

Flomeko 2003 - Paper 135

Calibration of 24 ton weighing scale by Coriolis mass master meter

Uncertainty calculation in load and in load difference

by

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Introduction

At the MicroMotion Flowfacilities (= division of Emerson Process Management) in Veenendaal – the Netherlands, the Coriolis MicroMotion meters are gravimetric calibrated for the European users via the standing start and stop method. These flowfacilities have a “stand uncertainty” (Calibration and Measurement Capability ; CMC) of 0.03%.

The biggest scale of this facility, a 24000 kg scale for flowcapacities up till 660 t/h and based on gyroscopic balance, is calibrated since three years via a Coriolis MicroMotion mass master meter. The reason for this method is that placing 3 times 24 * 1 ton weights on the bottom of the tank is a very timely consuming task (2 days) ; the master meter method is much shorter in time and should hopefully lead to approximately the same uncertainty as performed with weights.

The mass master meter method has a longer traceability chain than calibrating with weights so the question was if it is feasible to get again a CMC of 0.03 % at the final end.

This paper explains the calibration method ; latest results (February / March 2003) and, very surprisingly, the reasons why the results are better than obtained from calibration with weights.

This paper includes:

- Theory of weighing of liquid
- Introduction of three independent factors for the weighing scale: Weighing scale factor (WSF) ; Buoyancy Vapour Correction (BVC) and Immersed Pipe Correction (IPC)
- Determination of the uncertainty of scale in load
- Determination of the uncertainty of scale in load-difference, based on an agreed calculation method with NMI-VSL (Dutch National Standards institute)
- Determination of the CMC of a gravimetric flowcalibration facility under operating conditions
- How to minimise CMC for a special case
- Results of this performed procedure

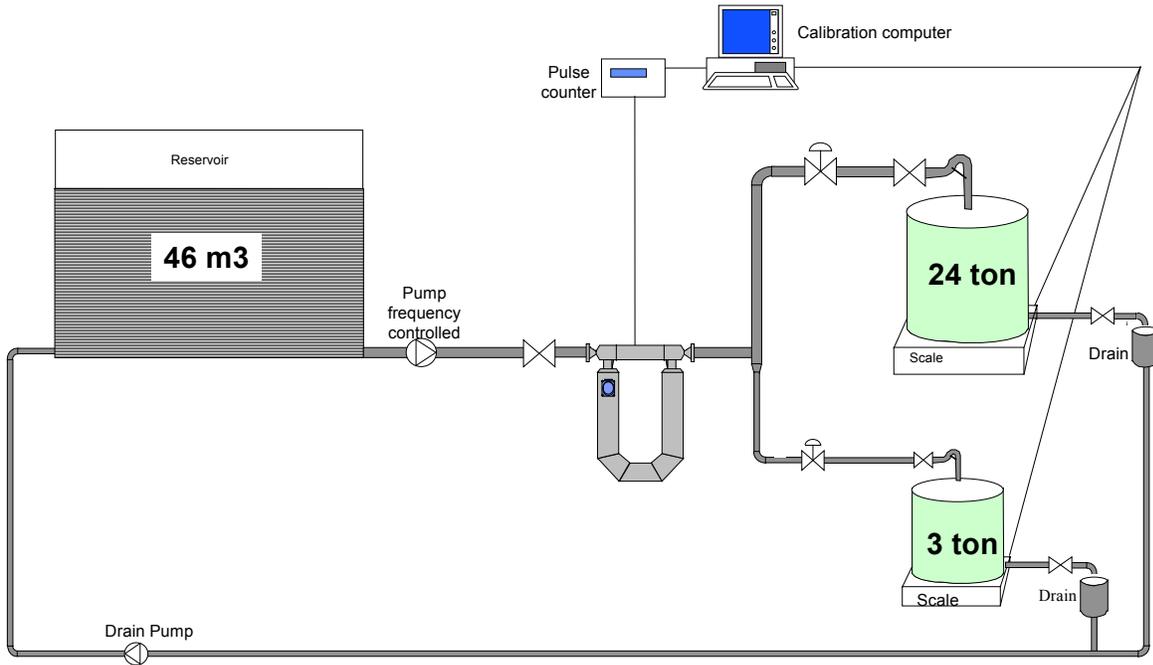
This paper ends with two conclusions:

- Reason why this master meter method gives a smaller uncertainty in relation to the calibration with weights
- There is a need for a well defined, written calculation method when a scale is used from one load to another load (load difference). Is currently very dependent of the involved company (authority) for the assessment.

Testfacility

The 24 t scale is one of two scales of the water calibration facility "stand # 4" ; the other scale is a 3000 kg scale.

By setting the valves in particular positions, the waterflow can be directed to the 3000 kg weighing tank or to the 24000 kg weighing tank.



The 24000 kg scale is calibrated by calibrating first the mass master meter against the well known 3000 kg scale and then pumping water in the tank of the 24000 kg scale via the well known master meter. After these tests, the master meter is verified against the 3000 kg scale for stability.

Weighing theory

A calibration of a scale results normally in stating the load (weight) with its deviation and corresponding uncertainty.

Because the scale, as described in this paper, is used for the calibration of flowmeters from load 1 to load 2 (load difference), the uncertainty in the "load difference" is also the objective of these activities.

The calibration of the mass master meter takes place in units of "mass in vacuo" while the scale indicates "mass in air" so that the buoyancy has to be taken into account.

To understand this unique calibration process of a scale as described in this paper, one should first exactly understand the theory of weighing, which is laid down in document "Calculation of liquid-mass out of weighing scale and its related uncertainty" by the same author as this paper. This document is a reference document for this paper and attached at the end.

Note: This document was already a reference document for the paper "Traceability and uncertainty analysis for a calibration process for flowmeters, using Coriolis flowmeters as reference", presented at the Flomeko 2000 in Brasil.

A scale is measuring in principle a force but adjusted in such a way that it indicates mass-units.

Indicating of weighing scale ws_{i-use} during use corresponds to:

$$ws_{i-use} = \frac{1}{WSF * g_{cal}} \cdot Force_{use} \quad (\text{equation 1})$$

WSF= Weighing Scale Factor, coming from weighing scale calibration

g_{cal} = gravity acceleration at calibrationlocation

$$\text{WSF} = \frac{\left(1 - \frac{1.2}{8000}\right) \cdot \left(1 - \frac{\rho_{\text{air-cal}}}{\rho_w}\right)}{\left(1 - \frac{1.2}{\rho_w}\right)} \quad (\text{equation 2})$$

$\rho_{\text{air-cal}}$ = density of ambient air during weighing scale calibration
 ρ_w = density of weights, used during weighing scale calibration

If liquid is weighed in an open container (liquid displaced the vapour), the force F_{liquid} on the scale corresponds to :

$$F_{\text{liquid}} = g_{\text{use}} \cdot m_{\text{liq}} \cdot \left(1 - \frac{\rho_{\text{vap}}}{\rho_{\text{liq}}}\right) = g_{\text{use}} \cdot m_{\text{liq}} \cdot \frac{1}{\text{BVC}} \quad (\text{equation 3})$$

g_{use} = gravity acceleration at location of scale during use
 m_{liq} = mass of liquid ("mass in vacuo")
 BVC = Buoyancy Vapour Correction →

$$\text{BVC} = \frac{1}{\left(1 - \frac{\rho_{\text{vap}}}{\rho_{\text{liq}}}\right)} \quad (\text{equation 4})$$

The scale will then indicate:

$$\Delta \text{WS}_i = \frac{m_{\text{liq}}}{\text{WSF} * \text{BVC}} * \frac{g_{\text{use}}}{g_{\text{cal}}} \quad (\text{equation 5})$$

($g_{\text{use}} = g_{\text{cal}}$ when scale is used on same location as calibrated)

Because the mass master meter is calibrated in mass in vacuo against the 3000 kg scale, its reading represents therefore mass in vacuo. When liquid (m_{liq}) passes the mass master meter and is caught in the tank, belonging to the 24 t scale, the indication of scale corresponds to equation 4.

Therefore the mass master meter reading (m_{liq}) is converted to a scale reading by means of equation 4 so that then the deviation can be determined between scale indication and reference (converted mass from mass master meter).

Calibration procedures

The calibration of the 24 ton scale occurs in five steps:

- Calibration of the 3000 kg scale with weights within 6 months before the calibration of the 24 ton takes place
- Calibration of a 3" Micro Motion Coriolis (CMF300) meter with the 3000 kg scale at one particular flowrate of 2000 kg/min (error and uncertainty of this meter at this flowrate is then well known) ; additional tests are performed to estimate the influence of flowrate and batch duration (= extra uncertainty).
- Calibrating the 24 ton scale with the master meter by delivering 12 batches of 2000 kg into the tank without draining, 3 times repeated.
- Calibrating and verifying the stability of the master meter against the 3000 kg scale.
- Calibration of the 3000 kg scale with weights within one month after the calibration of the 24 tons scale.

