 2017.1.4
Wenhao Gui Date

Emerson Process Management Southeast Asia Service Center
No. 9 Gul Road #01-01 Singapore 629361

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E-2 FIC 1226 Gas Coriolis flowmeter (A2) – 4 Jan 2017

FIC 1226 Source	Units	Value	Expanded Uncertainty Abs	Expanded Uncertainty (%)	Probability	Divisor	Std	Sens.	Variance	Ref.
Calibration	kg/s	1	0.0025	0.250	Normal(95%)	1.96	0.002	1	3.189E-06	[1]
Repeatability	kg/s	1	0.0018	0.175	Normal(95%)	1.96	0.001	1	7.972E-07	[1]
Zero Stability	kg/s	1	0.0005	0.050	Rectangular	1.73	0.000	1	8.353E-08	[1]
Drift	kg/s	1	0.0033	0.333	Rectangular	1.73	0.002	1	3.712E-06	[2]
Installation effect	kg/s	1	0.0004	0.035	Rectangular	1.73	0.000	1	4.093E-08	[3]
RFI	Kg/s	1	0.0004	0.035	Rectangular	1.73	0.000	1	4.093E-08	[3]
Line pressure variation	kg/s	1	0.0001	0.009	Normal(95%)	1.93	0.000	1	2.175E-09	[1]
Mass Flow Uncertainty	**kg/s**	**1**	**0.01**	**0.50**	**Normal(95%)**	**1.96**	**0.003**	**1**	**6.304E-06**	

Ref:
[1]: MicroMotion Product Datasheet PS-00374 Rev AD, www.emerson.com
[2]: NEL data, based on return of experience
[3]: NEL data, based on return of experience

EMERSON
Process Management

ilac-MRA   ACCREDITED LABORATORY SAC-SINGLAS

ISO\IEC 17025 Accredited Calibration Certificate: 8.00001991

Model Code	Serial ID	Order ID	Line	Item	Customer Tag
CMFS150M419N2BMEKZZ	12103625	31031233	11.1	1	FIC-1226
ECP 800	33088005	31031233	_	_	FIC-1226
Comments:	Calibration done using Stand Transmitter				

Calibration Information	
Date / Time:	2016.12.24 19:13:00
Calibration Stand:	FLC2A
Fluid:	H2O
Mass Uncertainty (%):	0.050
Density Uncertainty (kg/m³):	0.15
Volume Uncertainty (%):	0.053
Max Rate P/T (kPa/°C)	271.03 / 21.84
	CORIOLIS ISO/IEC 17025 VERIFY

The reported expanded uncertainties (U_{95}) are based on the combined uncertainty multiplied by a coverage factor k=2, which provides a confidence level of approximately 95%. All uncertainties have been determined in accordance with the GUM and EA 04/2.

Calibration Constants			
D1:	0.00000	FCF:	675.04
D2:	1.00000	FT:	4.34
K1:	3283.15	Flow Cal:	675.044.34
K2:	3908.00	Mass MF:	1.00000
DT:	4.34	Zero (µsec):	-0.003
FD:	3256.0000	DTG:	0.00
Dens Cal:	328339084.34	DFQ1:	0.00
Dens MF:	1.00000	DFQ2:	0.00
		FFQ:	0.00
Vol MF:	1.00000	FTG:	0.00
Mass Flow cut-off (kg/min):			0.1000

This calibration was performed by comparison to a reference meter (dynamic start/stop reference meter method) as described in ISO 10790:1999(E) "Measurement of fluid flow in closed conduits – Guidance to the selection, installation and use of Coriolis meters (mass flow, density and volume flow measurements)", Annex A "Calibration techniques", and the internal accredited product calibration procedure LWI S-21.

The results reported herein have been performed in accordance with the laboratory's term of accreditation under the Singapore Accreditation Council.

These measurements have been made using the calibration stand listed above, which is traceable to one or more of the following National Metrology Institutes: NIM-China, NIST-USA, and VSL-The Netherlands.

The processes used to obtain these calibration results comply with the requirements of ISO/IEC 17025:2005.

UUT Avg Results - Mass   ☑ AS FOUND   ☐ AS LEFT

Mass Rate (kg/min)	Fluid Pressure (kPa)	Fluid Temp (°C)	Mass Total (kg)	Mass Diff (%)	Rpts (n)	u_A Mean (%)	U_{95} (%)	Spec. (%)
36.3580	63.24	21.73	36.3585	-0.066	3	0.0031	0.051	0.100
182.406	74.58	21.79	182.364	-0.029	3	0.0031	0.051	0.100
364.923	271.0	21.84	365.077	-0.058	3	0.0017	0.051	0.100

UUT Avg Results - Density

Mass Rate (kg/min)	Fluid Pressure (kPa)	Fluid Temp (°C)	Density (kg/m³)	Density Diff (kg/m³)	Rpts (n)	u_A Mean (kg/m³)	U_{95} (kg/m³)	Spec. (kg/m³)
36.3580	63.24	21.73	998.651	0.62	3	0.041	0.18	0.500
182.406	74.58	21.79	998.705	0.68	3	0.013	0.16	0.500
364.923	271.0	21.84	998.575	0.47	3	0.019	0.16	0.500

UUT Avg Results - Volume

Volume Rate (l/min)	Fluid Pressure (kPa)	Fluid Temp (°C)	Volume Total (l)	Volume Diff (%)	Rpts (n)	u_A Mean (%)	U_{95} (%)	Spec. (%)
36.4071	63.24	21.73	36.4302	-0.066	3	0.0031	0.054	0.112
182.642	74.58	21.79	182.725	-0.029	3	0.0031	0.054	0.112
365.444	271.0	21.84	365.771	-0.058	3	0.0017	0.054	0.112

EMERSON MEASUREMENT FLOW TECHNOLOGIES CO., LTD. Quality Assurance Approved

Calibration Operator   2017.1.4
Aravind   Date

Cal & Quality Manager Gui Wenhao   2017.1.4
Wenhao Gui   Date

Emerson Process Management Southeast Asia Service Center
No. 9 Gul Road #01-01;Singapore 629361

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Process Management

ilac-MRA
ACCREDITED LABORATORY SAC-SINGLAS

ISO\IEC 17025 Accredited Calibration Certificate: 8.00001992

Model Code	Serial ID	Order ID	Line	Item	Customer Tag
CMFS150M419N2BMEKZZ	12103625	31031233	11.1	1	FIC-1226
ECP 800	33088005	31031233	_	_	FIC-1226
Comments:	Calibration done using Stand Transmitter				

Calibration Information	
Date / Time:	2016.12.24 19:46:00
Calibration Stand:	FLC2A
Fluid:	H2O
Mass Uncertainty (%):	0.050
Density Uncertainty (kg/m³):	0.15
Volume Uncertainty (%):	0.053
Max Rate P/T (kPa/°C)	271.12 / 21.92
CORIOLIS ISO/IEC 17025 VERIFY	

The reported expanded uncertainties (U_{95}) are based on the combined uncertainty multiplied by a coverage factor k=2, which provides a confidence level of approximately 95%. All uncertainties have been determined in accordance with the GUM and EA 04/2.

Calibration Constants			
D1:	0.00000	FCF:	675.04
D2:	1.00000	FT:	4.34
K1:	3282.35	Flow Cal:	675.044.34
K2:	3908.45	Mass MF:	1.00000
DT:	4.34	Zero (µsec):	-0.003
FD:	3256.0000	DTG:	0.00
Dens Cal:	328239084.34	DFQ1:	0.00
Dens MF:	1.00000	DFQ2:	0.00
		FFQ:	0.00
Vol MF:	1.00000	FTG:	0.00
Mass Flow cut-off (kg/min):			0.1000

This calibration was performed by comparison to a reference meter (dynamic start/stop reference meter method) as described in ISO 10790:1999(E) "Measurement of fluid flow in closed conduits – Guidance to the selection, installation and use of Coriolis meters (mass flow, density and volume flow measurements)", Annex A "Calibration techniques", and the internal accredited product calibration procedure LWI S-21.

The results reported herein have been performed in accordance with the laboratory's term of accreditation under the Singapore Accreditation Council.

These measurements have been made using the calibration stand listed above, which is traceable to one or more of the following National Metrology Institutes: NIM-China, NIST-USA, and VSL-The Netherlands.
The processes used to obtain these calibration results comply with the requirements of ISO/IEC 17025:2005.

