EXPERIENCE WITH COMPARATIVE TESTING AND CALIBRATION OF CORIOLIS AND TURBINE METER OFFSHORE AND IN THE LABORATORY

by

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"Experience with comparative testing and calibration of Coriolis and turbine meter off-shore and in the laboratory"

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1. Introduction

On request from the Danish company "Mærsk Olie og Gas", Dantest has performed comparative testing and calibration of a Coriolis mass flowmeter and turbine meter. The calibrations were first performed off-shore and then in Dantest's laboratory onshore.

The meters were installed in series on the outlet of a test separator, measuring the condensate, on a platform off-shore in the North Sea. Comparative tests have been performed during the platform staff's ordinary 6 hours determination of the gas / condensate / water from the individual wells.

After the off-shore tests, the meters were dismounted and shipped on-shore. In the laboratory the Coriolis mass flowmeter was calibrated on a gravimetric test rig under controlled conditions. This was to determine the meter's accuracy and offset, as well as to determine and evaluate possible installation effects.

2. Set-up off-shore on Tyra West

In the following the set-up of the turbine meter and the mass flowmeter off shore on Tyra West will be described.

2.1 Test separator

The test separator is used in connection with testing and determining the production of gas and condensate from each well. In the test separator the mixture from the well is separated into three parts: condensate, water and gas, see the diagram in figure 2.1.1. Each well is tested during 6 hours, in which mean hour values of condensate, water and gas is registered.

Turbine meters are used to measure the amount of condensate and water. The two meters are connected in parallell (tk1, tk2 and tv1, tv2 , see the figure) and each cover a different flow range. An orifice meter (or) is used to measure the gas.

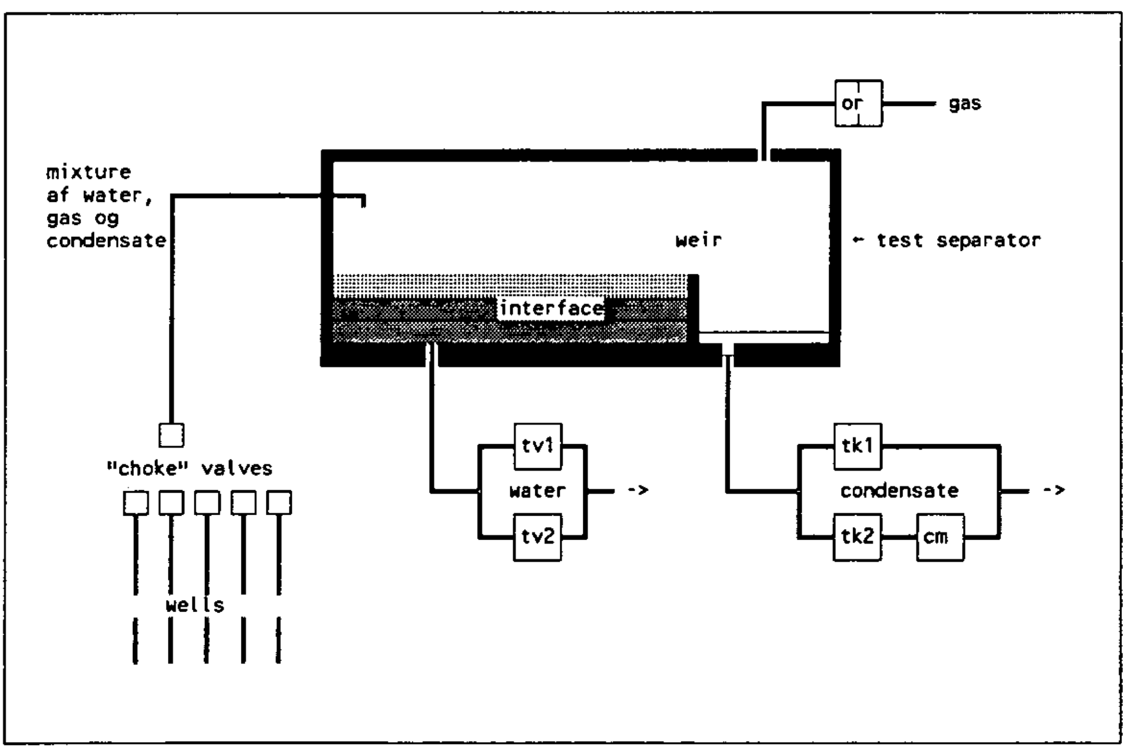


Figure 2.1.1 : Schematic diagram of the test separator on Tyra West

2.2 Condensate measurement system

The condensate measurement system is comprised of two turbine meters (tk1 & tk2) connected in parallell (see figure 2.1.1); each meter with a different flowrange. A mass flowmeter is installed in series downstreams the small turbine meter, see the photo in figure 2.2.1 :