Uncertainty analysis

The uncertainty calculation is based on equation 5 with two additions:

- correcting for observed errors of master meter and correcting for 50% of the observed shift over the last period for the 3000 kg scale, performed with meterfactor MF
- mass of the passed liquid through the master meter comes from counting the number of pulses, divided by the pulse scaling factor PSF ; $\text{mass}_{\text{liq}} = N/\text{PSF}$.

The final equation becomes:

$$\Delta WS_i = MF_{\text{mastermeter}} * \frac{1}{WSF * BVC} * \frac{N}{PSF} \quad \text{equation 6}$$

- Δwsi - indication weighing scale indication
- $MF_{\text{mastermeter}}$ - meterfactor of the mastermeter, as determined with the 3000 kg scale
- WSF - Weighing Scale Factor (see equation 2)
- BVC - Buoyancy Vapour Correction (see equation 4)
- N - number of pulses, as generated by the mass master meter
- PSF - Pulse Scale Factor (pulses/kg), as configured in the electronics of the master meter

There are 6 uncertainty sources (Δwsi ; $MF_{\text{mastermeter}}$; WSF ; BVC ; N and PSF), however PSF is a value in software, which is assumed to have an uncertainty of 0 so that only 5 sources are left.

Uncertainty determination, in relation to mass reference (“total load”)

$MF_{\text{mastermeter}}$

The uncertainty in meterfactor comes from statistical sum of CMC, on which the master meter is calibrated ; type A in mean as observed during the tests and the stop/stop effect .

The CMC for normal use of the 3000 kg scale (see uncertainty budget table in annex 1) is 0.03%.

However, for this event the CMC is adjusted to a smaller value and is based on following justification:

- * long term stability of 3000 kg scale is calculated from scale calibration before and directly after the master meter calibration (=19.7 g) so that the value can be reduced to 19.7 g / 2000 kg = 0.0010 % (long term stability for normal use is taken as 0.02%)
- * the number of pulses during each test is at least 250000 corresponding with 0.0005% (was 0.01 %)

The CMC during calibrating of master meter is laid down in table 1 below.

CMC special:

Calibration and Measurement Capability for 3000 kg scale in stand 4 ; special values represent expanded uncertainty with coverage factor $k=2$		
Source	Batchsize 2000 kg	
	gram	%
Scale interval (50 g)	58	0.0029
Repeatability (29 g ; 2s)	29	0.0015
M1 class weights (0.05 g / kg)	100	0.0050
Weighing Scale Factor (0.0019 g/kg)	3.8	0.0002
Long term stability (17 g shift with rect. distr.)	19.7	0.0010
Buoyancy Vapour Corr. (0.0133 g /kg)	26.6	0.0013
Transfer point (5.8 g with rect. distr.)	6.7	0.0003
Pulses (250000 with rect. distr.)	94	0.0005
CMC special	124.268	0.0063

Table 1

The repeatability (type A in the mean) is calculated as $2 \cdot \text{standard deviation} / \sqrt{n}$;
n is number of tests.

The error at a flowrate of 2000 kg/min is five times determined prior to 24 t scale calibration and five times afterwards.

The results of these 10 tests is an average error of -0.0820% and type A in mean is 0.0041% .

When calibrating the 24 ton scale, the indication of the master meter was corrected with a meter factor of 1.000820 , so that the observed, average error does not contribute in the uncertainty calculations.

Extra tests were also performed to determine the effect of smaller/bigger batch time and smaller/bigger batch sizes.

The results of these tests were such that they were interpreted to belong to the same population of the already mentioned 10 tests so that this effect was assumed to be negligible.

The start stop effect for a CMF 300 at 2000 kg/min for 2000 kg batches (duration 1 minute) is 0.0002% .

The combined uncertainty in the meter factor $MF_{\text{mastermeter}}$ is therefore :
 $\sqrt{(0.0063^2 + 0.0041^2 + 0.0002^2)} = 0.0076\%$

Weighing Scale Factor (WSF)

The uncertainty in Weighing Scale Factor (WSF) comes normally from uncertainty in air density during 24 ton scale calibration and uncertainty in density of weight material.

The uncertainty in WSF can be calculated with equation 29 out of referenced paper :

$$U_{\text{WSF}} = \sqrt{\left(\frac{\rho_{\text{air-cal}}}{\rho_w} \cdot U_{\rho_{\text{air-cal}}}\right)^2 + \left(\frac{(\rho_{\text{air-cal}} - 1.2)}{\rho_w} \cdot U_{\rho_w}\right)^2}$$

The air density in the facility is real time calculated on basis of measuring air temperature ; ambient pressure and relative humidity.

The relative uncertainty in the air density corresponds to 1% (worst case) and uncertainty in weight-material to 5% for normal calibration with weights (worst case).

In this particular case, U_{ρ_w} has value zero because calibration does not take place with weights.

However, to have only one consistent value for WSF for all scales, the uncertainty in WSF is taken from the normal scale calibration with weights.

Based on a worst case air density during scale calibration of 1.32 kg/m^3 (= indoor):

$$U_{\text{WSF}} = \sqrt{\left(\frac{1.32}{8000} * 1\%\right)^2 + \left(\frac{1.32 - 1.2}{8000} * 5\%\right)^2} = 0.00019\%$$

This corresponds to 1.9 mg/kg .

Buoyancy Vapour Correction (BVC)

The uncertainty in BVC can be calculated with equation 32 out of referenced paper :

$$U_{\text{BVC}} = \left(\frac{\rho_{\text{vap}}}{\rho_{\text{liq}}}\right) \sqrt{U_{\rho_{\text{vap}}}^2 + U_{\rho_{\text{liq}}}^2}$$

Based on a worst case air density during use of scale of 1.32 kg/m^3 +/- 1% ; water density of 995 +/- 0.13 kg/m^3 :

$$U_{\text{BVC}} = \left(\frac{1.32}{995}\right) \sqrt{(1\%)^2 + (0.013\%)^2} = 0.00133\%$$

This corresponds to 13.3 mg/kg for water.

Number of pulses (N)

During the calibration of 24 t scale, the number of pulses is at least 250000 per 2000 kg, corresponding with 0.0005%

Weighing scale indication (Δw_{si})

The uncertainty in the weighing scale indication comes from the scale interval ; transfer point and the type A in mean from the observed results.

- * Scale interval 100 g ; rectangular distributed gives $100 * 2/\sqrt{3} = 115.57$ g
- * Transfer point
 Elliptical area with radius $R1 = 23.2$ cm and $R2 = 13.4$ cm ; $A = 980$ cm² ;
 Variation in liquid height is assumed as 1 mm , corresponding to 0.098 kg; rectangular distributed $0.098 * 2/\sqrt{3} = 0.1132$ kg
 Uncertainty in relation to 2000 kg batchsize: $0.1132/2000 * 100 = 0.0057$ %
- * Type A in mean from observed tests is calculated as the **average** from type A in mean ($2 * \text{standard deviation}/\sqrt{n}$) at each load (see table 2), resulting in 0.0047 %.

Gyro indication kg	Deviation kg	2s (single) kg	2s mean	
			kg	%
2000.0	-1.298	0.5656	0.3266	0.0163
4000.0	-1.948	0.6598	0.3809	0.0095
6000.0	-2.490	0.3363	0.1942	0.0032
8000.0	-3.077	0.5538	0.3198	0.0040
10000.0	-3.660	0.6575	0.3796	0.0038
12000.0	-4.424	0.4631	0.2674	0.0022
14000.0	-4.998	0.7173	0.4141	0.0030
16000.0	-5.471	0.8463	0.4886	0.0031
18000.0	-5.985	0.9312	0.5376	0.0030
20000.0	-6.311	1.0525	0.6077	0.0030
22000.0	-6.862	1.0051	0.5803	0.0026
24000.0	-7.581	0.9782	0.5647	0.0024
Type A in mean at load			0.4218	0.0047

Table 2

The total uncertainty, expressed in relation to reference mass, comes from subsequent 2000 kg batches, sothat the relative total uncertainty corresponds to uncertainty in 2000 kg batches.

Total uncertainty 24 ton scale (calculated from 2000 kg batches) values represent expanded uncertainty with coverage factor $k=2$	
Source	Subsequent batches of 2000 kg (%)
Meterfactor master meter	0.0076
Weighing Scale Factor (0.0019 g/kg)	0.0002
Buoyancy Vapour Corr. (0.0133 g /kg)	0.0014
Pulses (250000 with rect. distr.)	0.0005
Scale interval 100 g (rect. distr.)	0.0058
Transfer point (0.098 kg with rect. distr.)	0.0057
Type A in mean (average all loads)	0.0047
Total uncertainty	0.0121 (=0.013)

Table 3

Uncertainty determination for load differences of 2000 kg

The uncertainty determination for 2000 kg batches (= load differences) corresponds with the uncertainty calculation for the load (see table 3 above) except that the type A in mean is different.

Type A in mean for load difference is calculated from the individual deviations per trajet (load difference per run; columns F ; G and H), then 2 * standard deviation/√n per trajet (column K) and then the average of column K, resulting in 0.0065 %.