UUT Avg Results - Mass ☐ AS FOUND ☑ AS LEFT

Mass Rate (kg/min)	Fluid Pressure (kPa)	Fluid Temp (°C)	Mass Total (kg)	Mass Diff (%)	Rpts (n)	u_A Mean (%)	U_{95} (%)	Spec. (%)
36.4813	64.15	21.89	36.4884	-0.087	3	0.0022	0.051	0.100
182.306	75.13	21.87	182.263	-0.034	3	0.0042	0.051	0.100
364.978	271.1	21.92	365.155	-0.053	3	0.0075	0.053	0.100

UUT Avg Results - Density

Mass Rate (kg/min)	Fluid Pressure (kPa)	Fluid Temp (°C)	Density (kg/m³)	Density Diff (kg/m³)	Rpts (n)	u_A Mean (kg/m³)	U_{95} (kg/m³)	Spec. (kg/m³)
36.4813	64.15	21.89	997.822	-0.18	3	0.022	0.16	0.500
182.306	75.13	21.87	997.878	-0.13	3	0.022	0.16	0.500
364.978	271.1	21.92	997.751	-0.34	3	0.010	0.16	0.500

UUT Avg Results - Volume

Volume Rate (l/min)	Fluid Pressure (kPa)	Fluid Temp (°C)	Volume Total (l)	Volume Diff (%)	Rpts (n)	u_A Mean (%)	U_{95} (%)	Spec. (%)
36.5609	64.15	21.89	36.5616	-0.087	3	0.0022	0.054	0.112
182.693	75.13	21.87	182.627	-0.034	3	0.0042	0.054	0.112
365.801	271.1	21.92	365.855	-0.053	3	0.0075	0.056	0.112

EMERSON PROCESS MANAGEMENT FLOW TECHNOLOGIES CO., LTD. Quality Assurance Approved

Calibration Operator
2017.1.4
Aravind Date

Cal & Quality Manager
Gui Wenhao
2017.1.4
Wenhao Gui Date

Emerson Process Management, Southeast Asia Service Center
No. 9 Gul Road #01-01, Singapore 629361

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E-3 FIC 1228 Gas Coriolis flowmeter (A3) – 4 Jan 2017

FIC 1226 Source	Units	Value	Expanded Uncertainty Abs	Expanded Uncertainty (%)	Probability	Divisor	Std	Sens.	Variance	Ref.
Calibration	kg/h	360	0.900	0.250	Normal(95%)	1.96	0.643	1	2.108E-01	[1]
Repeatability	kg/h	360	0.630	0.175	Normal(95%)	1.96	0.321	1	1.033E-01	[1]
Zero Stability	kg/h	360	0.180	0.050	Rectangular	1.73	0.104	1	1.083E-02	[1]
Drift	kg/h	360	1.200	0.333	Rectangular	1.73	0.694	1	4.811E-01	[2]
Installation effect	kg/h	360	0.126	0.035	Rectangular	1.73	0.073	1	5.305E-03	[3]
RFI	kg/h	360	0.126	0.035	Rectangular	1.73	0.073	1	5.305E-03	[3]
Line pressure variation	kg/h	360	0.032	0.009	Normal(95%)	1.93	0.017	1	2.818E-04	[1]
Mass Flow Uncertainty	**kg/h**	**360**	**1.98**	**0.50**	**Normal(95%)**	**1.96**	**0.904**	**1**	**8.170E-01**	

Ref:
[1]: Micromotion Product Datasheet PS-00374 Rev AD, www.emerson.com
[2]: NEL data, based on return of experience
[3]: NEL data, based on return of experience

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Process Management

ilac-MRA SAC-SINGLAS ACCREDITED LABORATORY

ISO\IEC 17025 Accredited Calibration Certificate: 8.00001990

Model Code	Serial ID	Order ID	Line	Item	Customer Tag
CMFS050M314N2BMEKZZ	12103821	31031233	10.1	1	FIC-1228
ECP 800	33088070	31031233	10.1	-	FIC-1228
Comments:					

Calibration Information

Date / Time:	2016.12.24 17:48:00
Calibration Stand:	FLC2A
Fluid:	H2O
Mass Uncertainty (%):	0.050
Density Uncertainty (kg/m³):	0.15
Volume Uncertainty (%):	0.053
Max Rate P/T (kPa/°C)	387.4 / 21.76

The reported expanded uncertainties (U_{95}) are based on the combined uncertainty multiplied by a coverage factor k=2, which provides a confidence level of approximately 95%. All uncertainties have been determined in accordance with the GUM and EA 04/2.

Calibration Constants

D1:	0.00000	FCF:	49.981
D2:	1.00000	FT:	4.55
K1:	4830.27	Flow Cal:	49.9814.55
K2:	5753.21	Mass MF:	1.00000
DT:	4.40	Zero (µsec):	-0.013
FD:	1922.0000	DTG:	0.00
Dens Cal:	483057534.4	DFQ1:	0.00
Dens MF:	1.00000	DFQ2:	0.00
		FFQ:	0.00
Vol MF:	1.00000	FTG:	0.00
Mass Flow cut-off (kg/min):			0.0100

This calibration was performed by comparison to a reference meter (dynamic start/stop reference meter method) as described in ISO 10790:1999(E) "Measurement of fluid flow in closed conduits – Guidance to the selection, installation and use of Coriolis meters (mass flow, density and volume flow measurements)", Annex A "Calibration techniques", and the internal accredited product calibration procedure LWI S-21.

The results reported herein have been performed in accordance with the laboratory's term of accreditation under the Singapore Accreditation Council.

These measurements have been made using the calibration stand listed above, which is traceable to one or more of the following National Metrology Institutes: NIM-China, NIST-USA, and VSL-The Netherlands.
The processes used to obtain these calibration results comply with the requirements of ISO/IEC 17025:2005.

UUT Avg Results - Mass ☑ AS FOUND ☑ AS LEFT

Mass Rate (kg/min)	Fluid Pressure (kPa)	Fluid Temp (°C)	Mass Total (kg)	Mass Diff (%)	Rpts (n)	u_A Mean (%)	U_{95} (%)	Spec. (%)
5.52483	165.7	21.45	5.52856	0.066	3	0.0047	0.051	0.100
28.3949	216.5	21.42	28.3998	0.022	3	0.00065	0.051	0.100
57.0444	387.4	21.76	57.0450	-0.0024	3	0.0040	0.051	0.100

UUT Avg Results - Density

Mass Rate (kg/min)	Fluid Pressure (kPa)	Fluid Temp (°C)	Density (kg/m³)	Density Diff (kg/m³)	Rpts (n)	u_A Mean (kg/m³)	U_{95} (kg/m³)	Spec. (kg/m³)
5.52483	165.7	21.45	998.551	0.41	3	0.024	0.16	0.500
28.3949	216.5	21.42	998.551	0.38	3	0.0037	0.16	0.500
57.0444	387.4	21.76	998.209	0.031	3	0.023	0.16	0.500

UUT Avg Results - Volume

Volume Rate (l/min)	Fluid Pressure (kPa)	Fluid Temp (°C)	Volume Total (l)	Volume Diff (%)	Rpts (n)	u_A Mean (%)	U_{95} (%)	Spec. (%)
5.53284	165.7	21.45	5.53885	0.066	3	0.0047	0.054	0.112
28.4361	216.5	21.42	28.4519	0.022	3	0.00065	0.054	0.112
57.1467	387.4	21.76	57.1491	-0.0024	3	0.0040	0.054	0.112

EMERSON PROCESS MANAGEMENT FLOW TECHNOLOGIES CO., LTD. Quality Assurance Approved

Calibration Operator
K.Karthik — 04-01-2017 Date

Cal & Quality Manager
Gui Wenhao
Wenhao Gui — 2017.1.4 Date

Emerson Process Management Southeast Asia Service Center
No. 9 Gul Road #01-01 Singapore 629361

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E-4 FIC 1223 Gas Orifice plate flow meter, P and T (B1) – 31 Dec 2016

EMERSON.