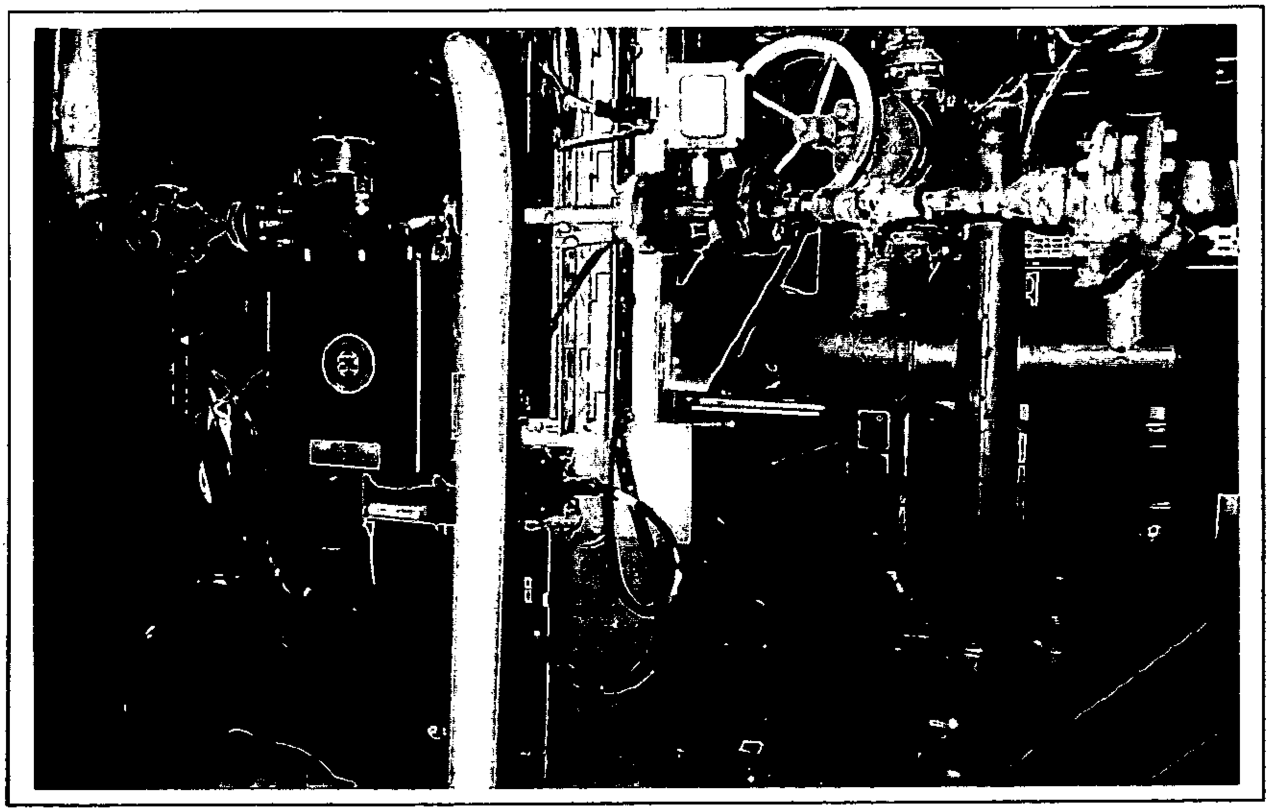


Figure 2.2.1 : Photo af the condensate measurement system the small turbine meter in series with the Coriolis mass flowmeter, Tyra West.

The turbine meter and the mass flowmeter will be described in more detail in the next two sections.

