30th International North Sea Flow Measurement Workshop
23 – 26 October 2012

Practical Considerations for Liquid Tank Calibration by Metering/Incremental Method

Mohammed Al-Torairi, Saudi Aramco

---

1 INTRODUCTION

Tank gauging is widely used in custody transfer applications. When applied, the liquid measured is a function of tank volume. Most tanks used in custody transfer applications are calibrated by calculating the tank's volume based on the physical measurement of the empty tank's dimensions. In hydrocarbon measurement and for large tanks, this method might be an optimum choice for operational reasons. The computed volume in this case may include multiple areas of potential error that could be eliminated by applying metering/incremental method. This includes: tank bottom movement, tank wall deflection, correction for deadweight, and compensation for roof weight.

In general there are associated losses/ errors with tank gauging. These losses can be in any area:

- The tank
- The calibration method
- The standard used to calibrate or strap the tank
- Computation of calibration table
- The gauging method
- System uncertainties

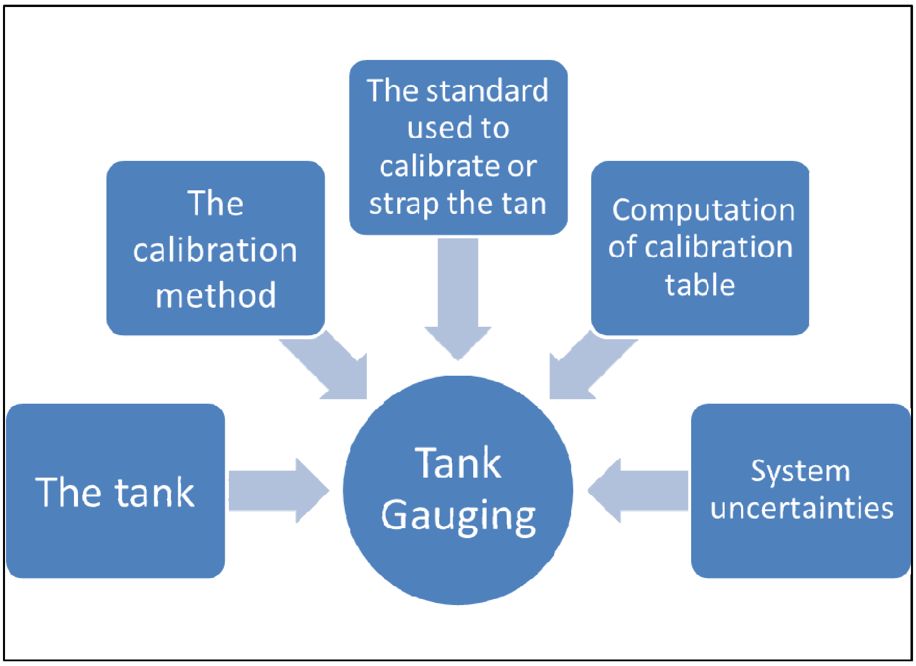

Fig. 1 – Sources of errors in Tank Gauging

Some of these sources or errors are system based or cannot be eliminated. But some are subject to improvement at the cost of other factors. The owner of the custody transfer tanks may decide considering all above. This paper focuses on potential error improvements when calibrating upright tanks — used in custody transfer — using a metering/volumetric incremental method based on author's experience with calibrating three 600,000 BBL crude oil floating roof tanks used in custody transfer application. The author was to ensure the calibration is conducted properly with acceptable control limits. The metering/incremental method is associated with high cost and many extensive logistics compared to the conventional method. A thorough evaluation process may be necessary to reach optimum selection.

2 INCREMENTAL METHOD USING VOLUMETRIC METERS

Per ISO4269, this method was applied to calibrate 600,000 BBL crude oil tanks used in custody transfer application. Calibration takes place by addition of multiple liquid batches as a volume transfer-medium. These liquid batches with proper control are measured accurately by a meter. The meter is calibrated by a prover prior to the process and is verified during batching. See calibration chain in figure 2. The system components per author experience are listed below. These maybe different depending on set-up configuration:

- The metering skid
- Sampling system
- Proving system (prover)
- Master meter
- Master prover
- Tank to be calibrated
- Associated instruments
- Control system
- Flow computer

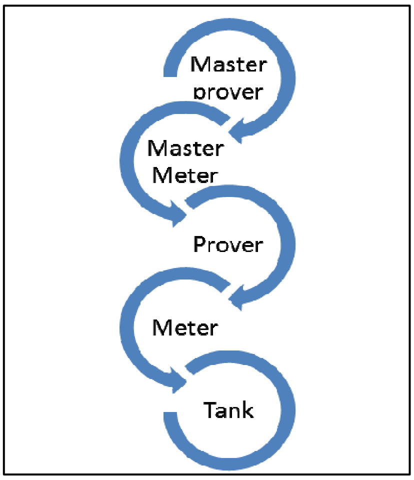

Fig. 2 – Calibration chain

Before commencing calibration, the system is checked for leakage downstream of the meter and all thermometers are calibrated in accordance with ISO 4268. Excessive variations in the temperature of the calibration liquid are avoided by selecting of fluid with temperature close to the expected prevailing ambient conditions throughout the calibration duration. Large fluctuations make it difficult to determine an accurate mean temperature and this in turn causes the following:

a. Uncertainties in applying the volume correction factors to the liquid.
b. Uncertainties in applying the correction factor for the expansion / contraction of the measuring equipment.
c. Uncertainties in applying the correction factor for the expansion / contraction of the tank being calibrated.

The exact height of the upper reference point above the dip-point is determined at the time of calibration and is recorded at the head of the table. The overall dipping height is marked on the top of the stilling well at or near to the dip hatch. The dip tape is used to measure the overall dipping height. The correction for thermal effect on tank shell is calculated in accordance with the equation given in ISO 4269 A.6. The check of the stability on the reference height is verified by the calibrator at every calibration.

In this method, the calibration liquid is transferred into the tank at the flow rate for which the meter has been calibrated and at such a rate as to minimize disturbance of the liquid surface in the tank. The calibration liquid is added in incremental volumes sufficient to produce a significant change in the liquid level with reference to the section of the tank being calibrated, and having due regard to the uncertainty of liquid level gauging. After the addition of each increment the liquid surface is allowed to settle and the liquid depth measured at the dip-point by use of a dip-tape and dip-weight. Liquid depth measurements is made and recorded to the nearest millimetre, the depth measurement is taken and is repeated the two measurements shall agree to within 1mm, if the readings differ from each other by more than 1mm, then the depth measurements is repeated until two consecutive readings are within that tolerance limit.