Emerson Automation Solutions
Emerson Process Management
Asia Pacific Private Limited
Southeast Asia Service Centre
9 Gul Road, #01-01
Singapore 629361

T 65 6363 7766
F 65 6770 8006
Company Reg. No.: 196500174M

CALIBRATION REPORT / TEST REPORT

Customer Information	Manufacturer Information
Name: SCHLUMBERGER OILFIELD S PTE LTD	Support Request: 1961412462
Device Information	**Calibration Information**
Device Type: Differential Pressure Flow Transmitter	Factory: Singapore
Tag No: FI-1223	Station Name: SGRMT_CAL
Serial No:03173818	Operator ID: 328391
Model No: 3051SFC1CS060N065T33JAIA3Q4M5T1	Calibration Date: 31 Dec 2016
Output Type: Linear	

Equipment Used:

EQUIPMENT NAME	SERIAL NO.	CAL. DUE DATE
Multimeter	27200029	29-Sep-17
Pressure Calibrator	2564-400873	4-Aug-17
Pressure Calibrator	1608020	2-Aug-17
Resistance Decade Box	4671	4-Aug-17

Calibration Data:

DP Range: 0 to 62.16 Kpa

% of Range	Applied Input (Kpa)	Desired Output (mA)	Measured Output (mA)	Measured Output (Kpa)	% Span Error
0%	0	4.000	4.000	0	0.000
25%	15.54	8.000	8.000	15.56	0.000
50%	31.08	12.000	12.001	31.09	0.006
75%	46.62	16.000	16.001	46.63	0.006
100%	62.16	20.000	19.999	62.16	-0.006

SP Range: 0 to 55.16 BarG

% of Range	Applied Input (BarG)	Desired Output (mA)	Measured Output (mA)	Measured Output (Barg)	% Span Error
0%	0.00	4.000	4.000	0.00	0.000
25%	13.79	8.000	7.999	13.78	-0.006
50%	27.58	12.000	11.999	27.58	-0.006
75%	41.37	16.000	16.000	41.37	0.000
100%	55.16	20.000	20.001	55.16	0.006

ROSEMOUNT

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FY17-0054

EMERSON

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Emerson Process Management
Asia Pacific Private Limited
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9 Gul Road, #01-01
Singapore 629361

T 65 6363 7766
F 65 6770 8006
Company Reg. No.: 196500174M

Temperature Range: -50 to 250 Deg C

% of Range	Applied Input		Desired Output (mA)	Measured Output (mA)	Measured Output (Deg C)	% Span Error
	Deg C	OHM				
0%	-50	80.307	4.000	3.999	-49.98	-0.006
25%	25	109.735	8.000	7.989	24.92	-0.069
50%	100	138.505	12.000	12.000	100.06	0.000
75%	175	166.627	16.000	15.991	174.86	-0.056
100%	250	194.098	20.000	19.995	249.93	-0.031

This is to certify that the listed product meets the applicable Rosemount Specifications. Measuring and test equipment used in the calibration and inspection of the listed product are traceable to the National Institute of Standards and Technology.

MOHD ME SULAIMAN	SELVAN VAJRAVELU	VINCENT ZHAO
SERVICE MANAGER	SERVICE SUPERVISOR	SERVICE ENGINEER

ROSEMOUNT

Page 2 of 2

FY17-0054

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E-5 EXXSOL D80 sample analysis report – 15 Dec 2015

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Tel : (65) 6863 4633
Fax : (65) 6863 3113

Co. Reg No.: 198500411W GST Reg No.: M2-0069439-2

CERTIFICATE OF ANALYSIS

Product : EXXSOL D80 FLUID
Lot / Batch : S15041511B
TS Ref No: C15-487
Manufacturer: ExxonMobil Chemical

Issued Date : 15 DEC 2015
Sample Date : 15 DEC 2015
Inspection Ref.: 0000012223234

ANALYSIS

Property	Method	Units	Specification	Results
APPEARANCE	VISUAL	-	BRIGHT & CLEAR	BRIGHT & CLEAR
AROMATICS BY UV	AMS 140.31	wt%	0.5 Max	<0.1
COLOUR, SAYBOLT	ASTM D156	-	+ 30 Min	+ 30
INITIAL BOILING POINT	ASTM D86	°C	200 Min	200
DISTILLATION TEMPERATURE, DP	ASTM D86	°C	250 Max	239
TOTAL SULPHUR	ASTM D5453	wppm	1 Max	< 1 #
FLASH POINT - PMCC	ASTM D93	°C	75 Min	78

Tests marked # are periodic values. They are not tested on each batch.

Remarks: This Certificate of Analysis is computer generated. No signature is required.

Issued by: Madein Toh
QA/QC Supervisor

E-6 Handheld densitometer calibration certificate

E-7 FIC 1318 Oil Coriolis flow meter (A1) – 04 Jan 2017

FIC 1318 Source	Units	Value	Expanded Uncertainty Abs	Expanded Uncertainty (%)	Probability	Divisor	Std	Sens.	Variance	Ref.
Calibration	kg/s	500	0.50	0.100	Normal(95%)	1.96	0.255	1	6.508E-02	[1]
Repeatability	kg/s	500	0.25	0.050	Normal(95%)	1.96	0.128	1	1.627E-02	[1]
Zero Stability	kg/s	500	0.25	0.050	Rectangular	1.73	0.145	1	2.088E-02	[1]
Drift	kg/s	500	0.05	0.009	Rectangular	1.73	0.026	1	6.766E-04	[2]
Installation effect	kg/s	500	0.25	0.050	Rectangular	1.73	0.145	1	2.088E-02	[3]
RFI	Kg/s	500	0.25	0.050	Rectangular	1.73	0.145	1	2.088E-02	[3]
Line pressure variation	kg/s	500	0.9	0.180	Normal(95%)	1.93	0.466	1	2.175E-01	[1]
Mass Flow Uncertainty	**kg/s**	**500**	**1.18**	**0.24**	**Normal(95%)**	**1.96**	**0.602**	**1**	**3.621E-01**	

Ref:
[1]: MicroMotion Product Datasheet PS-00374 Rev AD, www.emerson.com
[2]: NEL data, $drift = 0.0015 \times (operatingT - ambiantT)$
[3]: NEL data, based on return of experience

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ISO\IEC 17025 Accredited Calibration Certificate: 8.00001987

Model Code	Serial ID	Order ID	Line	Item	Customer Tag
CMF300M426NQBMEZZZ	13082785	31031233	17.1	1	FIC-1318
CP 700	3308872	31031233	17.1	-	FIC-1318
Comments:					

Calibration Information

Date / Time:	2016.12.24 13:09:00
Calibration Stand:	FLC2A
Fluid:	H2O
Mass Uncertainty (%):	0.050
Density Uncertainty (kg/m³):	0.15
Volume Uncertainty (%):	0.053
Max Rate P/T (kPa/°C)	171.86 / 21.34

The reported expanded uncertainties (U_{95}) are based on the combined uncertainty multiplied by a coverage factor k=2, which provides a confidence level of approximately 95%. All uncertainties have been determined in accordance with the GUM and EA 04/2.

Calibration Constants

D1:	0.00000	FCF:	711.73
D2:	1.00000	FT:	4.45
K1:	10544.25	Flow Cal:	711.734.45
K2:	12485.23	Mass MF:	1.00000
DT:	4.45	Zero (μsec):	0.041
FD:	232.4282	DTG:	0.00
Dens Cal:	10544124854.45	DFQ1:	0.00
Dens MF:	1.00000	DFQ2:	0.00
		FFQ:	0.00
Vol MF:	1.00000	FTG:	0.00
Mass Flow cut-off (kg/min):			1.6667

This calibration was performed by comparison to a reference meter.(dynamic start/stop reference meter method) as described in ISO 10790:1999(E) "Measurement of fluid flow in closed conduits – Guidance to the selection, installation and use of Coriolis meters (mass flow, density and volume flow measurements)", Annex A "Calibration techniques", and the internal accredited product calibration procedure LWI S-21.

The results reported herein have been performed in accordance with the laboratory's term of accreditation under the Singapore Accreditation Council.

These measurements have been made using the calibration stand listed above, which is traceable to one or more of the following National Metrology Institutes: NIM-China, NIST-USA, and VSL-The Netherlands.

The processes used to obtain these calibration results comply with the requirements of ISO/IEC 17025:2005.

UUT Avg Results - Mass ☑ AS FOUND ☑ AS LEFT

Mass Rate (kg/min)	Fluid Pressure (kPa)	Fluid Temp (°C)	Mass Total (kg)	Mass Diff (%)	Rpts (n)	u_A Mean (%)	U_{95} (%)	Spec. (%)
226.845	81.24	21.32	226.603	-0.0060	3	0.0063	0.052	0.100
1134.10	182.0	21.25	1133.27	-0.026	3	0.00096	0.051	0.100
2245.49	171.9	21.34	2244.63	-0.029	3	0.0020	0.051	0.100

UUT Avg Results - Density

Mass Rate (kg/min)	Fluid Pressure (kPa)	Fluid Temp (°C)	Density (kg/m³)	Density Diff (kg/m³)	Rpts (n)	u_A Mean (kg/m³)	U_{95} (kg/m³)	Spec. (kg/m³)
226.845	81.24	21.32	997.989	-0.14	3	0.017	0.16	0.500
1134.10	182.0	21.25	998.035	-0.16	3	0.0054	0.16	0.500
2245.49	171.9	21.34	998.029	-0.14	3	0.012	0.16	0.500

UUT Avg Results - Volume

Volume Rate (l/min)	Fluid Pressure (kPa)	Fluid Temp (°C)	Volume Total (l)	Volume Diff (%)	Rpts (n)	u_A Mean (%)	U_{95} (%)	Spec. (%)
227.302	81.24	21.32	227.027	-0.0060	3	0.0063	0.055	0.112
1136.33	182.0	21.25	1135.32	-0.026	3	0.00096	0.054	0.112
2249.93	171.9	21.34	2248.74	-0.029	3	0.0020	0.054	0.112

Quality Assurance Approved — Emerson Process Management Flow Technologies Co., Ltd.