A	B	C	D	E	F	G	H	I	J	K
Gyro indic. kg	Average deviation kg	Deviation run 1 kg	Deviation run 2 kg	Deviation run 3 kg	Deviation trajet 2000 run 1	Deviation trajet 2000 run 2	Deviation trajet 2000 run 3	2*st. dev single (kg)	2*st. dev single (%)	2* st. dev. mean (%)
2000.0	-1.298	-1.5080	-1.4096	-0.9764	-1.5080	-1.4096	-0.9764	0.5656	0.0283	0.0163
4000.0	-1.948	-2.2228	-2.0382	-1.5819	-0.7148	-0.6286	-0.6055	0.1153	0.0058	0.0033
6000.0	-2.490	-2.6480	-2.5093	-2.3133	-0.4252	-0.4711	-0.7314	0.3303	0.0165	0.0095
8000.0	-3.077	-3.2300	-3.2428	-2.7569	-0.5820	-0.7335	-0.4435	0.2901	0.0145	0.0084
10000.0	-3.660	-3.7216	-3.9532	-3.3045	-0.4916	-0.7105	-0.5476	0.2274	0.0114	0.0066
12000.0	-4.424	-4.5387	-4.5759	-4.1576	-0.8171	-0.6227	-0.8531	0.2479	0.0124	0.0072
14000.0	-4.998	-5.1411	-5.2630	-4.5899	-0.6024	-0.6870	-0.4323	0.2594	0.0130	0.0075
16000.0	-5.471	-5.6318	-5.7904	-4.9912	-0.4906	-0.5275	-0.4013	0.1298	0.0065	0.0037
18000.0	-5.985	-6.0450	-6.4181	-5.4927	-0.4132	-0.6276	-0.5015	0.2155	0.0108	0.0062
20000.0	-6.311	-6.4355	-6.7644	-5.7341	-0.3905	-0.3463	-0.2414	0.1532	0.0077	0.0044
22000.0	-6.862	-7.0287	-7.2599	-6.2972	-0.5932	-0.4955	-0.5631	0.1001	0.0050	0.0029
24000.0	-7.581	-7.6982	-8.0007	-7.0439	-0.6694	-0.7408	-0.7467	0.0860	0.0043	0.0025
Average type A mean										0.0065

Table 4

As can be noticed, the type A in mean for load difference is different (bigger) than type A in mean at a particular load.

The uncertainty in load difference of 2000 kg :

$$\sqrt{(0.0076^2 + 0.0002^2 + 0.0014^2 + 0.0005^2 + 0.0058^2 + 0.0057^2 + 0.0065^2)} = 0.0130 \% \text{ or } 0.013 \%$$

Uncertainty determination for load differences of 4000 kg

The uncertainty determination for 4000 kg batches (= load differences) deviates from 2000 kg load difference because scale interval and transfer point relative to 4000 kg is smaller and type A in mean is different for 4000 kg in relation to 2000 kg.

Scale interval of 100 g corresponds to 0.0029 % to 4000 kg with rectangular distribution.

Transfer point of 98 g corresponds to 0.0029% to 4000 kg with rectangular distribution.

Type A in mean for load difference is calculated from the individual deviations per trajet (load difference per run; columns F ; G and H), then 2 * standard deviation/√n per trajet (column K) and then the average of column K.

A	B	C	D	E	F	G	H	I	J	K
Gyro indic. kg	Average deviation kg	Deviation run 1 kg	Deviation run 2 kg	Deviation run 3 kg	Deviation trajet 2000 run 1	Deviation trajet 2000 run 2	Deviation trajet 2000 run 3	2*st. dev single (kg)	2*st. dev single (%)	2* st. dev. mean (%)
2000.0	-1.298	-1.5080	-1.4096	-0.9764	-	-	-	-	-	-
4000.0	-1.948	-2.2228	-2.0382	-1.5819	-0.7148	-0.6286	-0.6055	0.1153	0.0029	0.0017
6000.0	-2.490	-2.6480	-2.5093	-2.3133	1.0827	0.9386	0.2450	0.8958	0.0224	0.0129
8000.0	-3.077	-3.2300	-3.2428	-2.7569	0.1329	-0.1049	0.1620	0.2928	0.0073	0.0042
10000.0	-3.660	-3.7216	-3.9532	-3.3045	-0.0664	-0.2394	0.1838	0.4256	0.0106	0.0061
12000.0	-4.424	-4.5387	-4.5759	-4.1576	-0.2351	0.1108	-0.4096	0.5297	0.0132	0.0076
14000.0	-4.998	-5.1411	-5.2630	-4.5899	-0.1108	0.0234	0.1153	0.2274	0.0057	0.0033
16000.0	-5.471	-5.6318	-5.7904	-4.9912	0.3265	0.0952	0.4518	0.3618	0.0090	0.0052
18000.0	-5.985	-6.0450	-6.4181	-5.4927	0.1891	0.0594	-0.0692	0.2583	0.0065	0.0037
20000.0	-6.311	-6.4355	-6.7644	-5.7341	0.1001	0.1811	0.1599	0.0840	0.0021	0.0012
22000.0	-6.862	-7.0287	-7.2599	-6.2972	-0.1800	0.1322	-0.0616	0.3151	0.0079	0.0045
24000.0	-7.581	-7.6982	-8.0007	-7.0439	-0.2789	-0.3945	-0.5053	0.2264	0.0057	0.0033
Type A in mean									0.0049	

Table 5

The average of column K is taken as the type A in mean for load difference of 4000 kg (= 0.0049%).

The uncertainty in load difference of 4000 kg :

$$\sqrt{(0.0076^2 + 0.0002^2 + 0.0014^2 + 0.0005^2 + 0.0029^2 + 0.0029^2 + 0.0049^2)} = 0.0101 \% \text{ or } 0.011 \%$$

On basis of this uncertainty calculation, the Dutch physical standards institute NMI – VSI has issued a certificate for this 24 ton scale (see annex 2), based on calculation method a stated in this document.

The CMC of the 24 ton scale calibration facility could be calculated now; see annex 3 for the CMC table. As can be noticed, the target CMC of 0.03 % was reached in spite of the use of a master meter for the calibration of the 24 ton scale.

Reasons why the master meter method gives better results as with weights

The 24 ton scale was calibrated with weights for the last time in 1999 (also from zero to full load; three times). Certificate from Kalibra is attached in annex 4.

Results concerning type A unhcertainty from 1999 calibration with weights :

Traject	Type A uncertainty			
	2* st. dev in single measurement		2* st. dev. in mean	
	(kg)	(%)	(kg)	(%)
0 to 2000 kg	0.505	0.025	0.191	0.010
2000 to 4000 kg	0.403	0.020	0.202	0.010
4000 to 6000 kg	0.922	0.046	0.461	0.023
6000 to 8000 kg	0.818	0.041	0.409	0.020
8000 to 10000 kg	0.450	0.023	0.225	0.011
10000 to 12000 kg	0.915	0.046	0.457	0.023
12000 to 14000 kg	1.450	0.072	0.725	0.036
14000 to 16000 kg	0.841	0.042	0.420	0.021
16000 to 18000 kg	2.170	0.109	1.085	0.054
18000 to 20000 kg	2.546	0.127	1.273	0.064
20000 to 22000 kg	0.866	0.043	0.433	0.022
22000 to 24000 kg	1.120	0.056	0.560	0.028
Average	1.084	0.054	0.537	0.027

Table 6

As can be noticed from the last column, the type A in mean with weights corresponds to 0.027 % while the type A in mean with master meter corresponds to 0.0065 %. The uncertainty in load difference as stated in the Kalibra certificate for this scale is 0.028 % sothat a big majority of the final uncertainty is consumed due to type A from placing the weights (repeatability). Compare these values with master meter method (uncertainty in load difference is 0.013%).

The reason why type A is bigger with weights is the fact that placing a weight of 1000 kg will be a "shock" for a sensitive scale while filling with water will take place more smoothly.

Another reason why the target CMC for the 24 t scale calibration facility of 0.030 % was reached is that the CMC of the 3 ton scale facility was reduced for this event from 0.030 % down to 0.0063 % (stability scale and number of pulses).

Procedure for determination of uncertainty in load difference for a scale

Our experiences over the last 4 years have shown that the calculation method to come to an uncertainty for a "load difference" with scales is not well understood and not standardized by the accredited companies.

The companies for calibrating scales are only accredited to calculate and present the uncertainty (absolute or relative) at complete loads (and not for load difference).

Therefore, the presentation of uncertainty in load difference on a certificate is outside the scope of the accreditation and is marked on the certificate accordingly.

It is recommended that the uncertainty in load difference will be standardized (an ISO standard under TC 30 ??) and that companies are accredited for this task.

It is then up to the user to request also for the presentation of the uncertainty in load difference.

Conclusion:

- **Calibrating a scale via a Coriolis mass master meter gives better results than with weights (no shock effects)**
- **Target uncertainty for the 24 ton scale calibration facility (CMC) of 0.03 % is reached, in spite of longer traceability chain**
- **Determination of uncertainty in "load difference" for scale should be standardized within ISO TC 30 .**

References:

- [1] Calculation of liquid-mass out of weighing scale and its related uncertainty from May 2000 by A.R. Pruysen – Emerson Process Management (is attached at the end)

Note: This document was already a reference document for the paper "Traceability and uncertainty analysis for a calibration process for flowmeters, using Coriolis flowmeters as reference", presented at the Flomeko 2000 in Brasil.