The batch number, level and area covered are shown in table 1 below:

Table 1 batch number and level

Batch #	Level mm	Remarks
1	0	start-up of the clean out door + roof legs + rain water drain
2	100	the datum
3	200	
4	300	start-up of the mixers & man holes
5	460	total height of the bottom crown up + water drain pipe
6	620	completion of clean out door
7	750	completion of mixers & man holes
8	1400	start-up of pantograph
9	1600	completion of the pantograph + completion of roof legs + near touching the roof + rain water drain
10	2000	roof float
11	2880	20% of course 2
12	4320	80%of course 2
13	5280	20% of course 3
14	6720	80% of course 3
15	7680	20% of course 4
16	9120	80% of course 4
17	10080	20% of course 5
18	11520	80% of course 5
19	12480	20% of course 6
20	13920	80% of course 6
21	14880	20% of course 7
22	16000	Max operating level

After each increase in depth has been measured and recorded, the temperature of the liquid at the meter, using the thermowell and in the tank is taken to the neatest 0.25°C or better. The calibrator takes one temperature at every point (3 in total, 2 on the roof 1 at the dip pipe) per meter height. The temperature readings taken by at the meters thermowell are at 15 to 20 minutes intervals – Calibrator cross checks with the installed Temperature Transmitters.

The ambient air temperature is measured to the nearest 0.25°c or better, at intervals throughout the calibration period. The recorded temperatures are taken at intervals of time which will accurately reflect the ambient air temperature throughout the calibration process. The pressure on the liquid at the meter is measured and recorded at intervals throughout the calibration period at times which accurately reflect the pressures exerted on the liquid throughout the calibration process.

2.1 Measurement Controls

The meter is calibrated for the type of liquid, viscosity temperature and range of flow rates over which it is used for at 8 flow rates from 2'800 to 11'050 bph (445 to 1'750 m^3/hr). The meter was run within the linear range at 6'900 bph (1'100 m^3/hr). The repeatability of the meter is such that the results of five consecutive proving runs is within a range of +/-0.025% of the average after correcting for temperature pressure and viscosity.

The meter factor for the meter in use is the average of the factors calculated at the commencement and completion of the calibration. The meter factor at the commencement and completion of the calibration will not differ by more than 0.05% (see figure 3).

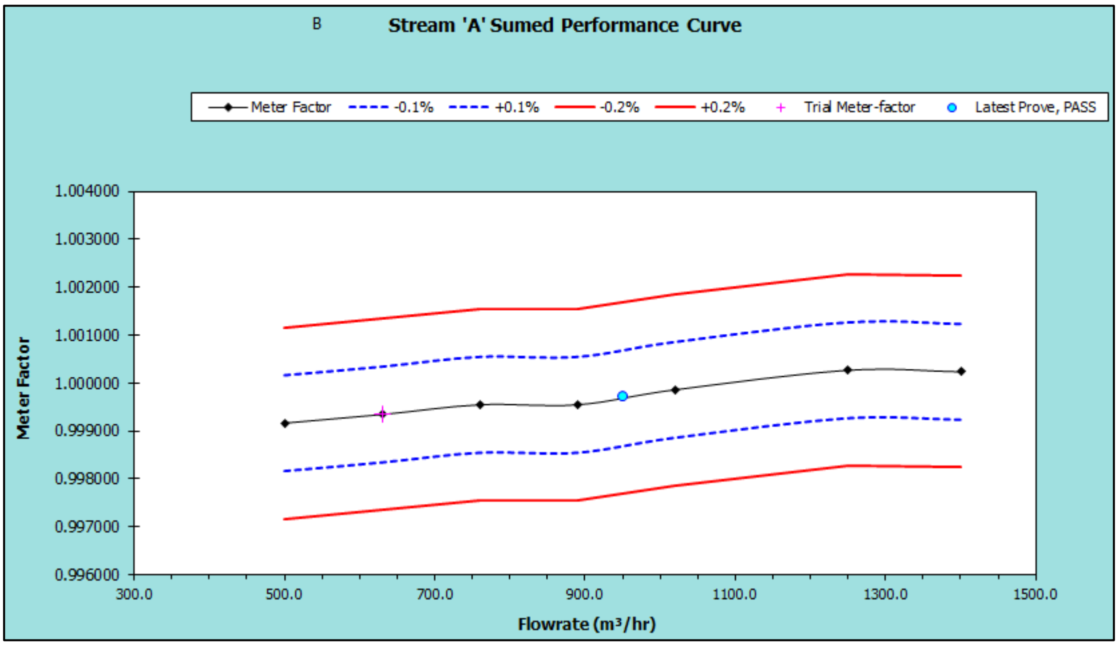

Fig. 3 meter factor control chart

2.2 Correction Factors

The pressure on the liquid is measured and recorded at intervals throughout the calibration period. A correction for the compressibility of the liquid is calculated using the tables contained in ISO 9770:1989.

Corrections for the hydrostatic effect of the liquid (liquid head correction) due to changes in dimension of the tank are automatically included in the final tank capacity tables, but only for liquids having similar densities to that of the calibration liquid used. if the liquid which the tank is to hold in operation differs significantly in density from that of the calibration liquid, correction for the effects of liquid head is required. Liquid head correction is calculated in accordance with ISO 7507-1.

A correction is made for any change in the temperature of the calibration liquid between the time that it is measured in the meter and the time that it is measured in the tank being calibrated. The volume delivered is corrected for temperature changes in the calibration liquid by using the volume correction factor (VCF) table for petroleum products in ISO 91-1: 1992.

The corrections are made in the following order:

- Correction of the observed calibration liquid temperature to reference temperature.
- Correction of the capacity of the tank shell for thermal effects.
- Correction of the liquid level measurement dip-tape for thermal effects.

A correction for the difference in temperature between the shell of the tank at the time of calibration and the standard reference temperature, 15°C, is made according to the method given in ISO 4269 annex A. the tank shell temperature is determined by one of the methods given in annex A of either ISO 7507-1:1993 or ISO7507-6:1997.