Calibration Operator
K.Karthik — 04-01-2017 — Date

Cal & Quality Manager Gui Wenhao
Wenhao Gui — 2017.1.4 — Date

Emerson Process Management Southeast Asia Service Center
No. 9 Gul Road #01-01;Singapore 629361

R2016.08.01 Page 1 of 1

E-8 FIC 1320 Oil Coriolis flowmeter (A2) – 04 Jan 2017

FIC 1320 Source	Units	Value	Expanded Uncertainty Abs	(%)	Probability	Divisor	Std	Sens.	Variance	Ref.
Calibration	kg/s	15	0.015	0.100	Normal(95%)	1.96	0.008	1	5.857E-05	[1]
Repeatability	kg/s	15	0.008	0.050	Normal(95%)	1.96	0.004	1	1.464E-05	[1]
Zero Stability	kg/s	15	0.008	0.053	Rectangular	1.73	0.005	1	2.138E-05	[1]
Drift	kg/s	15	0.045	0.300	Rectangular	1.73	0.026	1	6.766E-04	[2]
Installation effect	kg/s	15	0.002	0.010	Rectangular	1.73	0.001	1	7.518E-07	[3]
RFI	Kg/s	15	0.002	0.010	Rectangular	1.73	0.001	1	7.518E-07	[3]
Line pressure variation	kg/s	15	0.001	0.009	Normal(95%)	1.96	0.001	1	4.399E-07	[1]
Mass Flow Uncertainty	**kg/s**	**15**	**0.05**	**0.36**	**Normal(95%)**	**1.96**	**0.028**	**1**	**7.731E-04**	

Ref:
[1]: MicroMotion Product Datasheet PS-00374 Rev AD, www.emerson.com
[2]: NEL data, $drift = 0.0015 \times (operatingT - ambiantT)$
[3]: NEL data, based on return of experience

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ISO\IEC 17025 Accredited Calibration Certificate: 8.00001988

Model Code	Serial ID	Order ID	Line	Item	Customer Tag
CMFS100M419N2BMEKZZ	12103895	31031233	16.1	1	FIC-1320
ECP 800	33102537	31031233	16.1	-	FIC-1320
Comments:					

Calibration Information

Date / Time:	2016.12.24 15:21:00
Calibration Stand:	FLC2A
Fluid:	H2O
Mass Uncertainty (%):	0.050
Density Uncertainty (kg/m³):	0.15
Volume Uncertainty (%):	0.053
Max Rate P/T (kPa/°C):	162.59 / 20.98

The reported expanded uncertainties (U_{95}) are based on the combined uncertainty multiplied by a coverage factor k =2, which provides a confidence level of approximately 95%. All uncertainties have been determined in accordance with the GUM and EA 04/2.

Calibration Constants

D1:	0.00000	FCF:	213.51
D2:	1.00000	FT:	4.48
K1:	5028.71	Flow Cal:	213.514.48
K2:	6043.93	Mass MF:	1.00000
DT:	4.38	Zero (µsec):	-0.014
FD:	2473.0000	DTG:	0.00
Dens Cal:	502960444.38	DFQ1:	0.00
Dens MF:	1.00000	DFQ2:	0.00
		FFQ:	0.00
Vol MF:	1.00000	FTG:	0.00
		Mass Flow cut-off (kg/min):	0.1667

This calibration was performed by comparison to a reference meter,(dynamic start/stop reference meter method) as described in ISO 10790:1999(E) "Measurement of fluid flow in closed conduits – Guidance to the selection, installation and use of Coriolis meters (mass flow, density and volume flow measurements)", Annex A "Calibration techniques", and the internal accredited product calibration procedure LWI S-21.

The results reported herein have been performed in accordance with the laboratory's term of accreditation under the Singapore Accreditation Council.

These measurements have been made using the calibration stand listed above, which is traceable to one or more of the following National Metrology Institutes: NIM-China, NIST-USA, and VSL-The Netherlands.

The processes used to obtain these calibration results comply with the requirements of ISO/IEC 17025:2005.

UUT Avg Results - Mass ☑ AS FOUND ☑ AS LEFT

Mass Rate (kg/min)	Fluid Pressure (kPa)	Fluid Temp (°C)	Mass Total (kg)	Mass Diff (%)	Rpts (n)	U_A Mean (%)	U_{95} (%)	Spec. (%)
22.3260	315.5	21.01	22.2923	-0.086	3	0.0028	0.051	0.100
113.455	170.6	20.91	113.485	0.0018	3	0.0012	0.051	0.100
226.889	162.6	20.98	226.869	-0.011	3	0.0087	0.053	0.100

UUT Avg Results - Density

Mass Rate (kg/min)	Fluid Pressure (kPa)	Fluid Temp (°C)	Density (kg/m³)	Density Diff (kg/m³)	Rpts (n)	U_A Mean (kg/m³)	U_{95} (kg/m³)	Spec. (kg/m³)
22.3260	315.5	21.01	998.084	-0.22	3	0.021	0.16	0.500
113.455	170.6	20.91	998.509	0.25	3	0.0090	0.16	0.500
226.889	162.6	20.98	998.581	0.34	3	0.028	0.17	0.500

UUT Avg Results - Volume

Volume Rate (l/min)	Fluid Pressure (kPa)	Fluid Temp (°C)	Volume Total (l)	Volume Diff (%)	Rpts (n)	U_A Mean (%)	U_{95} (%)	Spec. (%)
22.3688	315.5	21.01	22.3301	-0.086	3	0.0028	0.054	0.112
113.624	170.6	20.91	113.683	0.0018	3	0.0012	0.054	0.112
227.212	162.6	20.98	227.268	-0.011	3	0.0087	0.056	0.112

EMERSON PROCESS MANAGEMENT FLOW TECHNOLOGIES CO., LTD Quality Assurance Approved

Calibration Operator
04·01·2017
K Karthik Date

Cal & Quality Manager
Gui Wenhao
2017.1.4
Wenhao Gui Date

Emerson Process Management Southeast Asia Service Center
No. 9 Gul Road #01-01 Singapore 629361
This certificate shall not be reproduced, except in full, without written permission of the calibration laboratory.
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E-9 FIC 1317 Oil Vortex flowmeter (B1) – 12 Jan 2017

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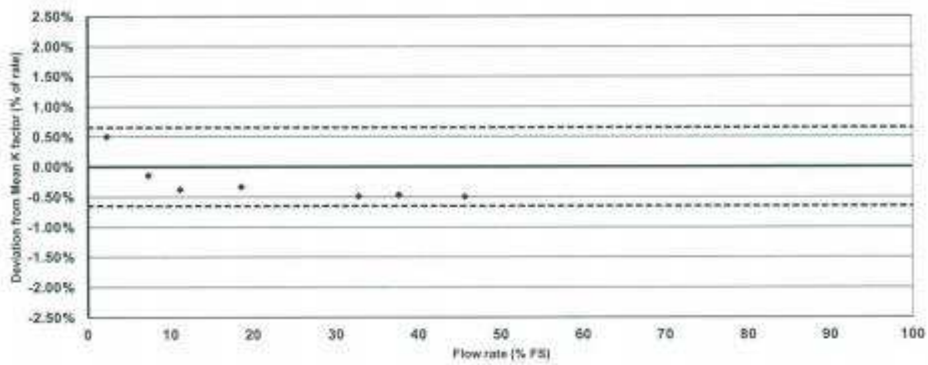
Process Management

Emerson Southeast Asia Flow Calibration and Service Center
9 Gul Rd, #01-01 Singapore 629361

Model number: 8800DF040SA3N1P1M5T1Q4
Serial number: 06133894
Computed mean K factor: 4.6758

Calibration Date: 11/1/2017 19:10
Trace Number: FI-1317

Run #	Flow Rate % FS	Velocity ft/s	Velocity m/s	Reynolds number	Flow rate US gpm	Flow rate m3/Hr	Deviation % rate
1	2.3	0.6	0.19	20	25	5.66	0.50%
2	7.4	2.0	0.61	62	79	18.00	-0.14%
3	11.2	3.0	0.91	93	119	27.00	-0.38%
4	18.6	5.0	1.52	155	198	45.00	-0.34%
5	32.8	8.8	2.69	274	350	79.50	-0.49%
6	37.7	10.2	3.09	315	402	91.30	-0.48%
7	45.7	12.3	3.75	383	488	111.00	-0.50%