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Annex 1 – CMC stand 4 3000 kg scale - normal use

<p align="center">Stand 4 - Calibration and Measurement Capability in mass for 3000 kg scale values represent expanded uncertainty with coverage factor $k=2$</p>						
Source	Batchsize 500 kg		Batchsize 1000 kg		Batchsize 2000 kg	
	gram	%	gram	%	gram	%
Scale interval	57.735	0.0115	57.735	0.0058	57.735	0.0029
Repeatability scale (2s)	28.868	0.0058	41.467	0.0041	28.868	0.0014
M1 class weights	25.000	0.0050	50.000	0.0050	100.000	0.0050
Weighing Scale Factor	0.950	0.0002	1.900	0.0002	3.800	0.0002
Long term stability	100.000	0.0200	200.000	0.0200	400.000	0.0200
Buoyancy Vapour Corr.	6.650	0.0013	13.300	0.0013	26.600	0.0013
Transfer point	6.700	0.0013	6.700	0.0007	6.700	0.0003
Pulses	57.735	0.0115	115.470	0.0115	230.940	0.0115
Software	3.500	0.0007	7.000	0.0007	14.000	0.0007
CMC	135.008	0.027	247.307	0.025	477.978	0.024

Annex 2 NMI-VSL certicate of 24 ton scale per March 2003

Certificate

Certificate number 39310720
Project number 301225
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Results During the calibration of the Wohwa weighing machine, the settings of the GCU 45 electronics were as listed in the table below. The "Korrekturwert" is 1,0000.

Staffepunkt	Impulswert
0,0	121 6937 5744
3 034,7	144 1694 9248
6 021,3	166 2841 2416
9 015,6	188 4559 3600
12 047,2	210 9009 1008
14 960,8	232 4701 5936
17 976,7	254 7910 6560
21 000,2	277 1634 9952
24 029,1	299 5790 2336

A. Deviation at different loads

Indicated mass [kg]	Deviation [kg]
2000	-1,30
4000	-1,95
6000	-2,49
8000	-3,08
10000	-3,66
12000	-4,42
14000	-5,00
16000	-5,47
18000	-5,99
20000	-6,31
22000	-6,86
24000	-7,58

Deviation [kg] = Indicated mass [kg] – Reference mass [kg]

The uncertainty of the deviations listed in the table above is 0,013% of the reference mass.

B. Relative uncertainty in "load-difference"

The Wohwa weighing machine is used to calibrate flow meters and therefore the uncertainty in the "load-difference" is subject of interest for the user. When corrected for known deviations, the total uncertainty in the measurement for a load difference of minimum 2000 kg is 0,013% and for a load difference of minimum 4000 kg is 0,011%.

The reported uncertainties are based on 95% confidence intervals. The coverage factor is $k=2$.

Results

Certificate number : 39310720
Project number : 301225
Page 1 of 2

Applicant:
Emerson Process Management
Groenewaldelaan 6-8
The Netherlands

Submitted
A weighing scale no.2 that is part of a test installation for the calibration of flowmeters with water (Stand 4; FR tool number 32221-01).

Manufacturer : Wohwa
Type : Gyroscopic balance
Model : GCU 45
Serial number : 11847
FR tool number : 23226-01
Capacity : 24000 Kg

Test method
The deviation of the weighing machine was determined by filling it with water using a Micro Motion coriolis mass flow meter (sensor type CMF300, sensor serial number 315427, RT transmitter model RT19739 with serial number 2020862, $Q_{nom} = 2250$ kg/min) as a reference.

The CMF300 was calibrated using a Mettler weighing machine (no.1, 3000 kg capacity) FR tool number 10130-01.
All calibrations were performed using water at a flow rate of 2000 kg/min \pm 5% and taking batches of 2000 kg \pm 5%. In order to investigate the influence of standing start stop, a limited number of other batch sizes were taken.

The uncertainty analysis is reported in the addendum to this certificate, called "Calibration of 24 ton weighing scale by master meter", version 2; 20 March 2003, edited by Mr. A. R. Pruijsen from Emerson Process Management in Veendam. This addendum was verified and hallmarked by NMI Swinden Laboratorium B.V.,

20 February 2003.

Results
The results are presented on page 2 of 2.

Traceability
All instrument used in the test installation were verified to be traceable to primary and/or (internationally accepted measurement standards.

Dordrecht, 24 March 2003
NMI Swinden Laboratorium B.V.

F.M. Smits
Metrologist

Netherlands Metrolink
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NMI B.V.
(Chamber of Commerce no. 21228-707)
Subsidiary Companies:
NMI Swinden Laboratorium B.V. (17 218-700)
NMI Centre B.V. (17 213-486)
Velpopet B.V. (17 218-149)

This certificate is issued under the provision that no liability is accepted for the accuracy of the data. The responsibility for each responsibility against third parties. Reproduction of the complete certificate is permitted, provided that the certificate may only be reproduced after written permission.

Annex 3 CMC stand 4 24000 kg scale normal use

<p align="center">Stand 4 - Calibration and Measurement Capability in mass for 24000 kg scale values represent expanded uncertainty with coverage factor $k=2$</p>				
Source	Batchsize 2000 kg (gross load \geq 6000 kg)		Batchsize 4000 kg	
	gram	%	gram	%
Scale uncertainty (NMI-VSL)	260.000	0.0130	440.000	0.0110
Long term stability	500.000	0.0250	1000.000	0.0250
Buoyancy Vapour Corr.	26.600	0.0013	53.200	0.0013
Transfer point	25.880	0.0013	25.880	0.0006
Pulses	230.940	0.0115	461.880	0.0115
Software	14.000	0.0007	28.000	0.0007
CMC	610.333	0.030	1187.947	0.030

Annex 4 Kalibra certificate of 24000 kg scale as result of calibrating with weights (1999)



NKO - Certificate
 Number: 994358.02A
 page 1 of 3

Accreditation number: K0288



Number: 994358.02A
 page 2 of 3

Number: 994358.02A
 page 3 of 3

Applicant
 Fisher Rosemount Flow
 T.a.v. dhr. A. R. Pruijssen
 Postbus 65
 3900 AB Veendam

This certificate replaces the certificate
 with number 994358.02

Submitted
 Non-automatic weighing instrument
Manufacturer: Wohwa
Model: GCU 45
Serial number: 11847
Brooks toonumber: 23226-01

Test method
 The non-automatic weighing instrument has been calibrated by comparison of the indicated value with the mass, induced by loading with mass-standards. The ambient temperature was between -5 °C and 35 °C.

Test date
 august, 20, 1999

Results
 The results of the calibrations are given from next page.
 The reported uncertainty is based on a standard uncertainty multiplied by a coverage factor of $k = 2$, which provides a confidence level of approximately 95 %. The standard uncertainty has been determined in accordance with EAL-R2.

Traceability
 The measurements have been executed using standards for which the traceability to (international) standards has been demonstrated towards the Read voor Accreditatie.

Deilt, december 8, 1999

 Calibration Engineer

KALIBRA NEDERLAND B.V.
 Postbus 283
 2600 AG Deilt (NL)
 Kalfjeslaan 66
 2623 AJ Deilt
 Tel.: 015 2780111
 Fax: 015 2572728
 KvK nr. 27228702

The Read voor Accreditatie is one of the signatories of the Mutual Agreement of the Laboratories (EAL) for the mutual recognition of calibration certificates.

This certificate is issued provided that KALIBRA NEDERLAND B.V., nor Read voor Accreditatie does not assume any liability. Reproduction of the complete certificate is allowed. Parts of the certificate may only be reproduced with written approval of KALIBRA NEDERLAND B.V.

Results

During the calibration of this scale, the settings within the the Wohwa scale electronics GCU 45 were as follows:

Korrektuurwert: 1,0000

punkt	staffel	impuls/wert
0,0		122 3048 8664
3000,0		144 3481 1904
6000,0		166 3977 0624
9000,1		188 4435 6908
12000,1		210 4948 7396
15000,1		232 5257 0112
18000,1		254 5577 1648
21000,2		276 5882 9248
24000,2		298 6343 6288

A Deviation (incl. uncertainty) at different loads

In the label below is given:
 - the indicated load m_i ;
 - the nominal load m_n ;
 - the deviation $m_i - m_n$.

m_i [kg]	m_n [kg]	$m_i - m_n$ [kg]
0,00	0,00	0,00
669,86	1000,00	-0,14
1959,74	2000,00	-0,26
3958,95	4000,00	-1,05
5957,93	6000,00	-2,08
7957,16	8000,00	-2,84
9956,53	10000,00	-3,48
11955,20	12000,00	-4,80
13954,04	14000,00	-5,96
15953,38	16000,00	-6,63
17952,83	18000,00	-8,17
19951,41	20000,00	-8,59
21950,46	24000,00	-10,54

The uncertainty in the deviation $m_i - m_n$ is : $\sqrt{[(6 \cdot 10^{-5} \text{ m})^2 + (0,52)^2]} \text{ kg}$

Results

B Relative uncertainty in "load-difference"
 This scale is used to calibrate flowmeters and therefore the relative uncertainty in the "load-difference" is subject of interest for the user.
 Table III below states the uncertainty for the load difference in case :
 - the scale indication is corrected with the reverse deviations,
 as stated in table II

Load difference (kg)	Uncertainty when corrected for deviations (%)
2000	0,028
4000	0,019

Reference document for Flomeko paper 135: “Calibration of 24 ton weighing scale by Coriolis master meter”

CALCULATION OF LIQUID-MASS (IN VACUO) OUT OF WEIGHING SCALE INDICATION AND ITS RELATED UNCERTAINTY

1. INTRODUCTION

When an object is weighed, the indication of the weighing scale does not exactly correspond with the mass in vacuo of the object due to the buoyancy-effect.