All readings of instruments are recorded as observed, without correction for errors which is shown separately. Recorded figures are checked for consistency before proceeding to the next entry. In all cases of doubt, the readings are verified. Temperature is recorded to at least the nearest 0.25^{0}C.

Factors obtained from tables are used without rounding. Other correction factors which require be calculated is correct to 5 significant figures. All calculations are carried out to be correct to at least 5 significant figures.

Depth measurements which is recorded to the nearest 1 mm, and is shown corrected to the nearest 1mm. The final tables are calculated by interpolation from the corrected cumulative volumes. Final volumes in tank capacity tables obtained by interpolation is rounded off to the nearest whole litres and shown against the required tabular interval of dip.

2.3 Sampling

Dynamic sampling system was installed to collect representative samples of fluid used. Before this system was used it was certified by water injection test. Water injection meter is installed and proven in accordance with API MPMS Chapters 4, and 5. The sampler is certified per API MPMS ch8.2 Appendix for the collection of S&W or free water samples.

Total system test is carried out. This test method is a volume balance test where tests are conducted for known amounts of water. It is designed to test the total system including the laboratory handling and mixing of sample. The test involves the sampler under test only.
The most common and worst case conditions to test the sampling system is the minimum flow rate of one single stream of 1'000 m^3/hr (6'300 BPH).

The test is designed for 1% increment in water content. For a total 2000 m^3 represented in the test sample, 20 m^3 of injected water is required. The duration of the test sample was approximately 2 hours. Same duration was seen for every base-line sample. At the rate of 1 m^3/sample, the minimum collected sample volume is 3 litres, which was adequate for the site sample receiver (9 litres can) and the lab mixing equipment.

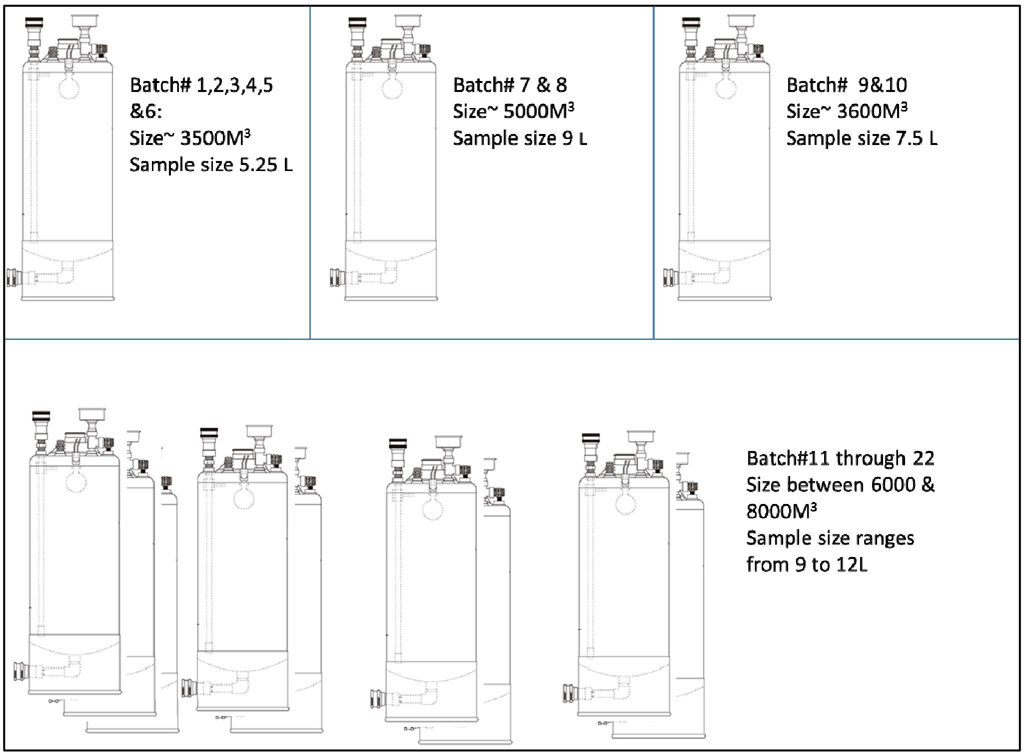

Fig. 4 Sample containers and batch

The following samples are collected:

- First 6 batches (around 3500 m^3) together in one sample in 9 litres sample receiver. At 1 m^3/sample grab, expected 3500 samples, equivalent to 5.25 Litters.
- Batches 7&8 (around 5000 m^3) together in one sample in 9 litres sample receiver. At 1 m^3/sample grab, expected 5000 samples, equivalent to 7.5 Litters.
- Batched 9&10 (around 3600 m^3) together in one sample in 9 litres sample receiver. At 1 m^3/sample grab, expected 3600 samples, equivalent to 5.5 Litters.
- Every batch from 11 to 22 in the cylindrical part. Each is sampled separately (approx 6'000 and 8'000 m^3) in 18 litres sample receiver. At 1 m^3/sample grab, expected 6'000 and 8'000 samples, equivalent to 9 and 12 Litters. See figure 4.

3 Data collection and processing

In each batching cycle when the fluid is metered and then pushed to the tank to be calibrated, data is collected from several points. Dynamic measurement data are collected at metering skid and sent to flow computer for net volume calculations. Dynamic measurement data includes pressure, temperature, meter output pulses and quality measurement of sampled fluid. The net standard volume calculation is computed using following calculations:

Indicated Volume (IV) = Meter output pulses X nominal K-factor (1)

Net Standard Volume = (IV) X MF X CTL X CPL (2)

Where:
- MF is meter factor
- CTL is temperature correction factor for liquid
- CPL is pressure correction factor for liquid

The static measurement data are collected for fluid level, tank reference height verified and temperature. As overall, each batch will then have observed volume, flow weighted average temperature, and flow weighted average pressure, meter factor, fluid quality and corresponding fluid level in tank. See table 2 below.