Calibration conditions:
Water temperature = 69.10 F (20.61 C), Water density = 62.328 lb/ft3 (998.403 kg/m3).
100% flow rate = 12.3 ft/sec (3.75 m/s) in schedule 40 pipe.
Minimum computed mean K factor specification is +/- 0.65%.
Calibration ID: 8.00002028

Printed: 12/1/2017 13:55

Calibrator: ARCHIE ROBLES

Schlumberger

E-10 PISH 1330 Oil Pressure transmitter (P) – 04 Jan 2017

MW Group Pte. Ltd.
196 Pandan Loop • #02-21 Pantech Business Hub • Singapore 128384
Tel: 65 - 6872 - 0811 • Fax: 65 - 6872 - 1811
E-mail: sales@mwgroup.com.sg
Website: www.mwgroup.com.sg

CERTIFICATE OF CALIBRATION

CLIENT	: SCHLUMBERGER OILFIELD (S) PTE LTD NO.1 BENOI CRESCENT SINGAPORE 629986	**DATE OF ISSUE**	: 04/JAN/17
		PAGE	: 1 OF 2
INSTRUMENT	: PRESSURE TRANSMITTER	**CERTIFICATE NO**	: 92150-S-P
SERIAL NO	: K6018121128	**DATE RECEIVED**	: 23/DEC/16
TAG NO	: PISH 1330	**DATE CALIBRATED**	: 04/JAN/17
MANUFACTURER	: ENDRESS+HAUSER	**RECOMMENDED DUE DATE**	: -
RANGE	: -1 to 40 bar		

Ambient Temperature : $20 \pm 2^{o}C$
Relative Humidity : $55 \pm 10\%$ r.h.

MW Group Pte Ltd and its practices are in compliance with ISO/IEC 17025 : 2005. The Quality System in accordance with Quality Standard ISO 9001 : 2008.

This Unit Under Test has been calibrated at MW GROUP PTE LTD, Calibration Laboratory under the ambient condition stated above.

Calibration Method :

Calibration method in accordance with our In-house Calibration Procedure MW 004. The calibration procedure using as a reference of API-6A, BS EN 837-1 : 1998 and DKD-R-6-1. This Unit Under Test was calibrated by comparison with reference calibrator. The reference standards used are traceable to national measurement standard maintained at National Metrology Centre (NMC-Singapore) and SAC-SINGLAS Accredited Calibration Laboratory.

Reference Equipment Used :

Equipment	: Pressure Automated Calibrator / Electronic Precision Digital Multimeter / Power Supply
Manufacturer	: Druck / Hewlett Packard / Manson
Serial No.	: 3507293 / 3146A60210 / 270364358
Traceability Ref.	: PL 002458 / EL 004686 / 6355-E-L

Calibration Results :
Refer to attached Page.

The expanded measurement uncertainty is estimated at a level of confidence at 95%.

The user should determine the suitability of this instrument for its intended use.

No adjustment was made on the instrument.

The calibration certificate shall not be reproduced in part except in full without the written approval of MW Group Pte Ltd.

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CERTIFICATE OF CALIBRATION

CERTIFICATE NO : 92150-S-P

PAGE NO : 2 OF 2

Actual Applied	Expected Output	Mean Indicated Value		Correction	Hysteresis	Coverage Factor	Uncertainty (±)
bar	mAdc	mAdc	bar	bar	bar	k	bar
-0.998	4.001	4.006	-0.985	-0.013	0.000	1.96	0.01
10.000	8.293	8.291	9.996	0.004	0.003	1.96	0.02
20.000	12.195	12.196	20.002	-0.002	0.003	1.96	0.03
30.000	16.098	16.101	30.009	-0.009	0.003	1.96	0.04
40.000	20.000	20.006	40.015	-0.015	-	1.96	0.05
30.000	16.098	16.100	30.006	-0.006	-	1.96	0.04
20.000	12.195	12.195	20.000	0.000	-	1.96	0.03
10.000	8.293	8.290	9.993	0.007	-	1.96	0.02
-0.998	4.001	4.006	-0.985	-0.013	-	1.96	0.01

Calibrated by : Technician — K. Gopu

Approved by : Authorised Signatory — V. Arunkumar

This certificate is issued under the US Department Of The Navy Metrology And Calibration Program, certificate number 7MW.

"The results reported herein have been performed in accordance with the laboratory terms of accreditation under the Singapore Laboratory Accreditation Council - Singapore Laboratory Accreditation Scheme".

Warning: The revision controlled source of this document is stored in the Document Management System; a paper version of this document is uncontrolled and should be compared by the user with the latest released source document to ensure it is up-to-date.

E-11 TISH 1314 Oil Temperature transmitter (T) – 28 Dec 2016

MW Group Pte. Ltd.
196 Pandan Loop • #02-21 Pantech Business Hub • Singapore 128384
Tel: 65 - 6872 - 0811 • Fax: 65 - 6872 - 1811
E-mail: sales@mwgroup.com.sg
Website: www.mwgroup.com.sg

CERTIFICATE OF CALIBRATION

CLIENT	: SCHLUMBERGER OILFIELD (S) PTE LTD NO.1 BENOI CRESCENT SINGAPORE 629986	**DATE OF ISSUE**	: 28/DEC/16
		PAGE	: 1 OF 2
INSTRUMENT	: TEMPERATURE TRANSMITTER	**CERTIFICATE NO**	: 11101-S-T
SERIAL NO	: K600EB97152	**DATE RECEIVED**	: 23/DEC/16
MODEL NO	: TMT82		
TAG NO	: TIC1314	**DATE CALIBRATED**	: 28/DEC/16
MANUFACTURER	: ENDRESS+HAUSER	**RECOMMENDED DUE DATE**	: -
RANGE	: 0 to 100°C		

Ambient Temperature : 23 ± 2°C.
Relative Humidity : 60 ± 10% r.h.

MW Group Pte Ltd and its practices are in compliance with ISO/IEC 17025 : 2005. The Quality System in accordance with Quality Standard ISO 9001 : 2008.

This Unit Under Test has been calibrated at MW GROUP PTE LTD, Calibration Laboratory under the ambient condition stated above.

Calibration Method :

Calibration method in accordance with In-house Calibration Procedure MW 005.

Traceability :

1.0, 1.1 The Reference equipments are traceable to National Metrology Centre (NMC) Singapore.
1.2, 1.3 The Reference equipments are traceable to National Metrology Centre (NMC) Singapore, via MW Group Pte Ltd.

Reference Equipment Used :

Equipment	: 1.0 Standard Platinum Resistance Thermometer / 1.1 Electronic Precision Digital Multimeter / 1.2 Precision Thermometer / 1.3 Power Supply
Manufacturer	: Isotech / Hewlett Packard / Isotech
Serial No.	: 909/1106 / 3146A60210 / 33321-3 / 270364358
Traceability Ref.	: TL 006634 / EL 004686 / 10762-S-T / 6355-E-L

Calibration Results :
Refer to attached Page.

The expanded measurement uncertainty is estimated at a level of confidence at 95% with a coverage factor k=1.96.
The user should determine the suitability of this instrument for its intended use.
No adjustment was made on the instrument.

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IMCA Member

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CERTIFICATE OF CALIBRATION

CERTIFICATE NO : 11101-S-T

PAGE NO : 2 OF 2

Actual Applied	Expected Output	Mean Indicated Value		Correction	mA Reading	Coverage Factor	Uncertainty (±)
°C	mAdc	mAdc	°C	°C	% OF F.S	k	°C
0.000	4.000	3.998	-0.013	0.013	0.013	1.96	0.12
24.987	7.998	7.994	24.963	0.024	0.024	1.96	0.13
49.979	11.997	11.993	49.956	0.023	0.023	1.96	0.14
74.962	15.994	15.992	74.950	0.012	0.012	1.96	0.15
99.958	19.993	19.995	99.969	-0.011	-0.011	1.96	0.16

Calibrated by : Technician V. Ramesh

Approved by : Authorised Signatory V. Arunkumar

This certificate is issued under the US Department Of The Navy Metrology And Calibration Program, certificate number 7MW.