This paper derives the exact equation to calculate out of the weighing scale indication the mass in vacuo for objects and for liquids, weighed in:

- an open container
- an open container with immersed inletpipe
- a closed container

Therefore, the calibration of the weighing scale is handled first and then the weighing of an object or liquid in a tank.

Also the corresponding uncertainty in the mass of the weighed liquid is derived for the different situations.

2. CALIBRATION OF A WEIGHING SCALE

A weighing scale is calibrated with exactly determined weights.

These weights are made of steel (or other metal) with a material density of 8000 kg/m³ +/- 5 %.

When an object is weighed, a force downwards due to gravity and a force upwards due to buoyancy are effective.

The resulting force downwards, F_w , caused by a weight with real mass m_r and density-material ρ_w with an air-density of 1.2 kg/m³ corresponds therefore to:

$$F_w = m_r \cdot g \cdot \left(1 - \frac{1.2}{\rho_w} \right) \quad \text{eq. 1}$$

Out of above equation follows that the weighing scale will undergo different forces downwards with exact the same real mass when material of weight (= density ρ_w) is different.

Therefore there is introduced the “conventional mass” of the weight m_w , for a material density of 8000 kg/m³ with following relationship between real-mass and conventional mass:

$$m_w \cdot \left(1 - \frac{1.2}{8000} \right) = m_r \cdot \left(1 - \frac{1.2}{\rho_w} \right) \quad \text{eq. 2}$$

m_w = “conventional” mass of weight
 m_r = “real” mass of weight
 ρ_w = density weight-material

The value of the weights (m_w), also called “conventional mass”, is chosen in such a way that a force, induced by the weight on a weighing scale, corresponds with a material density of 8000 kg/m^3 and an air-density of exactly 1.2 kg/m^3 .

When the value of a weight is given, the conventional mass m_w is meant and not the real mass.

When weights are placed on the weighing scale during calibration, the indication is made equal to the (conventional) mass-weight m_w .

Force downwards during calibration due to the weight:

$$F_{\text{cal}} = g_{\text{cal}} \cdot m_r \cdot \left(1 - \frac{\rho_{\text{air-cal}}}{\rho_w} \right) \quad \text{eq. 3}$$

Substitute equation 2 in 3:

$$F_{\text{cal}} = g_{\text{cal}} \cdot m_w \frac{\left(1 - \frac{1.2}{8000} \right) \cdot \left(1 - \frac{\rho_{\text{air-cal}}}{\rho_w} \right)}{\left(1 - \frac{1.2}{\rho_w} \right)} \quad \text{eq. 4}$$

The indication of the weighing scale ws_i is made equal to m_w by adjustment when undergoing the force F_{cal} :

$$ws_i = m_w = \text{Adjustment} * F_{\text{cal}} \quad \text{eq. 5}$$

Substitute equation 4 in 5:

$$ws_i = m_w = \text{Adjustment} * g_{\text{cal}} \cdot m_w \frac{\left(1 - \frac{1.2}{8000} \right) \cdot \left(1 - \frac{\rho_{\text{air-cal}}}{\rho_w} \right)}{\left(1 - \frac{1.2}{\rho_w} \right)} \quad \text{----->}$$

$$\text{Adjustment} = \frac{\left(1 - \frac{1.2}{\rho_w} \right)}{g_{\text{cal}} \cdot \left(1 - \frac{1.2}{8000} \right) \cdot \left(1 - \frac{\rho_{\text{air-cal}}}{\rho_w} \right)} = \frac{1}{\text{WSF} * g_{\text{cal}}}$$

WSF (Weighing Scale Factor) is introduced, coming from the weighing scale calibration. During the use of a weighing scale, the relation between the applied force and indication of weighing scale is therefore:

Indication weighing scale due to applied force:

$$WS_{i-use} = \frac{1}{WSF * g_{cal}} \cdot Force_{use}$$

WSF= Weighing Scale Factor, coming from weighing scale calibration

g_{cal} = gravity at calibration location

$$WSF = \frac{\left(1 - \frac{1.2}{8000}\right) \cdot \left(1 - \frac{\rho_{air-cal}}{\rho_w}\right)}{\left(1 - \frac{1.2}{\rho_w}\right)}$$

$\rho_{air-cal}$ = density of ambient air during weighing scale calibration

ρ_w = density of weights, used during weighing scale calibration

eq. 6

The value of WSF varies on the altitude (=air density) and density of weight material; average value on sea level is approx. 0.999850 .

The exact value of WSF on sea level varies between:

- 0.999828 and 0.999870 for out-door applications due to a variation of 14 % of air-density (ambient temperature -10 up till 40 °Celcius ; ambient pressure 970 up till 1030 mbar; humidity from 10 up till 90 % and density weightmaterial 8000 kg/m³ +/- 400 kg/m³). When WSF is considered as a fixed constant with a value of 0.999850, then WSF has an systematic (type B) uncertainty of 0.0022% .
- 0.999841 and 0.999863 for in-door applications due to a maximum variation of 8.3 % of air-density (ambient temperature 10 up till 30 °Celcius ; ambient pressure 970 up till 1030 mbar; humidity from 10 up till 90 % and density weightmaterial 8000 kg/m³ +/- 400 kg/m³), which means then that WSF has an systematic (type B) uncertainty of 0.0013% .

Conclusion from above is that, at sea level, 1% variation in air density corresponds to 0.00015 % variation in WSF; influence of density weight material is negligible.

For high elevation places, such as the flow facility of Micro Motion in Boulder with an average density close to 1 kg/m³, other values apply.

The exact uncertainty calculation for WSF is laid down in clause 7.2.

3. Mass of weighed object:

When the object is placed on weighing scale, then the force-downwards corresponds to:

$$F_{\text{use}} = g_{\text{use}} * m_o * \left(1 - \frac{\rho_{\text{air-use}}}{\rho_o} \right) \quad \text{eq. 7}$$

Indication of weighing scale:

$$WS_{i\text{-use}} = \frac{1}{WSF} * \frac{g_{\text{use}}}{g_{\text{cal}}} * m_o * \left(1 - \frac{\rho_{\text{air-use}}}{\rho_o} \right) \quad \text{eq. 8}$$

In many cases, the weighing scale is used on the same location as calibrated ->

$$g_{\text{use}} = g_{\text{cal}}$$

Indication of weighing scale:

$$WS_{i\text{-use}} = \frac{1}{WSF} * m_o * \left(1 - \frac{\rho_{\text{air-use}}}{\rho_o} \right) \quad \text{eq. 9}$$

The real mass of the object follows out of equation 9:

“Real” mass of object (object displaces air):

$$m_o = WS_{i\text{-use}} * \frac{WSF}{\left(1 - \frac{\rho_{\text{air-use}}}{\rho_o} \right)}$$

$WS_{i\text{-use}}$ = indication of weighing scale when in use

$\rho_{\text{air-use}}$ = density of air during weighing of object

ρ_o = density of weighed object

WSF = Weighing Scale Factor coming from weighing scale calibration

$$WSF = \frac{\left(1 - \frac{1.2}{8000} \right) \cdot \left(1 - \frac{\rho_{\text{air-cal}}}{\rho_w} \right)}{\left(1 - \frac{1.2}{\rho_w} \right)}$$

WSF is a constant ; if airdensity not measured during calibration, then WSF at sea level $\approx 0.99985 \pm 0.000021$ (± 0.0021 %) outdoor and ± 0.000013 (± 0.0013 %) indoor

$\rho_{\text{air-cal}}$ = density of ambient air during weighing scale calibration

ρ_w = density of weights, used during weighing scale calibration

eq. 10

4. Mass of weighed liquid in an open container without immersed inlet pipe

When liquid is weighed in an open container, vapour (air) is displaced by the liquid and moved to ambient.

The mass of displaced vapour corresponds to volume of liquid V_{liq} multiplied with density of vapour ρ_{vap} .

Therefore, the difference in weighing scale indication ΔWS_i represents not exactly the mass of the liquid, transferred into the container.