Table 2 data collection

Batch No	Nominal Flow Rate, m^3/h	Level mm	Batch Observed Volume, m^3	FWAT Deg.C	FWAP Bar	Meter Factor	API @ 60 Deg.F
1	650	0	119.8	31.63	5.18	0.998959	33.77
2	1000	100	358.2	30.92	4.67	0.999377	33.77
3	1000	200	516.8	30.54	4.64	0.999377	33.77
4	1000	300	899.5	29.98	4.61	0.999377	33.77
5	1000	460	908.2	29.71	4.62	0.999347	33.77
6	1000	620	3022.9	29.44	4.60	0.999361	33.77
7	1375	750	2432.8	29.36	3.58	0.999635	33.26
8	1375	1400	5552.9	29.28	3.56	0.999676	33.26
9	1375	1600	3274.6	29.25	3.49	0.999636	33.27
10	1375	2000	8807.5	29.30	3.43	0.999540	33.28
11	1375	2880	5932.0	29.39	3.42	0.999663	33.15
12	1375	4320	8845.1	29.19	3.38	0.999689	33.23
13	1375	5280	5900.8	29.17	3.33	0.999659	33.15
14	1375	6720	8896.5	29.35	3.25	0.999685	33.28

15	1375	7680	5949.7	29.23	3.23	0.999209	33.15
16	1375	9120	8849.3	29.10	3.11	0.999658	33.26
17	1375	10080	5938.5	29.27	3.11	0.999643	33.19
18	1375	11520	8847.3	29.33	3.05	0.999669	33.25
19	1375	12480	6010.2	29.22	3.03	0.999700	33.21
20	1375	13920	8555.6	29.22	2.98	0.999670	33.26
21	1375	14880	6280.5	29.33	2.91	0.999678	33.19
22	1375	16000	4946.9	29.45	2.87	0.999631	33.09

As each batch is terminated, the calculation for that batch is verified per equation 1 and 2 above. While batch is running, proving is conducted to ensure that each meter factor is valid. Example of proving run is shown in figure 5.

RUN No	METER						PROVER			
	Pulses									
	Forward	Reverse	R/Trip	Temp.(F)	Press.(Bar)	Run Time (s)	Temp. In (F)	Temp. Out (F)	Press. In (Bar)	Press.Out (Bar)
	11690.48			86.6	3.4	8.912	86.3	86.4	3.4	2.9
1		11676.46	23366.94	86.6	3.4	8.916	86.2	86.5	3.4	2.9
	11688.45			86.5	3.4	8.906	86.2	86.4	3.4	2.9
2		11680.17	23368.62	86.4	3.4	8.917	86.2	86.3	3.4	2.9
	11692.01			86.4	3.4	8.916	86.2	86.3	3.4	2.9
3		11679.79	23371.80	86.5	3.4	8.910	86.2	86.4	3.4	2.9
	11693.68			86.5	3.4	8.916	86.2	86.3	3.4	2.9
4		11685.65	23379.33	86.5	3.4	8.914	86.2	86.4	3.4	2.9
	11688.10			86.5	3.4	8.916	86.2	86.3	3.4	2.9
5		11671.43	23359.53	86.5	3.4	8.920	86.3	86.4	3.4	2.9

Fig. 5 Proving runs

The development of the capacity tables is per ISO 7507-2 and ISO 7507-5 where the calculated space inside the tank is replaced by batched volume. Each batch volume is then corrected to in tank temperature and summed to obtain the volume of product in the tank at tank temperature. The weight of the floating roof is calculated based upon the batch volume during which the roof was floated, the difference in volume for the same level difference in the dry calibration table, and the density of product at tank temperature in the tank. As floating roof is lifted and must be taken out of the liquid calibration to allow for a separate correction page for the 2 critical zones, the batch volume, in which the roof is lifted, is corrected for the calculated roof weight divided by the density of product. Correction for the effect of fluid head due to changes in tank demotions is already included in tank capacity table. This applies only for liquids having similar densities to that used in calibration

Now the fluid drops out of the equation and the volume height temperature combination can be corrected using shell steel expansion to the reference temperature of the table. The density of the product in the tank must then be offset against the reference density for the table in order to calculate the difference for expansion under liquid head, to be applied for each of the stop points.

This delivers a skeleton table which must then be interpolated to obtain the final table. Interpolation methods used for the liquid calibration in two zones:

- For the bottom part where of volume change vs. vertical distance is sharp, Quadratic spline interpolation is applied by calibrator.
- For part when bottom is covered and where of volume change vs. vertical distance is less, linear interpolation is used.

The Quadratic mathematical interpellation in first part accounts for shaper and irregular changes in displaced volume versus height. This is due to the fact the lower part of the tank has more deadwoods and is more likely to be affected by an initial flexing in bottom plates. As the level of liquid increased beyond 2 meters say, the changes in tanks physical shape which contributes to directly to displaced volume enclosed within are better predictable with linear interpolation. This is evident in the resulting calibration table seen in table 3 and 4.

Table 3 Tank Calibration table

(LIQUID CALIBRATION)