"The results reported herein have been performed in accordance with the laboratory terms of accreditation under the Singapore Laboratory Accreditation Council - Singapore Laboratory Accreditation Scheme"

E-12 FIC 1311 Water Coriolis flowmeter (A1) – 04 Jan 2017

FIC 1311 Source	Units	Value	Expanded Uncertainty Abs	(%)	Probability	Divisor	Std	Sens.	Variance	Ref.
Calibration	kg/s	500	0.50	0.100	Normal(95%)	1.96	0.255	1	6.508E-02	[1]
Repeatability	kg/s	500	0.25	0.050	Normal(95%)	1.96	0.128	1	1.627E-02	[1]
Zero Stability	kg/s	500	0.25	0.050	Rectangular	1.73	0.145	1	2.088E-02	[1]
Drift	kg/s	500	0.05	0.009	Rectangular	1.73	0.026	1	6.766E-04	[2]
Installation effect	kg/s	500	0.25	0.050	Rectangular	1.73	0.145	1	2.088E-02	[3]
RFI	Kg/s	500	0.25	0.050	Rectangular	1.73	0.145	1	2.088E-02	[3]
Line pressure variation	kg/s	500	0.9	0.180	Normal(95%)	1.93	0.466	1	2.175E-01	[1]
Mass Flow Uncertainty	**kg/s**	**500**	**1.18**	**0.24**	**Normal(95%)**	**1.96**	**0.602**	**1**	**3.621E-01**	

Ref:
[1]: MicroMotion Product Datasheet PS-00374 Rev AD, www.emerson.com
[2]: NEL data, $drift = 0.0015 \times (operatingT - ambiantT)$
[3]: NEL data, based on return of experience

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ilac-MRA SAC-SINGLAS ACCREDITED LABORATORY

ISO\IEC 17025 Accredited Calibration Certificate: 8.00001986

Model Code	Serial ID	Order ID	Line	Item	Customer Tag
CMF300M426N2BMEZZZ	13082347	31031233	14.1	1	FIC-1311
ECP 800	33102513	31031233	14.1	-	FIC-1311
Comments:					

Calibration Information	
Date / Time:	2016.12.24 11:15:00
Calibration Stand:	FLC2A
Fluid:	H2O
Mass Uncertainty (%):	0.050
Density Uncertainty (kg/m³):	0.15
Volume Uncertainty (%):	0.053
Max Rate P/T (kPa/°C)	169.38 / 21.71

The reported expanded uncertainties (U_{95}) are based on the combined uncertainty multiplied by a coverage factor k=2, which provides a confidence level of approximately 95%. All uncertainties have been determined in accordance with the GUM and EA 04/2.

Calibration Constants			
D1:	0.00000	FCF:	714.15
D2:	1.00000	FT:	4.45
K1:	10516.71	Flow Cal:	714.154.45
K2:	12451.88	Mass MF:	1.00000
DT:	4.45	Zero (μsec):	0.001
FD:	258.5079	DTG:	0.00
Dens Cal:	10517124524.45	DFQ1:	0.00
Dens MF:	1.00000	DFQ2:	0.00
		FFQ:	0.00
Vol MF:	1.00000	FTG:	0.00
Mass Flow cut-off (kg/min):			1.6667

This calibration was performed by comparison to a reference meter.(dynamic start/stop reference meter method) as described in ISO 10790:1999(E) "Measurement of fluid flow in closed conduits – Guidance to the selection, installation and use of Coriolis meters (mass flow, density and volume flow measurements)", Annex A "Calibration techniques", and the internal accredited product calibration procedure LWI S-21.

The results reported herein have been performed in accordance with the laboratory's term of accreditation under the Singapore Accreditation Council.

These measurements have been made using the calibration stand listed above, which is traceable to one or more of the following National Metrology Institutes: NIM-China, NIST-USA, and VSL-The Netherlands.
The processes used to obtain these calibration results comply with the requirements of ISO/IEC 17025:2005.

UUT Avg Results - Mass ☑ AS FOUND ☑ AS LEFT

Mass Rate (kg/min)	Fluid Pressure (kPa)	Fluid Temp (°C)	Mass Total (kg)	Mass Diff (%)	Rpts (n)	u_A Mean (%)	U_{95} (%)	Spec. (%)
226.807	81.06	21.64	226.728	-0.0061	3	0.0064	0.052	0.100
1133.17	181.7	21.57	1132.90	0.00041	3	0.0011	0.051	0.100
2247.21	169.4	21.71	2248.31	-0.00034	3	0.00075	0.051	0.100

UUT Avg Results - Density

Mass Rate (kg/min)	Fluid Pressure (kPa)	Fluid Temp (°C)	Density (kg/m³)	Density Diff (kg/m³)	Rpts (n)	u_A Mean (kg/m³)	U_{95} (kg/m³)	Spec. (kg/m³)
226.807	81.06	21.64	998.259	0.20	3	0.0088	0.16	0.500
1133.17	181.7	21.57	998.314	0.19	3	0.019	0.16	0.500
2247.21	169.4	21.71	998.139	0.052	3	0.036	0.17	0.500

UUT Avg Results - Volume

Volume Rate (l/min)	Fluid Pressure (kPa)	Fluid Temp (°C)	Volume Total (l)	Volume Diff (%)	Rpts (n)	u_A Mean (%)	U_{95} (%)	Spec. (%)
227.202	81.06	21.64	227.169	-0.0061	3	0.0064	0.055	0.112
1135.08	181.7	21.57	1135.03	0.00041	3	0.0011	0.054	0.112
2251.41	169.4	21.71	2252.62	-0.00034	3	0.00075	0.054	0.112

EMERSON PROCESS MANAGEMENT FLOW TECHNOLOGIES CO., LTD Quality Assurance Approved

Calibration Operator
K.Karthik — 04-01-2017 Date

Cal & Quality Manager
Gui Wenhao
Wenhao Gui — 2017.1.4 Date

Emerson Process Management Southeast Asia Service Center
No. 9 Gul Road #01-01 Singapore 629361

R2016.08.01 Page 1 of 1

E-13 FIC 1313 Water Coriolis flowmeter (A2) – 04 Jan 2017

FIC 1313 Source	Units	Value	Expanded Uncertainty Abs	(%)	Probability	Divisor	Std	Sens.	Variance	Ref.
Calibration	kg/s	15	0.015	0.100	Normal(95%)	1.96	0.008	1	5.857E-05	[1]
Repeatability	kg/s	15	0.008	0.050	Normal(95%)	1.96	0.004	1	1.464E-05	[1]
Zero Stability	kg/s	15	0.008	0.053	Rectangular	1.73	0.005	1	2.138E-05	[1]
Drift	kg/s	15	0.045	0.300	Rectangular	1.73	0.026	1	6.766E-04	[2]
Installation effect	kg/s	15	0.002	0.010	Rectangular	1.73	0.001	1	7.518E-07	[3]
RFI	Kg/s	15	0.002	0.010	Rectangular	1.73	0.001	1	7.518E-07	[3]
Line pressure variation	kg/s	15	0.001	0.009	Normal(95%)	1.96	0.001	1	4.399E-07	[1]
Mass Flow Uncertainty	**kg/s**	**15**	**0.05**	**0.36**	**Normal(95%)**	**1.96**	**0.028**	**1**	**7.731E-04**	

Ref:
[1]: MicroMotion Product Datasheet PS-00374 Rev AD, www.emerson.com
[2]: NEL data, $drift = 0.0015 \times (operatingT - ambiantT)$
[3]: NEL data, based on return of experience

EMERSON
Process Management

ISO\IEC 17025 Accredited Calibration Certificate: 8.00002011

Model Code	Serial ID	Order ID	Line	Item	Customer Tag
CMFS100M419N2BMEKZZ	12104192	31031233	13.1	1	FIC-1313
ECP 800	33102251	31031233	_	_	FIC-1313
Comments:	Calibration done using stand transmitter				

Calibration Information	
Date / Time:	2016.12.27 20:02:00
Calibration Stand:	FLC2A
Fluid:	H2O
Mass Uncertainty (%):	0.050
Density Uncertainty (kg/m³):	0.15
Volume Uncertainty (%):	0.053
Max Rate P/T (kPa/°C)	164.03 / 22.07
	CORIOLIS ISO/IEC 17025 VERIFY

The reported expanded uncertainties (U_{95}) are based on the combined uncertainty multiplied by a coverage factor k=2, which provides a confidence level of approximately 95%. All uncertainties have been determined in accordance with the GUM and EA 04/2.

Calibration Constants			
D1:	0.00000	FCF:	207.58
D2:	1.00000	FT:	4.48
K1:	5024.73	Flow Cal:	207.584.48
K2:	6053.97	Mass MF:	1.00000
DT:	4.38	Zero (µsec):	-0.003
FD:	2473.0000	DTG:	0.00
Dens Cal:	502560544.38	DFQ1:	0.00
Dens MF:	1.00000	DFQ2:	0.00
		FFQ:	0.00
Vol MF:	1.00000	FTG:	0.00
		Mass Flow cut-off (kg/min):	0.1668

This calibration was performed by comparison to a reference meter,(dynamic start/stop reference meter method) as described in ISO 10790:1999(E) "Measurement of fluid flow in closed conduits – Guidance to the selection, installation and use of Coriolis meters (mass flow, density and volume flow measurements)", Annex A "Calibration techniques", and the internal accredited product calibration procedure LWI S-21.