Induced force on the weighing scale due to the transferred liquid :

$$F_{liquid} = g_{use} \cdot m_{liq} \cdot \left(1 - \frac{\rho_{vap}}{\rho_{liq}} \right) \quad \text{eq. 11}$$

Substitute equation 11 in 6:

$$\Delta WS_i = \frac{1}{WSF} * \frac{g_{use}}{g_{cal}} * m_{liq} * \left(1 - \frac{\rho_{vap}}{\rho_{liq}} \right) \quad \text{eq. 12}$$

In many cases, the weighing scale is used on the same location as calibrated \rightarrow

$$g_{use} = g_{cal}$$

Define Buoyancy Vapour Correction : $BVC = \frac{1}{\left(1 - \frac{\rho_{vap}}{\rho_{liq}} \right)}$ \rightarrow eq. 13

Mass of liquid in open container without immersed inlet pipe (liquid displaces the vapour out of container)

$$m_{\text{liq}} = \Delta w_{\text{si}} * \text{WSF} * \text{BVC}$$

Δw_{si} = difference in indication of weighing scale

WSF = Weighing Scale Factor coming from weighing scale calibration

$$\text{WSF} = \frac{\left(1 - \frac{1.2}{8000}\right) \cdot \left(1 - \frac{\rho_{\text{air-cal}}}{\rho_w}\right)}{\left(1 - \frac{1.2}{\rho_w}\right)}$$

WSF is a constant ; if air density not measured during calibration, then WSF at sea level $\approx 0.99985 \pm 0.000021$ ($\pm 0.0021\%$) outdoor and ± 0.000013 ($\pm 0.0013\%$) indoor

$\rho_{\text{air-cal}}$ = density of ambient air during weighing scale calibration

ρ_w = density of weights, used during weighing scale calibration

$$\text{BVC} = \frac{1}{\left(1 - \frac{\rho_{\text{vap}}}{\rho_{\text{liq}}}\right)} \quad (\text{Buoyancy Vapour Correction})$$

ρ_{vap} = density of vapour in container, displaced by liquid

ρ_{liq} = density of liquid during calibration

eq. 14

Examples for liquid mass calculation with density-air 1.2 kg/m^3 and density weight material 8000 kg/m^3 :

- a product water ---> $\rho_{\text{liq}} = 1000 \text{ kg/m}^3$; no vapour inside container, only air ---> $\rho_{\text{vap}} = 1.2 \text{ kg/m}^3$; WSF = 0.99985 ; BVC = 1.00120
 $m_{\text{liq}} = 1.00105 * \Delta m_i$; addition to mass-indication of 0.105 %
- b product gasoline ---> $\rho_{\text{liq}} = 750 \text{ kg/m}^3$; $\rho_{\text{vap}} = 2.0 \text{ kg/m}^3$
 WSF = 0.99985 ; BVC = 1.00267
 $m_{\text{liq}} = 1.00253 * \Delta m_i$; addition to mass-indication of 0.253 %
- c product propane at 20°C and vapour is returned to storage tank --->
 $\rho_{\text{liq}} = 502 \text{ kg/m}^3$; $\rho_{\text{vap}} = 17.8 \text{ kg/m}^3$; WSF = 0.99985 ; BVC = 1.03668
 $m_{\text{liq}} = 1.03661 * \Delta m_i$; addition to mass-indication of 3.661 %

When making this calculation, an error is introduced when not exactly the density of vapour or density of liquid is known.

The uncertainty in the vapour density will result in a systematic uncertainty (type B uncertainty) in mass which is a factor $\rho_{\text{vap}}/\rho_{\text{liq}}$ smaller ; the same applies for uncertainty in the liquid density.

The exact derivation for the uncertainty is given in clause 8.

Examples for uncertainty calculation in liquidmass, based on the equation out of clause 8:

Product water ---> $\rho_{\text{liq}} = 1000 \text{ kg/m}^3$; uncertainty water density 1 %;

no vapour inside container, only air ---> $\rho_{\text{vap}} = 1.2 \text{ kg/m}^3$

Uncertainty mass due to uncertainty liquid-density is 0.0012%

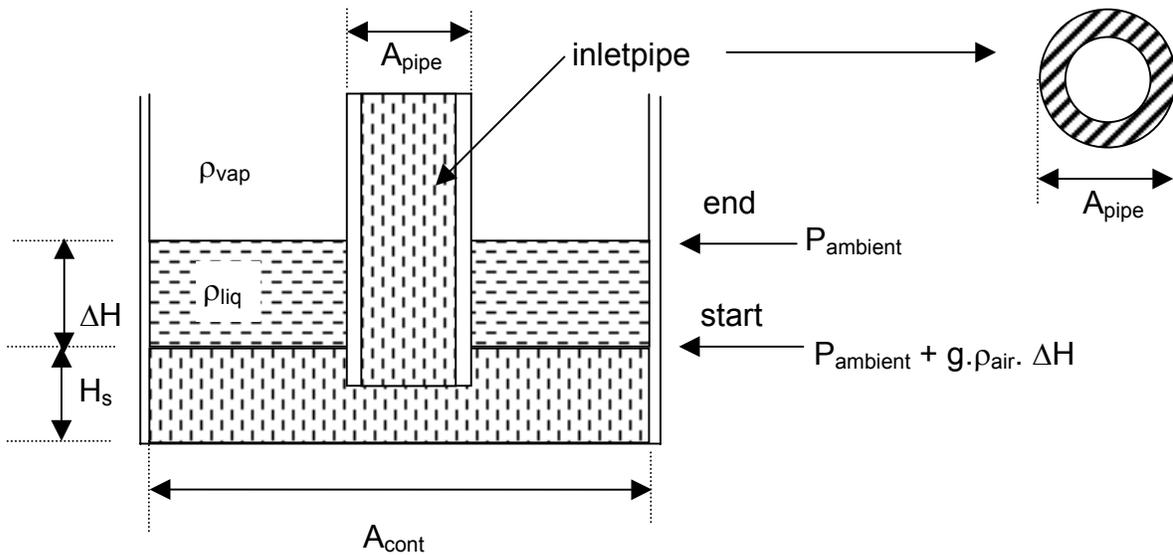
product water ---> $\rho_{\text{liq}} = 1000 \text{ kg/m}^3$;

no vapour inside container, only air ---> $\rho_{\text{vap}} = 1.2 \text{ kg/m}^3$ with an uncertainty of 1 %

Uncertainty mass due to uncertainty air-density is 0.0012%

5. Mass of weighed liquid in open container with immersed inlet pipe

Assume the inlet pipe is always filled with the liquid, before, during and after the transfer of liquid, as shown in the drawing.



Force on weighing scale before filling: $(g \cdot \rho_{\text{liq}} \cdot H_s + P_{\text{ambient}} + g \cdot \rho_{\text{vap}} \cdot \Delta H) \cdot A_{\text{cont}}$

Force on weighing scale after filling: $(g \cdot \rho_{\text{liq}} \cdot H_s + g \cdot \rho_{\text{liq}} \cdot \Delta H + P_{\text{ambient}}) \cdot A_{\text{cont}}$

$\Delta \text{Force} : (g \cdot \rho_{\text{liq}} \cdot \Delta H - g \cdot \rho_{\text{vap}} \cdot \Delta H) \cdot A_{\text{cont}}$

Indication weighing scale (see equation 6):

$$ws_i = \frac{\Delta \text{Force}}{WSF * g_{\text{cal}}} = \frac{g_{\text{use}} \cdot (\rho_{\text{liq}} - \rho_{\text{vap}}) \cdot \Delta H \cdot A_{\text{cont}}}{g_{\text{cal}} * WSF}$$

In many cases, the weighing scale is used on the same location as calibrated \rightarrow

$$g_{\text{use}} = g_{\text{cal}}$$

$$ws_i = \frac{(\rho_{\text{liq}} - \rho_{\text{vap}}) \cdot \Delta H \cdot A_{\text{cont}}}{WSF} \quad \text{eq. 15}$$

$$\text{Displaced liquid: } m_{\text{liq}} = (A_{\text{cont}} - A_{\text{pipe}}) \cdot \Delta H \cdot \rho_{\text{liq}} \cdot \quad \text{eq. 16}$$

Correction to weighing scale indication:

$$m_{\text{liq}} = \text{correction} * ws_i \quad \text{eq. 17}$$

Substitute equations 15 and 16 in 17:

$$(A_{\text{cont}} - A_{\text{pipe}}) \cdot \Delta H \cdot \rho_{\text{liq}} = \text{Correction} * \frac{(\rho_{\text{liq}} - \rho_{\text{vap}}) \cdot \Delta H \cdot A_{\text{cont}}}{\text{WSF}} \quad \text{---->}$$

$$\text{Correction} = \text{WSF} * \frac{\rho_{\text{liq}}}{\rho_{\text{liq}} - \rho_{\text{vap}}} * \frac{A_{\text{cont}} - A_{\text{pipe}}}{A_{\text{cont}}} = \text{WSF} * \left(\frac{1}{1 - \frac{\rho_{\text{vap}}}{\rho_{\text{liq}}}} \right) * \left(1 - \frac{A_{\text{pipe}}}{A_{\text{cont}}} \right)$$

$$\text{Define Immersed inlet Pipe Correction: } \text{IPC} = 1 - \frac{A_{\text{pipe}}}{A_{\text{cont}}} \quad \text{--->} \quad \text{eq. 18}$$