MAIN CAPACITY TABLE

HEIGHT mm	CAPACITY M3	HEIGHT mm	CAPACITY M3	HEIGHT mm	CAPACITY M3	HEIGHT mm	CAPACITY M3
10	132.689	390	2 127.621	770	4 438.969	1150	6 744.260
20	166.123	400	2 188.538	780	4 499.756	1160	6 804.743
30	199.852	410	2 249.454	790	4 560.543	1170	6 865.226
40	234.102	420	2 310.370	800	4 621.331	1180	6 925.709
50	269.100	430	2 371.286	810	4 682.118	1190	6 986.192
60	305.072	440	2 432.202	820	4 742.905	1200	7 046.675
70	342.245	450	2 493.119	830	4 803.693	1210	7 107.158
80	380.846	460	2 554.035	840	4 864.480	1220	7 167.641
90	421.101	470	2 614.951	850	4 925.267	1230	7 228.124
100	463.236	480	2 675.867	860	4 986.054	1240	7 288.607
110	507.465	490	2 736.783	870	5 046.842	1250	7 349.090
120	553.788	500	2 797.699	880	5 107.629	1260	7 409.573
130	602.042	510	2 858.500	890	5 168.416	1270	7 470.056
140	652.061	520	2 919.287	900	5 229.204	1280	7 530.538
150	703.678	530	2 980.074	910	5 289.991	1290	7 591.021
160	756.726	540	3 040.861	920	5 350.778	1300	7 651.504
170	811.040	550	3 101.649	930	5 411.565	1310	7 711.987
180	866.452	560	3 162.436	940	5 472.353	1320	7 772.470
190	922.796	570	3 223.223	950	5 533.140	1330	7 832.953
200	979.906	580	3 284.011	960	5 593.927	1340	7 893.436
210	1 037.621	590	3 344.798	970	5 654.715	1350	7 953.919
220	1 095.860	600	3 405.585	980	5 715.502	1360	8 014.402
230	1 154.586	610	3 466.372	990	5 776.289	1370	8 074.885
240	1 213.760	620	3 527.160	1000	5 837.016	1380	8 135.368
250	1 273.347	630	3 587.947	1010	5 897.499	1390	8 195.851
260	1 333.310	640	3 648.734	1020	5 957.982	1400	8 256.334
270	1 393.611	650	3 709.522	1030	6 018.464	1410	8 316.620
280	1 454.215	660	3 770.309	1040	6 078.947	1420	8 376.905
290	1 515.083	670	3 831.096	1050	6 139.430	1430	8 437.191
300	1 576.180	680	3 891.883	1060	6 199.913	1440	8 497.476
310	1 637.469	690	3 952.671	1070	6 260.396	1450	8 557.762
320	1 698.912	700	4 013.458	1080	6 320.879	1460	8 618.047
330	1 760.473	710	4 074.245	1090	6 381.362	1470	8 678.333
340	1 822.115	720	4 135.033	1100	6 441.845	1480	8 738.618
350	1 883.801	730	4 195.820	1110	6 502.328	1490	8 798.904
360	1 944.873	740	4 256.607	1120	6 562.811	1500	8 859.189
370	2 005.789	750	4 317.394	1130	6 623.294	1510	8 919.475
380	2 066.705	760	4 378.182	1140	6 683.777	1520	8 979.760

Based on thank height some corrections were made to account to roof weight effect as follows:

Zone 1: For height where the roof is resting on its support and liquid is not touching any part of the roof, no correction has to be made to values obtained from tank capacity tables.

Zone 2 (critical zone): At heights where roof is resting on its support but partially immersed in liquid, the values obtained from tank capacity tables are not accurate for volume. Opening and closing reading shall not start or end in this zone.

Zone 3: For heights where the roof is fully floating, the values obtained from tank capacity tables are corrected if the density of the measured fluid is deferring than used in calibration. The correction table is provided in table 5.

Table 4 Tank Calibration table

HEIGHT mm	CAPACITY M3	HEIGHT mm	CAPACITY M3	HEIGHT mm	CAPACITY M3	HEIGHT mm	CAPACITY M3
1530	9 040.046	1910	11 330.896	2290	13 621.746	2670	15 918.510
1540	9 100.331	1920	11 391.182	2300	13 682.032	2680	15 979.014
1550	9 160.617	1930	11 451.467	2310	13 742.317	2690	16 039.519
1560	9 220.902	1940	11 511.753	2320	13 802.603	2700	16 100.023
1570	9 281.188	1950	11 572.038	2330	13 862.888	2710	16 160.528
1580	9 341.474	1960	11 632.324	2340	13 923.174	2720	16 221.033
1590	9 401.759	1970	11 692.609	2350	13 983.459	2730	16 281.537
1600	9 462.045	1980	11 752.895	2360	14 043.745	2740	16 342.042
1610	9 522.330	1990	11 813.180	2370	14 104.030	2750	16 402.546
1620	9 582.616	2000	11 873.466	2380	14 164.316	2760	16 463.051
1630	9 642.901	2010	11 933.751	2390	14 224.601	2770	16 523.555
1640	9 703.187	2020	11 994.037	2400	14 284.887	2780	16 584.060
1650	9 763.472	2030	12 054.322	2410	14 345.392	2790	16 644.564
1660	9 823.758	2040	12 114.608	2420	14 405.896	2800	16 705.069
1670	9 884.043	2050	12 174.893	2430	14 466.401	2810	16 765.573
1680	9 944.329	2060	12 235.179	2440	14 526.905	2820	16 826.078
1690	10 004.614	2070	12 295.465	2450	14 587.410	2830	16 886.583
1700	10 064.900	2080	12 355.750	2460	14 647.914	2840	16 947.087
1710	10 125.185	2090	12 416.036	2470	14 708.419	2850	17 007.592
1720	10 185.471	2100	12 476.321	2480	14 768.923	2860	17 068.096
1730	10 245.756	2110	12 536.607	2490	14 829.428	2870	17 128.601
1740	10 306.042	2120	12 596.892	2500	14 889.932	2880	17 189.105
1750	10 366.328	2130	12 657.178	2510	14 950.437	2890	17 249.610
1760	10 426.613	2140	12 717.463	2520	15 010.942	2900	17 310.114
1770	10 486.899	2150	12 777.749	2530	15 071.446	2910	17 370.619
1780	10 547.184	2160	12 838.034	2540	15 131.951	2920	17 431.123
1790	10 607.470	2170	12 898.320	2550	15 192.455	2930	17 491.628
1800	10 667.755	2180	12 958.605	2560	15 252.960	2940	17 552.133
1810	10 728.041	2190	13 018.891	2570	15 313.464	2950	17 612.710
1820	10 788.326	2200	13 079.176	2580	15 373.969	2960	17 673.296
1830	10 848.612	2210	13 139.462	2590	15 434.473	2970	17 733.882
1840	10 908.897	2220	13 199.747	2600	15 494.978	2980	17 794.468
1850	10 969.183	2230	13 260.033	2610	15 555.482	2990	17 855.053
1860	11 029.468	2240	13 320.319	2620	15 615.987	3000	17 915.639
1870	11 089.754	2250	13 380.604	2630	15 676.492	3010	17 976.225
1880	11 150.039	2260	13 440.890	2640	15 736.996	3020	18 036.811
1890	11 210.325	2270	13 501.175	2650	15 797.501	3030	18 097.397
1900	11 270.611	2280	13 561.461	2660	15 858.005	3040	18 157.982

Table 5 Density correction table

Weight of floating roof as measured : 477602 Kg.