The results reported herein have been performed in accordance with the laboratory's term of accreditation under the Singapore Accreditation Council.

These measurements have been made using the calibration stand listed above, which is traceable to one or more of the following National Metrology Institutes: NIM-China, NIST-USA, and VSL-The Netherlands.
The processes used to obtain these calibration results comply with the requirements of ISO/IEC 17025:2005.

UUT Avg Results - Mass ☑ AS FOUND ☐ AS LEFT

Mass Rate (kg/min)	Fluid Pressure (kPa)	Fluid Temp (°C)	Mass Total (kg)	Mass Diff (%)	Rpts (n)	u_A Mean (%)	U_{95} (%)	Spec. (%)
22.7115	374.8	21.97	22.7222	-0.041	3	0.0030	0.051	0.100
113.545	171.0	21.96	113.403	0.034	3	0.0019	0.051	0.100
226.971	164.0	22.07	226.894	0.033	3	0.0064	0.052	0.100

UUT Avg Results - Density

Mass Rate (kg/min)	Fluid Pressure (kPa)	Fluid Temp (°C)	Density (kg/m³)	Density Diff (kg/m³)	Rpts (n)	u_A Mean (kg/m³)	U_{95} (kg/m³)	Spec. (kg/m³)
22.7115	374.8	21.97	998.210	0.091	3	0.031	0.17	0.500
113.545	171.0	21.96	998.792	0.76	3	0.019	0.16	0.500
226.971	164.0	22.07	998.809	0.81	3	0.017	0.16	0.500

UUT Avg Results - Volume

Volume Rate (l/min)	Fluid Pressure (kPa)	Fluid Temp (°C)	Volume Total (l)	Volume Diff (%)	Rpts (n)	u_A Mean (%)	U_{95} (%)	Spec. (%)
22.7522	374.8	21.97	22.7650	-0.041	3	0.0030	0.054	0.112
113.683	171.0	21.96	113.627	0.034	3	0.0019	0.054	0.112
227.242	164.0	22.07	227.348	0.033	3	0.0064	0.055	0.112

Emerson Process Management Flow Technologies Co. Ltd — Quality Assurance Approved

Calibration Operator 2017.1.4
Aravind Date

Cal & Quality Manager
Gui Wenhao 2017.1.4
Wenhao Gui Date

Emerson Process Management Southeast Asia Service Center
No. 9 Gul Road #01-01 Singapore 629361

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EMERSON
Process Management

ilac-MRA SAC-SINGLAS ACCREDITED LABORATORY

ISO\IEC 17025 Accredited Calibration Certificate: 8.00002021

Model Code	Serial ID	Order ID	Line	Item	Customer Tag
CMFS100M419N2BMEKZZ	12104192	31031233	13.1	1	FIC-1313
ECP 800	33102251	31031233			FIC-1313
Comments:	Calibration done using stand transmitter				

Calibration Information

Date / Time:	2016.12.28 20:00:00
Calibration Stand:	FLC2A
Fluid:	H2O
Mass Uncertainty (%):	0.050
Density Uncertainty (kg/m³):	0.15
Volume Uncertainty (%):	0.053
Max Rate P/T (kPa/°C)	164.39 / 21.98
CORIOLIS ISO/IEC 17025 VERIFY	

The reported expanded uncertainties (U_{95}) are based on the combined uncertainty multiplied by a coverage factor k=2, which provides a confidence level of approximately 95%. All uncertainties have been determined in accordance with the GUM and EA 04/2.

Calibration Constants

D1:	0.00000	FCF:	207.58
D2:	1.00000	FT:	4.48
K1:	5024.73	Flow Cal:	207.584.48
K2:	6053.97	Mass MF:	1.00000
DT:	4.38	Zero (µsec):	-0.004
FD:	5603.9019	DTG:	0.00
Dens Cal:	502560544.38	DFQ1:	0.00
Dens MF:	1.00000	DFQ2:	0.00
		FFQ:	0.00
Vol MF:	1.00000	FTG:	0.00
Mass Flow cut-off (kg/min):			0.1668

This calibration was performed by comparison to a reference meter (dynamic start/stop reference meter method) as described in ISO 10790:1999(E) "Measurement of fluid flow in closed conduits – Guidance to the selection, installation and use of Coriolis meters (mass flow, density and volume flow measurements)", Annex A "Calibration techniques", and the internal accredited product calibration procedure LWI S-21.

The results reported herein have been performed in accordance with the laboratory's term of accreditation under the Singapore Accreditation Council.

These measurements have been made using the calibration stand listed above, which is traceable to one or more of the following National Metrology Institutes: NIM-China, NIST-USA, and VSL-The Netherlands.

The processes used to obtain these calibration results comply with the requirements of ISO/IEC 17025:2005.

UUT Avg Results - Mass ☐ AS FOUND ☑ AS LEFT

Mass Rate (kg/min)	Fluid Pressure (kPa)	Fluid Temp (°C)	Mass Total (kg)	Mass Diff (%)	Rpts (n)	u_A Mean (%)	U_{95} (%)	Spec. (%)
22.3210	384.0	21.92	22.3246	-0.013	3	0.0028	0.051	0.100
113.812	172.3	21.88	113.742	0.039	3	0.00078	0.051	0.100
226.869	164.4	21.98	227.205	0.030	3	0.010	0.055	0.100

UUT Avg Results - Density

Mass Rate (kg/min)	Fluid Pressure (kPa)	Fluid Temp (°C)	Density (kg/m³)	Density Diff (kg/m³)	Rpts (n)	u_A Mean (kg/m³)	U_{95} (kg/m³)	Spec. (kg/m³)
22.3210	384.0	21.92	998.204	0.068	3	0.0094	0.16	0.500
113.812	172.3	21.88	998.507	0.46	3	0.012	0.16	0.500
226.869	164.4	21.98	997.757	-0.27	3	0.0094	0.16	0.500

UUT Avg Results - Volume

Volume Rate (l/min)	Fluid Pressure (kPa)	Fluid Temp (°C)	Volume Total (l)	Volume Diff (%)	Rpts (n)	u_A Mean (%)	U_{95} (%)	Spec. (%)
22.3611	384.0	21.92	22.3663	-0.013	3	0.0028	0.054	0.112
113.982	172.3	21.88	113.965	0.039	3	0.00078	0.054	0.112
227.378	164.4	21.98	227.655	0.030	3	0.010	0.057	0.112

EMERSON PROCESS MANAGEMENT FLOW TECHNOLOGIES CO., LTD Quality Assurance Approved

Calibration Operator 2017.1.4
Aravind Date

Cal & Quality Manager Gui Wenhao 2017.1.4
Wenhao Gui Date

Emerson Process Management Southeast Asia Service Center
No. 9 Gul Road #01-01, Singapore 629361

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E-14 FI 1310 Water Magnetic flowmeter (B1) – 12 Jan 2017

EMERSON
Process Management

Emerson Southeast Asia Flow Calibration and Service Center
9 Gul Rd, #01-01 Singapore 629361

Calibration Date: 12/1/2017 14:21
Model number: 8705NHA030C3W0E5B3Q4
Serial number: 06133891
Trace Number: 06133891
Transmitter: 06133892
Frequency: 5Hz
Calibration Number: 0940805709368005

0 9 4 0 8 0 5 7 0 9 3 6 8 0 0 5

Run #	Flow Rate % FS	Velocity ft/s	Velocity m/s	Flow rate US gpm	Flow rate m3/Hr	Deviation % rate
1	94.7	10.2	3.11	235	53.40	1.829
2	94.7	10.2	3.11	235	53.40	1.840
3	94.7	10.2	3.11	235	53.30	1.827
4	28.4	3.1	0.93	70	16.00	1.710
5	28.4	3.1	0.93	70	16.00	1.666
6	28.4	3.1	0.93	70	16.00	1.665
7	9.4	1.0	0.31	23	5.30	1.425
8	9.4	1.0	0.31	23	5.31	1.433
9	9.4	1.0	0.31	23	5.31	1.445

Calibration conditions:
Water temperature = 69.74 F (20.97 C). Water conductivity > 200 microMho.
100% flow rate = 10.2 ft/sec (3.11 m/s) in schedule 40 pipe.
Calibration ID: 8.00002029

Out Of Tolerance!!!