(see next page)

Mass of liquid in open container with immersed inletpipe (liquid displaces the vapour out of container)

$$m_{\text{liq}} = \Delta w_{\text{si}} * \text{WSF} * \text{BVC} * \text{IPC}$$

Δw_{si} = difference in indication of weighing scale

WSF = Weighing Scale Factor coming from weighing scale calibration

$$\text{WSF} = \frac{\left(1 - \frac{1.2}{8000}\right) \cdot \left(1 - \frac{\rho_{\text{air-cal}}}{\rho_w}\right)}{\left(1 - \frac{1.2}{\rho_w}\right)}$$

WSF is a constant ; if airdensity not measured during calibration, then WSF at sea level $\approx 0.99985 \pm 0.000021$ (± 0.0021 %) outdoor and ± 0.000013 (± 0.0013 %) indoor

$\rho_{\text{air-cal}}$ = density of ambient air during weighing scale calibration

ρ_w = density of weights, used during weighing scale calibration

$$\text{BVC} = \frac{1}{\left(1 - \frac{\rho_{\text{vap}}}{\rho_{\text{liq}}}\right)} \quad (\text{Bouyancy Vapour Correction})$$

ρ_{vap} = density of vapour in container, displaced by liquid

ρ_{liq} = density of liquid during calibration

$$\text{IPC} = 1 - \frac{A_{\text{pipe}}}{A_{\text{cont}}} \quad (\text{Immersed inlet Pipe Correction})$$

A_{pipe} = outside area of the immersed inletpipe

A_{cont} = internal area of container

eq. 19

The correction for the immersed inletpipe has an opposite sign as the bouyancy correction.

6. Mass of weighed liquid in closed container

When liquid is weighed in a closed container, the vapour will not be removed but partly condensate.

Therefore this situation differs from the “open container situation”

Induced force on the weighing scale due to liquid, passed through the flowmeter under test:

$$F_{\text{liquid}} = g_{\text{use}} \cdot m_{\text{liq}} \quad \text{eq. 20}$$

Substitute equation 20 in 6:

$$\Delta w_{S_i} = \frac{1}{\text{WSF}} * \frac{g_{\text{use}}}{g_{\text{cal}}} * m_{\text{liq}} \quad \text{eq. 21}$$

In many cases, the weighing scale is used on the same location as calibrated →

$$g_{\text{use}} = g_{\text{cal}}$$

Mass of liquid in closed container (vapour remains in container; partly condensating)

$$m_{\text{liq}} = \Delta w_{S_i} * \text{WSF}$$

Δw_{S_i} = difference in indication of weighing scale

WSF = Weighing Scale Factor coming from weighing scale calibration

$$\text{WSF} = \frac{\left(1 - \frac{1.2}{8000}\right) \cdot \left(1 - \frac{\rho_{\text{air-cal}}}{\rho_w}\right)}{\left(1 - \frac{1.2}{\rho_w}\right)}$$

WSF is a constant ; if air density not measured during calibration,
then WSF at sea level $\approx 0.99985 \pm 0.000021$ ($\pm 0.0021\%$) outdoor
and ± 0.000013 ($\pm 0.0013\%$) indoor

eq. 22

Uncertainty density-vapour and uncertainty density liquid does not affect the uncertainty in mass-liquid.

7. Uncertainty calculation

The goal is to calculate the uncertainty in weighed liquid for open container without immersed inletpipe (equation 14); open container with immersed inletpipe (equation 19) and closed container (equation 22).

The equation of liquid-mass for open container with immersed inletpipe (equation 19) is the most extended equation in relation to equations 14 and 22 and consists of 4 terms; the other two equations do have respectively 3 and 2 terms, each of them correspond with one of the four terms from equation 19 (open container with immersed inletpipe).

These four terms are (see equation 19) :

A Δw_{si} - indication of weighing scale

B WSF - weighing scale Factor

C Buoyancy vapour correction (BVC) :
$$\frac{1}{\left(1 - \frac{\rho_{vap}}{\rho_{liq}}\right)}$$

D Immersed Inletpipe correction (IPC) :
$$\left(1 - \frac{A_{pipe}}{A_{cont}}\right)$$

7.1 Uncertainty of weighing scale indication (wsi), directly after calibration

The accuracy of a measuring instrument as specified by the manufacturer (error limit) will normally act as the uncertainty for the user if no calibration data is available.

However, for the purpose of calibrating flowmeters, a better uncertainty can be achieved by calibrating the weighing scale and correct for the determined deviations.

The indication of the weighing scale has two uncertainties, namely the “combined uncertainty in single measurement U_{CS-wsi} ” and the “combined uncertainty in mean U_{CM-wsi} ”, both coming from the weighing scale calibration.

The “combined uncertainty in single measurement U_{CS-wsi} ” will have to be applied when an uncertainty has to be given for one measurement and “combined uncertainty in mean U_{CM-wsi} ” when the weighing scale is used as reference in the traceability chain e.g. to calibrate flowmeters.

The combined uncertainties U_{CS-wsi} and U_{CM-wsi} are calculated from the root of the sum square of the statistical uncertainty, type A, and of those uncertainties which are assumed to be constant during the calibration tests (type B).

Type A uncertainty in single measurement for mass-indication of weighing scale U_{AS-wsi} with 95% confidence level can be calculated after a number a repeatable tests :

$$U_{AS-wsi} = k \sqrt{\frac{\sum_{j=1}^n (q_j - \bar{q})^2}{n-1}} \quad \text{eq.23}$$

- index AS-wsi of uncertainty U : type A evaluation for Single measurement in mass-indication of weighing scale
- k is coverage factor and normally equal to a value of 2 ; may also be replaced with another value, depending of degree of freedom (also called student's T-factor)

Meaning of U_{AS-wsi} : when a single measurement is repeated after the series of measurements, one can expect that the observed error of this single measurement lies within the mean value $\pm U_{AS-wsi}$.

U_{AS-wsi} corresponds to the \pm repeatability of weighing scale.

Type A uncertainty in Mean U_{AM-wsi} with 95% confidence level

$$U_{AM-wsi} = \frac{U_{AS-wsi}}{\sqrt{n}} \quad \text{eq.24}$$

index AM-mi of uncertainty U : type A evaluation for the arithmetic Mean in mass-indication of weighing scale

Meaning of U_{AM-wsi} : when a second series of measurements are repeated, then the mean value of this second serie should lie within the mean value of first serie $\pm U_{AM-wsi}$ in 95% of cases.

U_{AM-wsi} corresponds to the uncertainty in the mean error of weighing scale.

Note: By increasing the number of measurements, the "type A" statistical uncertainty in mean will decrease, so the more measurements, the smaller the uncertainty in the mean.

When determining the type A single and mean uncertainties of the weighing scale, one should also take into account the special operating conditions of this weighing scale. When e.g. flowmeters are calibrated with a container, this container is installed on a fixed position on the weighing scale in most cases and the liquid will be equally spread over the container area, therefore:

- no eccentric load
- less hysteresis, due to only increasing load during flowmetercalibration
- indoor installation
- always complete drained

The weighing scale is used as difference in load (weight 1 – weight 2) so that the uncertainty should also be calculated for the smallest difference and not only for the total indication.

The type B uncertainty of weighing scale comes from:

- uncertainty in mean of the weights U_w , used during the weighing scale calibration
- uncertainty $U_{\text{sen-max}}$, worst case of uncertainty, coming from scale interval (discrimination) and sensitivity. Normally, the sensitivity is smaller than scale interval, so that scale interval is dominant. In many cases a rounding (not truncation) is applied so that the uncertainty in mass-units corresponds to $2/\sqrt{3} \cdot \text{resolution}/2$ (rectangular distribution), to be converted to percent by dividing with the minimum batchsize * 100.
- uncertainty in WSF, Weighing Scale Factor. This factor is influenced by two uncertainties, density air and density of weight material; see clause 7.3

Combined uncertainty in single measurement of weighing scale indication, directly after calibration when weights are used:

$$U_{\text{CS-wsi}} = \sqrt{U_{\text{AS-wsi}}^2 + U_w^2 + U_{\text{sen-max}}^2 + U_{\text{WSF}}^2} \quad \text{eq.25}$$

Combined uncertainty in mean of weighing scale indication, directly after calibration when weights are used:

$$U_{\text{CM-wsi}} = \sqrt{U_{\text{AM-wsi}}^2 + U_w^2 + U_{\text{sen-max}}^2 + U_{\text{WSF}}^2} \quad \text{eq.26}$$

7.2. Uncertainty in Weighing Scale Factor (WSF)

The weighing scale factor WSF is a “type B” uncertainty source (WSF is a constant but unknown) , which has to be introduced during the use of the weighing scale. This factor will have to applied when the mass of an object (or liquid-quantity) has to be determined.