DENS	.000	.001	.002	.003	.004	.005	.006	.007	.008	.009
0.81	589.63	588.91	588.18	587.46	586.73	586.01	585.30	584.58	583.87	583.15
0.82	582.44	581.73	581.02	580.32	579.61	578.91	578.21	577.51	576.81	576.12
0.83	575.42	574.73	574.04	573.35	572.66	571.98	571.29	570.61	569.93	569.25
0.84	568.57	567.90	567.22	566.55	565.88	565.21	564.54	563.87	563.21	562.55
0.85	561.88	561.22	560.57	559.91	559.25	558.60	557.95	557.30	556.65	556.00
0.86	555.35	554.71	554.06	553.42	552.78	552.14	551.50	550.87	550.23	549.60

4 Analysis

The calibration on subject tank above was conducted using crude oil. Another typical calibration was conducted using EODR method. It is interesting to compare some parameters for tank capacity tables resulting from each method.

Figure 6 shows the volume difference between values obtained from liquid calibration tables and values obtained from dry calibration for tank T1. These differences were computed at even heights starting at 1000mm through 16000 mm with 1000 mm increments. The variations in volume at these stops are large. For instance at 6000, 7000 and 1400 mm the difference seen is more than 17,000 m^3. It is apparent that these differences are function of the heights or level of liquid. This means if these selected points to compare were different then we could see another trend. More interestingly, the summation of these differences will result in relatively small value close to 100 m^3. It was suggested by the calibrator that for dry calibration, the litres per mm value only changes at the change of rings. For liquid calibration, it will change every stop height. With a change of 1mm in liquid level at the start and end of each stop, and a stop for just every 1 meter interval, the variation of incremental differences will be influenced easily by 0.2%.He suggested to compare for differences against total quantity in tank to indicate total difference between tables, after subtracting bottom quantity.

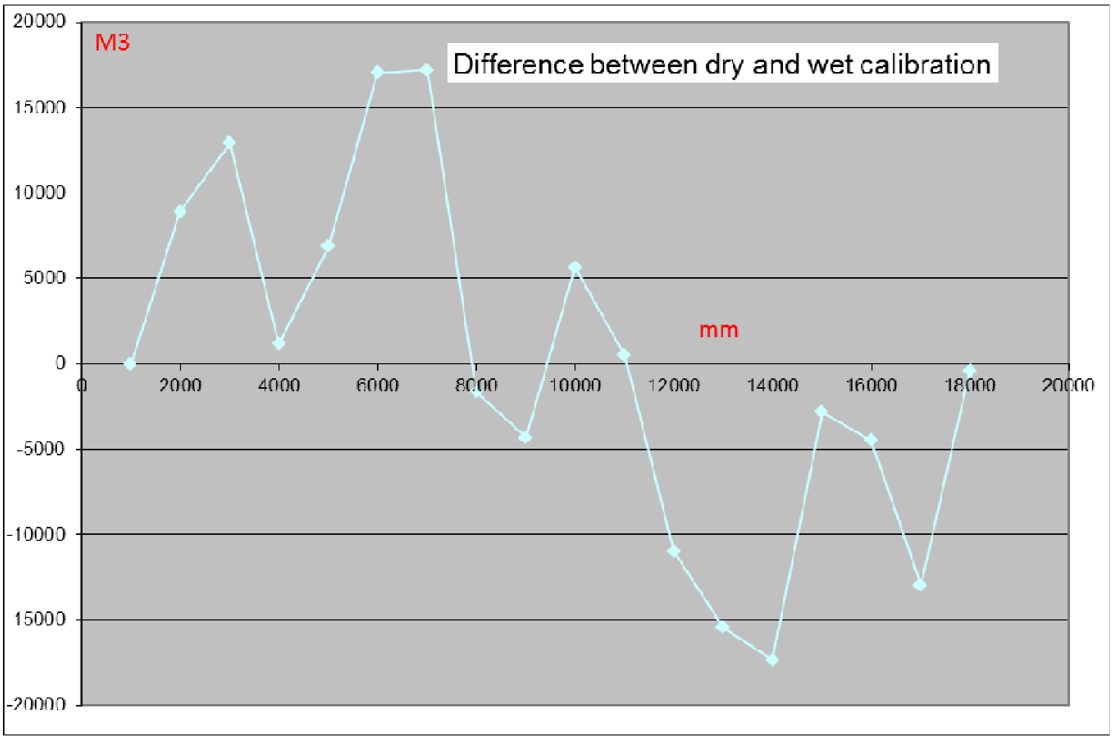

Fig. 6 Volume differential of wet and dry calibration for Tank T1

While these conclusions stand for tank T1, other tanks did not show the same results. For tank T3, the differences seen were in one direction and the summation of all differences were more than 0.10% of the total volume of the tank, see Figure 7. Unlike tank T3, tank T1 was recently tested, inspected and maintained. This could explain for the change in Litre/ MM values. But that could not provide explanation for the overall difference in tank volume. That can be further investigated by simulating the stress deformation on tank dimensions which is beyond the scope of this paper but can be addressed in future.

Analysing the source of errors of these tanks based on earlier studies by C. Stewart Ash and Frank J. Berto we could produce table 6. Note that if the datum plat was securely fixed and did not experience any physical movement due to tank wall stress, then the tank capacity tables are the source of the highest error in that table. That can be realized knowing that estimating the enclosed volume based physical measurement while the tank is empty does the