2.2.1 Turbine meter

The signal from the turbine meter is transmitted via cables to the "Auxiliary Metering System" display in the control room. Besides the data from the condensate turbine meters the display also monitors the signals from the water- and gas metering system and the flare gas metering system. Some selected data for the turbine meter is:

Manufacturer: Hydril, AOT Flow Systems
Model, s/n : Model F/0.75"/ 30 , S/N : 50242
Size : 3/4 ", 0.8 - 8 m^3/hour
Accuracy : Linearity , spec. ± 0.25 %
Repeatability , spec. ± 0.02 to ± 0.05 %

The turbine meter has last been calibrated (with water) 22.11.88 by Hydril, with following calibration results : Average K-factor : K = 433.24 pulses/litre & linearity ≈ ± 0.29 %

On the control room display (WA-23401) the following parameters for the turbine meter can be read :

1)	GROSS VOL. :	$Q_{t,g}$	[m^3/h]	$V_{t,g}$	[m^3]
2)	NET. VOL. :	$Q_{t,n}$	[m^3/h]	$V_{t,n}$	[m^3]
2)	MASS :	$Q_{t,m}$	[kg/h]	$M_{t,m}$	[kg]

Re.1) Gross vol. is the total volume: volume flow ($Q_{t,g}$) and accumulated volume ($V_{t,g}$), which are calculated as :

$$Q_{t,g} = 3.6 \cdot (f / K) \quad ; \quad V_{t,g} = \Sigma\, Q_{t,g} \cdot d\tau$$

where f = pulses per. secund from the turbine meter
K = 433.24 pulses/liter, $d\tau$= integr./summ. time

Re.2) Net vol. is the net volume : volume flow ($Q_{t,n}$) and accumulated net volume ($V_{t,n}$), calculated as :

$$Q_{t,n} = Q_{t,g} \cdot C_{tl} \cdot C_{pe} \quad ; \quad V_{t,n} = \Sigma\, Q_{t,n} \cdot d\tau$$

where C_{tl}/C_{pe} = temperature/pressure correctionsfactor
$d\tau$ = integration/summation time

Re.3) Mass is the total mass: flow rate ($Q_{t,m}$) and the accumulated mass ($M_{t,m}$), the parameters are calcuated as follows:

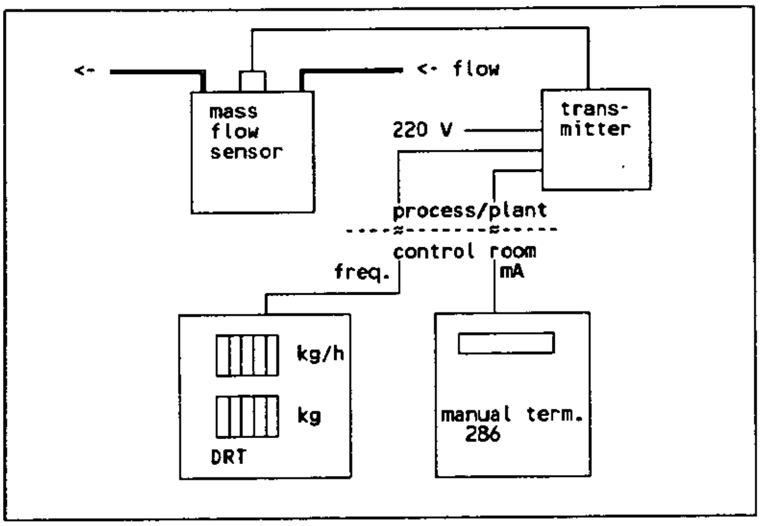
$$Q_{t,m} = Q_{t,g} \cdot \text{density} \quad ; \quad M_{t,m} = \Sigma\, Q_{t,g} \cdot 640 \cdot d\tau$$

Note that the density is fixed at a constant value : 640 kg/m^3 !

2.2.2 Coriolis mass flowmeter

The signal from the sensor of the mass flowmeter is send via cabel to the transmitter, from which the frequency (and milliampere-) signal is transmitted to the Digital Rate Totalizer, DRT (and manual terminal, 268) in the control room.

A shematic diagram of the connections can be seen in figure 2.2.2.1.