Calibrator: ARCATE ROBLES

Printed: 12/1/2017 14:58

EMERSON
Process Management

Emerson Southeast Asia Flow Calibration and Service Center
9 Gul Rd, #01-01 Singapore 629361

Calibration Date: 12/1/2017 14:52
Model number: 8705NHA030C3W0E5B3Q4
Serial number: 06133891
Trace Number: 06133891
Transmitter: 06133892
Frequency: 5Hz
Calibration Number: 0958205309557005

0 9 5 8 2 0 5 3 0 9 5 5 7 0 0 5

Run #	Flow Rate % FS	Velocity ft/s	Velocity m/s	Flow rate US gpm	Flow rate m3/Hr	Deviation % rate
1	93.0	10.1	3.06	231	52.40	0.050
2	93.0	10.1	3.06	231	52.40	0.037
3	93.0	10.1	3.05	231	52.40	0.025
4	27.9	3.0	0.91	69	15.70	-0.051
5	27.9	3.0	0.91	69	15.70	-0.045
6	27.9	3.0	0.91	69	15.70	-0.041
7	9.3	1.0	0.31	23	5.23	-0.069
8	9.3	1.0	0.31	23	5.24	-0.013
9	9.3	1.0	0.31	23	5.24	-0.064

Calibration conditions:
Water temperature = 69.67 F (20.93 C), Water conductivity > 200 microMho.
100% flow rate = 10.1 ft/sec (3.08 m/s) in schedule 40 pipe.
Calibration ID: 8.00002030

Calibrator: ARCHIE ROBLES

Printed: 12/1/2017 14:57

Schlumberger

E-15 PISH 1329 Water Pressure transmitter (P) – 04 Jan 2017

MW Group Pte. Ltd.
196 Pandan Loop • #02-21 Pantech Business Hub • Singapore 128384
Tel: 65 - 6872 - 0811 • Fax: 65 - 6872 - 1811
E-mail: sales@mwgroup.com.sg
Website: www.mwgroup.com.sg

CERTIFICATE OF CALIBRATION

CLIENT	: SCHLUMBERGER OILFIELD (S) PTE LTD NO.1 BENOI CRESCENT SINGAPORE 629986	DATE OF ISSUE PAGE	: 04/JAN/17 : 1 OF 2
INSTRUMENT	: PRESSURE TRANSMITTER	CERTIFICATE NO	: 92151-S-P
SERIAL NO	: K6018021128	DATE RECEIVED	: 23/DEC/16
TAG NO	: PISH 1329	DATE CALIBRATED	: 04/JAN/17
MANUFACTURER	: ENDRESS+HAUSER	RECOMMENDED DUE DATE	: -
RANGE	: -1 to 40 bar		

Ambient Temperature : 20 ± 2°C
Relative Humidity : 55 ± 10% r.h.

MW Group Pte Ltd and its practices are in compliance with ISO/IEC 17025 : 2005. The Quality System in accordance with Quality Standard ISO 9001 : 2008.

This Unit Under Test has been calibrated at MW GROUP PTE LTD, Calibration Laboratory under the ambient condition stated above.

Calibration Method :

Calibration method in accordance with our In-house Calibration Procedure MW 004. The calibration procedure using as a reference of API-6A, BS EN 837-1 : 1998 and DKD-R-6-1. This Unit Under Test was calibrated by comparison with reference calibrator. The reference standards used are traceable to national measurement standard maintained at National Metrology Centre (NMC-Singapore) and SAC-SINGLAS Accredited Calibration Laboratory.

Reference Equipment Used :

Equipment	: Pressure Automated Calibrator / Electronic Precision Digital Multimeter / Power Supply
Manufacturer	: Druck / Hewlett Packard / Manson
Serial No.	: 3507293 / 3146A60210 / 270364358
Traceability Ref.	: PL 002458 / EL 004686 / 6355-E-L

Calibration Results :
Refer to attached Page.

The expanded measurement uncertainty is estimated at a level of confidence at 95%.

The user should determine the suitability of this instrument for its intended use.

No adjustment was made on the instrument.

IMCA Member
bizSAFE 3
NAVSEA
SAC-SINGLAS

CERTIFICATE OF CALIBRATION

CERTIFICATE NO : 92151-S-P

PAGE NO : 2 OF 2

Actual Applied	Expected Output	Mean Indicated Value		Correction	Hysteresis	Coverage Factor	Uncertainty (±)
bar	mAdc	mAdc	bar	bar	bar	k	bar
-0.998	4.001	4.002	-0.995	-0.003	0.000	1.96	0.01
10.000	8.293	8.293	10.001	-0.001	0.000	1.96	0.02
20.000	12.195	12.199	20.010	-0.010	0.000	1.96	0.03
30.000	16.098	16.104	30.017	-0.017	0.000	1.96	0.04
40.000	20.000	20.008	40.021	-0.021	-	1.96	0.05
30.000	16.098	16.104	30.017	-0.017	-	1.96	0.04
20.000	12.195	12.199	20.010	-0.010	-	1.96	0.03
10.000	8.293	8.293	10.001	-0.001	-	1.96	0.02
-0.998	4.001	4.002	-0.995	-0.003	-	1.96	0.01

Calibrated by : K. Gopu
Technician

Approved by : V. Arunkumar
Authorised Signatory

This certificate is issued under the US Department Of The Navy Metrology And Calibration Program, certificate number 7MW.

"The results reported herein have been performed in accordance with the laboratory terms of accreditation under the Singapore Laboratory Accreditation Council - Singapore Laboratory Accreditation Scheme"

E-16 TIC 1314 Water Temperature transmitter (T) – 28 Dec 2016

MW Group Pte. Ltd.
196 Pandan Loop • #02-21 Pantech Business Hub • Singapore 128384
Tel: 65 - 6872 - 0811 • Fax: 65 - 6872 - 1811
E-mail: sales@mwgroup.com.sg
Website: www.mwgroup.com.sg

CERTIFICATE OF CALIBRATION

CLIENT	: SCHLUMBERGER OILFIELD (S) PTE LTD NO.1 BENOI CRESCENT SINGAPORE 629986	**DATE OF ISSUE** **PAGE**	: 28/DEC/16 : 1 OF 2
INSTRUMENT	: TEMPERATURE TRANSMITTER	**CERTIFICATE NO**	: 11101-S-T
SERIAL NO **MODEL NO** **TAG NO**	: K600EB97152 : TMT82 : TIC1314	**DATE RECEIVED** **DATE CALIBRATED**	: 23/DEC/16 : 28/DEC/16
MANUFACTURER	: ENDRESS+HAUSER	**RECOMMENDED DUE DATE**	: -
RANGE	: 0 to 100°C		

Ambient Temperature : 23 ± 2°C.
Relative Humidity : 60 ± 10% r.h.

MW Group Pte Ltd and its practices are in compliance with ISO/IEC 17025 : 2005. The Quality System in accordance with Quality Standard ISO 9001 : 2008.

This Unit Under Test has been calibrated at MW GROUP PTE LTD, Calibration Laboratory under the ambient condition stated above.

Calibration Method :

Calibration method in accordance with In-house Calibration Procedure MW 005.

Traceability :

1.0, 1.1 The Reference equipments are traceable to National Metrology Centre (NMC) Singapore.
1.2, 1.3 The Reference equipments are traceable to National Metrology Centre (NMC) Singapore, via MW Group Pte Ltd.

Reference Equipment Used :

Equipment	: 1.0 Standard Platinum Resistance Thermometer / 1.1 Electronic Precision Digital Multimeter / 1.2 Precision Thermometer / 1.3 Power Supply
Manufacturer	: Isotech / Hewlett Packard / Isotech
Serial No.	: 909/1106 / 3146A60210 / 33321-3 / 270364358
Traceability Ref.	: TL 006634 / EL 004686 / 10762-S-T / 6355-E-L

Calibration Results :
Refer to attached Page.

The expanded measurement uncertainty is estimated at a level of confidence at 95% with a coverage factor k=1.96.
The user should determine the suitability of this instrument for its intended use.
No adjustment was made on the instrument.

CERTIFICATE OF CALIBRATION

CERTIFICATE NO : 11101-S-T

PAGE NO : 2 OF 2

Actual Applied	Expected Output	Mean Indicated Value		Correction	mA Reading	Coverage Factor	Uncertainty (±)
°C	mAdc	mAdc	°C	°C	% OF F.S	k	°C
0.000	4.000	3.998	-0.013	0.013	0.013	1.96	0.12
24.987	7.998	7.994	24.963	0.024	0.024	1.96	0.13
49.979	11.997	11.993	49.956	0.023	0.023	1.96	0.14
74.962	15.994	15.992	74.950	0.012	0.012	1.96	0.15
99.958	19.993	19.995	99.969	-0.011	-0.011	1.96	0.16

Calibrated by : V. Ramesh
Technician

Approved by : V. Arunkumar
Authorised Signatory

This certificate is issued under the US Department Of The Navy Metrology And Calibration Program, certificate number 7MW.

"The results reported herein have been performed in accordance with the laboratory terms of accreditation under the Singapore Laboratory Accreditation Council - Singapore Laboratory Accreditation Scheme"