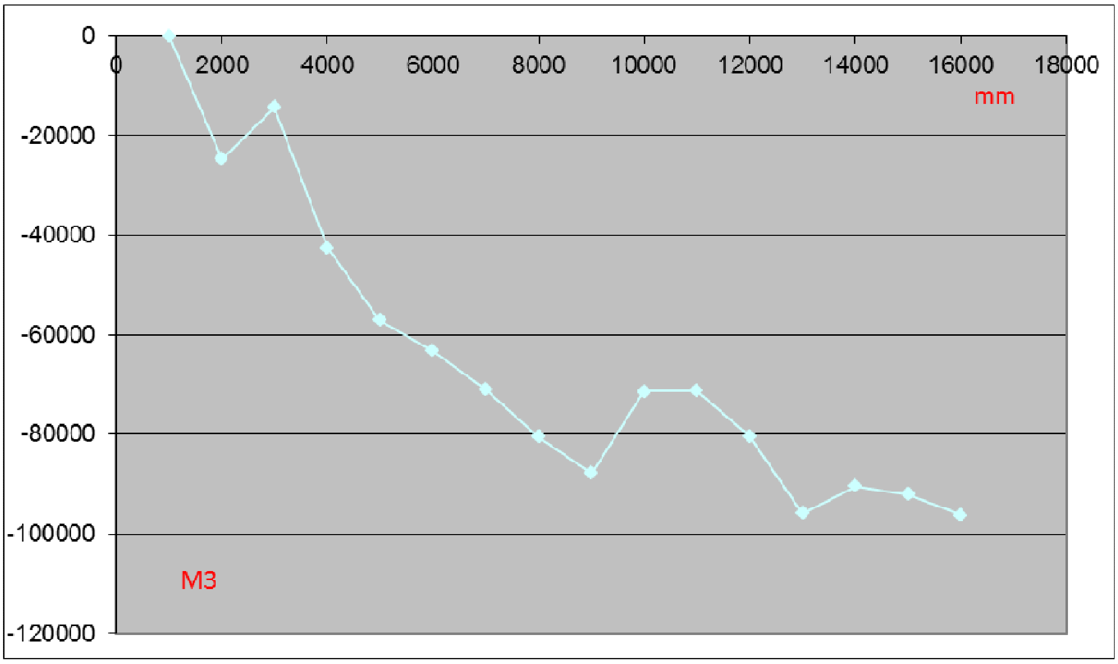

Fig. 7 Volume differential of wet and dry calibration for Tank T3

calibration process. Hence that when the calibration is conducted using a metering/volumetric incremental method then some factors in this table add in while others drop out due to the nature of process. For example the bottom movement and datum plat movement are less likely to affect the calibration as their movement effect factors-in during filling. In another word, for none-permanent structural changes that results from fluid load on tanks sides and bottom, metering/volumetric incremental method should account for these changes as they happen during filling/ calibration. Note that bottom flexing for bottom shell is normal provided that flexing will always result in volume changes that are below datum plate. The weight of the fluid or liquid head against the tank wall causes the wall to bow see figure 9. "Large tanks tend to have rounded corners to transition from vertical side walls to bottom profiles to help withstand hydraulic hydrostatically induced pressure of contained liquid" according to a major tank gauging instruments vendor.

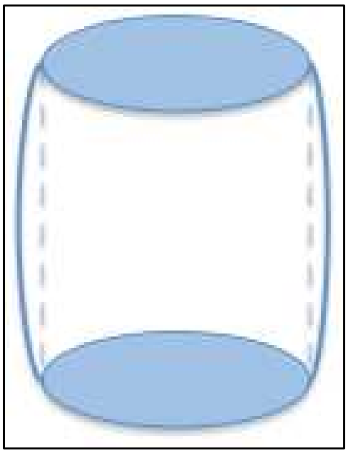

Fig. 9 Tank

Table 8 Estimated errors in tank measurement for a 600,000 tank

Source of error	**In inches**	**In barrels**	**In %**
Tank Table Errors	±0.6 in	±900bbl	±0.15%
Bottom Movement	+0.25 in	+ 360 bbl	+0.06%
Shell Diameter Thermal Expansion	+0.25 in	+ 360 bbl	+0.06%
Datum Plate Upward Movement	+1.5 in	+2100 bbl	+0.35%
Error in Temperature Reading	±0.5 in	±720bbl	±0.12%
Tape Calibration	±0.12 in	± 180 bbl	±0.03%
Tape Thermal Expansion	±0.15 in	± 240 bbl	±0.04%
Human Errors - Level Reading	±0.12 in	± 180 bbl	±0.03%

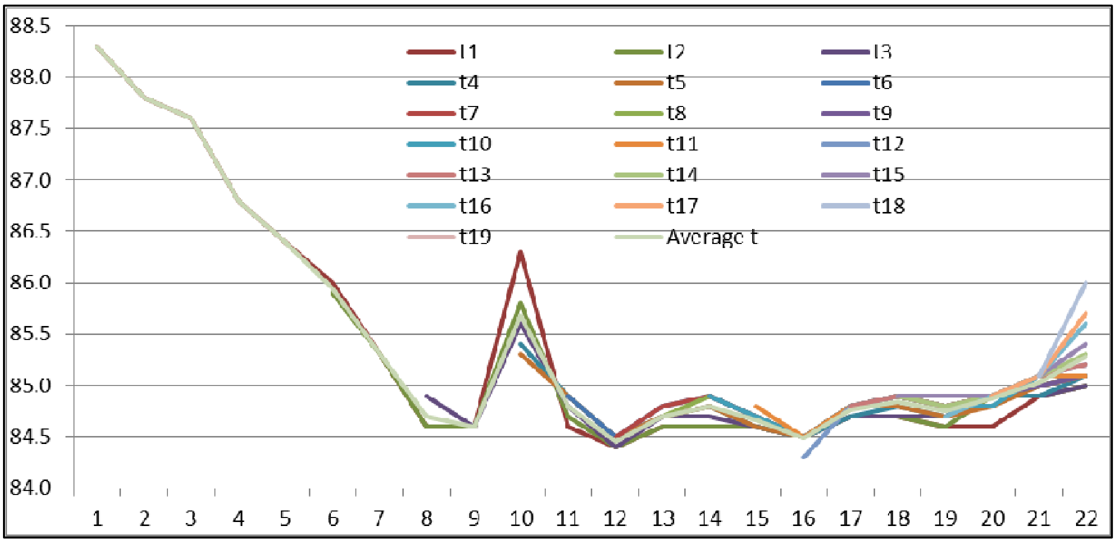

Fig. 8 Temperature trend on tank vs. batch #

Looking at temperature readings from manual gauging measurement for the tank (figure 7) where t1 through t19 are at each level where the batch number indicates, some remarks can be made. Temperature has the largest impact on tank bottom measurement due to difference between tank temperature, ambient temperature and fluid temperature. While effect of thermal expansion or contraction is corrected-for in measurement calculation, the induced error remains a factor. In addition, average temperature readings for fluids at higher level have better confident level from statistical prospective. This is evident in figure 8 where maximum and minimum temperatures for batch 21 are just 0.2 ^{o}F apart. Another factor to consider is incoming fluid batch temperature. Batches with varying temperature are more likely to introduce more uncertainty on tank shell expansion and fluid density calculation . This will be addressed in conclusion for better control of calibration process.