Figur 2.2.2.1 : Electrical connections of the mass flowmeter

Some selected data for the mass flowmeter is:

Manufacturer:	Micro Motion
Sensor :	Model DS065 S , s/n : 136894
Size :	DN 15 mm , Qmax = 136 kg/minute(8160 kg/hour)
Transmitter :	in EX box in proces/plant
DRT :	Model FMS-3
Model, s/n :	Model F/0.75"/ 30 , S/N : 50242
Size :	3/4 ", 0.8 - 8 m^3/hour
Accuracy :	Spec. ± 0.2 % of rate ± zero stability where zero stability = 0.84 kg/hour

The mass flowmeter is latest calibrated 91-11-16 (with water) by Rosemount, with following results :

Flow calibration factor = 20.5205.13
Density calibration factor = 12550142754.44

3. Test / calibration on Tyra West

The calibrations on Tyra West in the periode 25th of January to the 28th of January 1992 were performed by Lars Mandrup-Jensen (Force Institutes) with the help of Simon Hockenhull.

3.1 Method

The Coriolis mass flowmeter is tested / calibrated against the turbine meter both mounted on the condensate pipe downstream the test separator on Tyra West. The zero point of the Coriolis meter has been adjusted before the calibration, by performing a Zero Calibration with the valves before and after the meter closed (no flow condition).

The method applied in the calibrations is flying start/flying stop. The accumulated mass shown on the turbine meter ($M_{t,m}$) is noted simultaneously with the accumulated mass shown by the mass flowmeter(M_c), and these two values are compared using following equation :

$$F_{c-t} = \frac{M_c - M_{t,m} \cdot (Dc/640)}{M_{t,m} \cdot (Dc/640)} \cdot 100\ (\%) \qquad [3.1.1]$$

where: F_{c-t} = Deviation in percent between the coriolis meter and the turbine meter.
M_c = the mass flowmeter's display of total mass in kg.
$M_{t,k}$ = the turbine meter's display of total mass.
Dc = density (kg/ltr), measured by the mass flowmeter

Other relevant parameters have also been noted, e.g. the process temperature and the process pressure. Also the temperature and density displayed by the coriolis meter.

<u>Calculating the uncertainty of F_{c-t} :</u>

The uncertainty of the determination of F_{c-t} can be estimated by applying the law of propagation of uncertainties as seen in equation [3.1.2].

$$u^2(F_{c-t}) \approx [(\delta F_{c-t}/\delta M_c) \cdot u(M_c)]^2 + [(\delta F_{c-t}/\delta M_t) \cdot u(M_t)]^2 + [(\delta F_{c-t}/\delta D_c) \cdot u(D_c)]^2 \qquad [3.1.2]$$

By rewriting equation [3.1.2] and applying the approximations $M_t \approx M_c$ and $F_{c-t} << 100$ equation [3.1.3] can be written.

$$u(F_{c-t}) \approx 100\cdot[\ (u^2(M_c)+u^2(M_t))/M_c^2\ +\ u^2(D_c)/D_c^2\ ]^{1/2} \qquad [3.1.3]$$

The uncertainties of M_c , M_t og D_c is estimated in the following:

The display of the mass flowmeter (M_c) is "trigged" (manually read) at the same time as the shift in the display of the turbine meter (M_t), which is updated with every 4 kg. The display of the mass flowmeter is updated with every 1 kg. On this basis the uncertainty of M_c og M_t , on a 95 % confidence level, is estimated to be:

$$u(M_c) \approx (0.5^2 + 0.5^2)^{1/2} \approx 0.7\ \text{kg} \qquad [3.1.4]$$
$$u(M_t) \approx (\ 1^2 +\ 1^2)^{1/2} \approx 1.4\ \text{kg} \qquad [3.1.5]$$

The density (D_c) determined by the coriolis meter, which is necessary for the calculation of F_{c-t}, is calculated as the mean value over the duration of the measurement. On this the uncertainty of D_c is estimated to be :

$$u(D_c) \approx 0.5\ \text{kg/m}^3 \qquad [3.1.6]$$

By inserting equation [3.1.4], [3.1.5] og [3.1.6] in equation [3.1.3], the uncertainty of F_{c-t} can be calculated as :

$$u(F_{c-t}) \approx 100\cdot\ [\ 2.45/M_c^2\ +\ 0.25/D_c^2\ ]^{1/2} \qquad [3.1.7]$$