Equation 6 for Weighing Scale Factor :

$$WSF = \frac{\left(1 - \frac{1.2}{8000}\right) \cdot \left(1 - \frac{\rho_{\text{air-cal}}}{\rho_w}\right)}{\left(1 - \frac{1.2}{\rho_w}\right)}$$

WSF contains two uncertainty-sources: $\rho_{\text{air-cal}}$ and ρ_w

Uncertainty source $\rho_{\text{air-cal}}$:

$$\frac{\partial WSF}{\partial \rho_{\text{air-cal}}} = \frac{-\frac{1}{\rho_w} \cdot \left(1 - \frac{1.2}{8000}\right)}{\left(1 - \frac{1.2}{\rho_w}\right)} \quad \text{---->}$$

$$U_{WSF} = \frac{\Delta WSF}{WSF} = -\frac{\rho_{\text{air-cal}}}{\rho_w} \cdot \frac{1}{1 - \frac{\rho_{\text{air-cal}}}{\rho_w}} \cdot \frac{\Delta \rho_{\text{air-cal}}}{\rho_{\text{air-cal}}} \quad \text{approx. equal to ---->}$$

$$U_{WSF} = -\frac{\rho_{\text{air-cal}}}{\rho_w} \cdot U_{\rho_{\text{air-cal}}} \quad \text{eq. 27}$$

Uncertainty source ρ_w

$$\frac{\partial WSF}{\partial \rho_w} = \frac{\left(1 - \frac{1.2}{8000}\right) \cdot \frac{(\rho_{\text{air-cal}} - 1.2)}{\rho_w^2}}{\left(1 - \frac{1.2}{\rho_w}\right)^2} \quad \text{----->}$$

$$U_{WSF} = \frac{\Delta WSF}{WSF} = \frac{\frac{\rho_{\text{air-cal}} - 1.2}{\rho_w}}{\left(1 - \frac{1.2}{\rho_w}\right) \left(1 - \frac{\rho_{\text{air-cal}}}{\rho_w}\right)} \cdot \frac{\Delta \rho_w}{\rho_w} \quad \text{approximately equal to:}$$

$$U_{\text{WSF}} = \left(\frac{\rho_{\text{air-cal}} - 1.2}{\rho_w} \right) \cdot U_{\rho_w} \quad \text{eq. 28}$$

Apply root of the sum square for combining equations 27 and 28:

$$U_{\text{WSF}} = \sqrt{\left(\frac{\rho_{\text{air-cal}}}{\rho_w} \cdot U_{\rho_{\text{air-cal}}} \right)^2 + \left(\frac{(\rho_{\text{air-cal}} - 1.2)}{\rho_w} \cdot U_{\rho_w} \right)^2} \quad \text{eq. 29}$$

The second term is negligible at sea level (<0.0001%), also when air-density is not measured.

7.4 Uncertainty of Buoyancy Vapour Correction (BVC)

$$\text{BVC} = \frac{1}{\left(1 - \frac{\rho_{\text{vap}}}{\rho_{\text{liq}}} \right)}$$

BVC includes two uncertainty sources : ρ_{vap} and ρ_{liq}

Uncertainty source ρ_{vap} :

$$\frac{\partial \text{BVC}}{\partial \rho_{\text{vap}}} = \frac{1}{\rho_{\text{liq}} \left(1 - \frac{\rho_{\text{vap}}}{\rho_{\text{liq}}} \right)^2} \quad \text{--->}$$

$$U_{\text{BVC}} = \frac{\Delta \text{BVC}}{\text{BVC}} = \frac{\frac{\rho_{\text{vap}}}{\rho_{\text{liq}}} \cdot \frac{\Delta \rho_{\text{vap}}}{\rho_{\text{vap}}}}{1 - \frac{\rho_{\text{vap}}}{\rho_{\text{liq}}}} \quad \text{is approximately equal to}$$

$$U_{\text{BVC}} = \frac{\Delta \text{BVC}}{\text{BVC}} = \frac{\rho_{\text{vap}}}{\rho_{\text{liq}}} \cdot \frac{\Delta \rho_{\text{vap}}}{\rho_{\text{vap}}} \quad \text{eq. 31}$$

Uncertainty source ρ_{liq} :

$$\frac{\partial \text{BVC}}{\partial \rho_{\text{liq}}} = \frac{-\left(\frac{\rho_{\text{vap}}}{\rho_{\text{liq}}^2}\right)}{\left(1 - \frac{\rho_{\text{vap}}}{\rho_{\text{liq}}}\right)^2} \quad \text{--->}$$

$$U_{\text{BVC}} = \frac{\Delta \text{BVC}}{\text{BVC}} = \frac{-\frac{\rho_{\text{vap}}}{\rho_{\text{liq}}} \cdot \frac{\Delta \rho_{\text{liq}}}{\rho_{\text{liq}}}}{\left(1 - \frac{\rho_{\text{vap}}}{\rho_{\text{liq}}}\right)} \quad \text{is approximately equal to}$$

$$U_{\text{BVC}} = \frac{\Delta \text{BVC}}{\text{BVC}} = -\frac{\rho_{\text{vap}}}{\rho_{\text{liq}}} \cdot U_{\rho_{\text{liq}}} \quad \text{eq. 32}$$

Total uncertainty in Buoyancy Vapour Correction:

$$U_{\text{BVC}} = \left(\frac{\rho_{\text{vap}}}{\rho_{\text{liq}}}\right) \sqrt{(U_{\rho_{\text{vap}}})^2 + (U_{\rho_{\text{liq}}})^2} \quad \text{eq. 33}$$

7.5 Uncertainty of Immersed inletPipe Correction (IPC)

$$\text{IPC} = \left(1 - \frac{A_{\text{pipe}}}{A_{\text{cont}}}\right)$$

IPC includes two uncertainty sources A_{pipe} and A_{cont}

Uncertainty source A_{pipe}

$$\frac{\partial \text{IPC}}{\partial A_{\text{pipe}}} = -\frac{1}{A_{\text{cont}}} \quad \text{----->}$$

$$\frac{\Delta \text{IPC}}{\text{IPC}} = -\frac{A_{\text{pipe}}}{A_{\text{cont}} - A_{\text{pipe}}} \cdot \frac{\Delta A_{\text{pipe}}}{A_{\text{pipe}}} \quad \text{----->}$$

$$U_{\text{IPC}} = -\frac{A_{\text{pipe}}}{A_{\text{cont}} - A_{\text{pipe}}} \cdot U_{A_{\text{pipe}}} \quad \text{eq. 34}$$

Uncertainty source A_{cont}

$$\frac{\partial \text{IPC}}{\partial A_{\text{cont}}} = \frac{A_{\text{pipe}}}{(A_{\text{cont}})^2} \text{ ----->} \quad \frac{\Delta \text{IPC}}{\text{IPC}} = \frac{A_{\text{pipe}}}{A_{\text{cont}} - A_{\text{pipe}}} \cdot \frac{\Delta A_{\text{cont}}}{A_{\text{cont}}} \text{ ----->}$$

$$U_{\text{IPC}} = - \frac{A_{\text{pipe}}}{A_{\text{cont}} - A_{\text{pipe}}} \cdot U_{A_{\text{cont}}} \quad \text{eq. 35}$$

Total uncertainty in Immersed inletPipe Correction (IPC)

$$U_{\text{IPC}} = \left(\frac{A_{\text{pipe}}}{A_{\text{cont}} - A_{\text{pipe}}} \right) \sqrt{(U_{A_{\text{pipe}}})^2 + (U_{A_{\text{cont}}})^2} \quad \text{eq. 36}$$

8. Uncertainty in mass-liquid

8.1 Open container without immersed inletpipe

Equation 14 for mass-liquid, when weighed in open container (liquid displaces the vapour) :

$$m_{liq} = \Delta m_i * WSF * BVC$$

Uncertainty in mass-liquid comes from three terms:

- Δwsi (weighing scale indication) ; the weighing scale is used only once for measuring that quantity in the tank, therefore combined uncertainty in single measurement has to be applied ; equation 25
- WSF (weighing scale factor) ; equation 30, which is part of equation 25
- BVC (buoyancy vapour correction) ; equation 33

Combining equations 25 ; 30 and 33 with root of sum square

8.2 Open container with immersed inletpipe

Equation 19 for mass-liquid, when weighed in open container (liquid displaces the vapour) with immersed inletpipe:

$$m_{liq} = \Delta wsi * WSF * BVC * IPC$$

Uncertainty in mass-liquid comes from four terms:

- Δwsi (weighing scale indication) ; the weighing scale is used only once for measuring that quantity in the tank, therefore combined uncertainty in single measurement has to be applied ; equation 25
- WSF (weighing scale factor) ; equation 30, which is part of equation 25
- BVC (buoyancy vapour correction) ; equation 33
- IPC (Immersed inletpipe correction) ; equation 36

Combining equations 25 ; 30 ; 33 and 36 with root of sum square

8.3 Closed container (no vapour displaced out of container)

Equation 22 for mass-liquid, when weighed in closed container :

$$m_{liq} = \Delta wsi * WSF$$

Uncertainty in mass-liquid comes from two terms:

- Δwsi (weighing scale indication) ; the weighing scale is used only once for measuring that quantity in the tank, therefore combined uncertainty in single measurement has to be applied ; equation 25
- WSF (weighing scale factor) ; equation 30, which is part of equation 25

Combining equations 25 and 30 with root of sum square