Batch No	Temperatures (Deg.F)																		Avg. Temp.	ATG. Temp.	Abt. Temp.
1	88.3																		88.3	---------	81.9
2	87.8																		87.8	---------	82.7
3	87.6																		87.6	---------	79.5
4	86.8																		86.8	80.80	81.0
5	86.4																		86.4	80.30	81.0
6	86.0	85.9																	86.0	77.50	77.4
7	85.3	85.3																	85.3	74.32	73.9
8	84.6	84.6	84.9																84.7	69.60	68.9
9	84.6	84.6	84.6																84.6	69.06	67.0
10	86.3	85.8	85.6	85.4	85.3														85.7	81.90	78.2
11	84.6	84.7	84.8	84.9	84.9	84.9													84.8	82.26	76.8
12	84.4	84.4	84.4	84.5	84.5	84.5	84.5												84.5	79.93	66.4
13	84.6	84.6	84.7	84.7	84.7	84.8	84.8	84.7											84.7	84.98	76.0
14	84.6	84.6	84.7	84.8	84.8	84.9	84.9	84.9	84.9	84.9									84.8	84.32	86.9
15	84.6	84.6	84.6	84.6	84.6	84.7	84.7	84.7	84.7	84.7	84.8								84.7	83.11	76.2
16	84.5	84.5	84.5	84.5	84.5	84.5	84.5	84.5	84.5	84.5	84.5	84.3							84.5	83.47	71.1
17	84.7	84.7	84.7	84.7	84.8	84.8	84.8	84.8	84.8	84.8	84.8	84.8	84.8						84.8	84.45	84.5
18	84.7	84.7	84.7	84.8	84.8	84.9	84.9	84.9	84.9	84.9	84.9	84.9	84.9	84.9	84.9				84.8	84.17	88.3
19	84.6	84.6	84.7	84.7	84.7	84.8	84.8	84.8	84.8	84.8	84.8	84.8	84.8	84.8	84.9	84.7			84.8	84.00	82.0
20	84.6	84.9	84.9	84.9	84.8	84.9	84.9	84.9	84.9	84.8	84.9	84.9	84.9	84.9	84.9	84.9	84.9		84.9	84.04	83.5
21	84.9	84.9	84.9	84.9	85.0	85.0	85.0	85.0	85.0	85.1	85.1	85.1	85.1	85.1	85.1	85.1	85.1	85.1		85.0	84.11	88.8
22	85.0	85.0	85.0	85.1	85.1	85.1	85.1	85.1	85.1	85.1	85.1	85.2	85.2	85.3	85.4	85.6	85.7	86.0	86.1	85.3	84.25	92.0

Fig. 8 Temperature reading on tank vs. batch #

5 Conclusion

Applying metering/volumetric incremental method when calibrating upright cylindrical tanks used in custody transfer applications has some merits over other methods. Some of these merits were discussed in section 4 above. These merits are not absolute and can vary from one site to another. In order to get the best out of this method the following is suggested to apply good control of the process:

- Writing a detailed procedure that lists down all items, reference standards, agreements and deviations. This must be carefully reviewed by all parties involved before the calibration starts. It is costly stop the process if a flaw or mistake is discovered after calibration commences.
- Selecting an experience Third Party Calibrator. This will contribute to the accreditation of the calibration process and ensure adherence to respective codes and standards followed.
- Certify each component of the chain. The sampling system, the master meter, the master prover, the working prover, the working meter(s), the temperature and pressure sensing elements, the electronic loops and the gauging tape(s) must be all certified.
- Quality control of fluid used in calibration. It is essential that the fluid density used is selected as close as possible to the fluid to be gauged later. If not or if water is used then proper correction shall be applied for liquid head. Fluids used must be well mixed where its properties at both sampling points dynamic and static are not different.
- Temperature control of fluid used in calibration. Where possible, allow enough time for fluid's temperature to stabilize. Uniform and steady temperature throughout all batches leads to better results.
- Decrease the batch size and increase batch numbers. This will allow better interpolation especially for the lower part of the tank where more the litres per mm are more critical.

When deciding on metering/volumetric incremental for tank calibration method applied Comprehensive consideration to the following must take place:

- <u>The Tank experience factor history</u>: if tank is known to have erroneous loading or discharge history even when calibrated using typical methods
- <u>Tank size and usage</u>: although this method is not targeting super-size tanks, the capacity of the tank must be taken into consideration as the cost of the calibration might offset any savings resulting from calibration
- <u>Ability to apply good control to the process</u>: this method involves transferring traceability. Good control will ensure the validity of each standard.
- <u>Comparing wet and dry calibration data</u>: it is a good practice to check the tank capacity tables when applying liquid calibration against old one using typical method. This will confirm the need to recalibrate using same method.

6 REFERENCES

[1] ISO 4269:2001 Petroleum and liquid petroleum products - Tank calibration by liquid measurement - Incremental method using volumetric meters. - 1st edition.

[2] ISO 91-1:1992, Petroleum measurement tables- Part 1: Tables based on references temperature of 15°C and 60°F.

[3] ISO 91-2:1991, Petroleum measurement tables- Part 2: Tables based on a reference temperature of 20°C.

[4] ISO 2715:1981, Liquid hydrocarbons-volumetric measurement by turbine meter systems.

[5] ISO 4268, Petroleum and liquid petroleum products-temperature measurements-manual methods.

[6] ISO 7507-2:2005, Petroleum and liquid petroleum products -- Calibration of vertical cylindrical tanks -- Part 2: Optical-reference-line method.

[7] ISO 7507-5:2000, Petroleum and liquid petroleum products -- Calibration of vertical cylindrical tanks -- Part 5: External electro-optical distance-ranging method.

[8] ISO 9770:1989, Crude petroleum and petroleum products-compressibility factors for hydrocarbons in the range 638 kg/ m^3 to 1074 kg/ m^3.

[9] IEC 60079-10, Electrical apparatus for explosive gas atmospheres – Part 10: Classification of hazardous areas.

[10] API MPMS chapter 8.2 Standard Practice for Automatic Sampling of Liquid Petroleum and Petroleum Products

[11] C. Stewart Ash, Measurement accuracy and sources of error in tank gauging.

[10] Frank J. Berto, Method for volume measurement using tank-gauging devices can be prone, oil & gas journal, 1989.