As the value of D_c is approximately 650 kg/m^3 following values for the uncertainty of F_{c-t} as a function of M_c can be given:

Mc [kg]	100	500	1000	2000	∞
u(Fc-t) [%]	1.6	0.3	0.2	0.1	0.08

The values of F_{c-t} determined by equation [3.1.1] should therefore be regarded in the light of and with respect to the estimates for the uncertainty as given in the table above. It should although be noted that besides the above mentioned contributors to the uncertainty there is of course contributions from the non-stability of the two meters due to variations in the process parameters (flow, temperature and pressure) as well as from the accuracy /repeatability of the coriolis meter regarding the determination of the density.

3.2 Results

The test / calibrations of the coriolis meter versus the turbine meter has been performed simultaneously with the platforms normal "6 hours test" on the following wells : TW B08, TW B12 og TW CO2. The table given in Figure 3.2.1 gives an extraction of the results.

date [m/d/y]	well I.d.	flow [kg/h]	Dev. [%]	density [kg/m3]	Xm , s, n % %	Qmin - Qmax [kg/h]	Mc [kg] u(Fc-t) [%]
1/26/92	TW B12	288.0	8.98	666.8	Xm= 9.49 s = ± 0.50 (n = 4)	288 - 320	≈ 100 - 200 ≈ 1.6 - 0.8
1/26/92	TW B12	300.0	9.95	667.0			
1/26/92	TW B12	302.0	9.89	666.5			
1/26/92	TW B12	302.1	9.13	666.9			
1/26/92	TW B12	970.9	1.75	665.9	Xm= 1.39 s = ± 0.25 (n = 4)	971 - 1083	≈ 300 -1000 ≈ 0.5 - 0.2
1/26/92	TW B12	1,012.5	1.37	665.8			
1/26/92	TW B12	1,062.0	1.27	665.9			
1/26/92	TW B12	1,082.9	1.18	665.9			
1/25/92	TW B8	1,584.0	.73	665.3	Xm= 0.88 s = ± 0.18 (n = 22)	1584 - 2180	≈ 1000-1500 ≈ 0.2 - 0.1
1/25/92	TW B8	1,664.5	1.10	663.5			
1/25/92	TW B8	1,783.6	.82	665.3			
1/25/92	TW B8	1,815.0	.81	664.0			
1/25/92	TW B8	1,835.6	.84	665.0			
1/25/92	TW B8	1,842.9	.90	665.6			
1/25/92	TW B8	1,854.9	.90	664.8			
1/25/92	TW B8	1,864.4	.89	665.3			
1/25/92	TW B8	1,876.9	.93	664.0			
1/26/92	TW B12	1,877.0	.83	665.7			
1/25/92	TW B8	1,886.9	.88	663.5			
1/25/92	TW B8	1,929.4	.80	663.9			
1/26/92	TW B12	1,938.2	1.23	666.2			
1/26/92	TW B12	1,940.0	.77	668.3			
1/26/92	TW B12	1,947.9	1.09	665.9			
1/26/92	TW B12	1,979.0	.96	665.7			
1/26/92	TW B12	2,000.0	.67	666.0			
1/26/92	TW B12	2,032.0	.88	665.8			
1/26/92	TW B12	2,038.7	.69	665.8			
1/25/92	TW B8	2,042.0	.73	664.3			
1/26/92	TW B12	2,042.1	1.31	666.1			
1/26/92	TW B12	2,180.0	.55	665.9			
1/27/92	TW C02	3,050.8	.59	645.0	Xm= 0.53 s = ± 0.12 (n = 11)	3051 - 3369	≈ 1500-3000 ≈ 0.1 - 0.1
1/27/92	TW C02	3,054.2	.48	644.8			
1/27/92	TW C02	3,099.3	.39	645.4			
1/27/92	TW C02	3,105.0	.41	645.5			
1/27/92	TW C02	3,108.0	.69	644.1			
1/27/92	TW C02	3,143.6	.55	645.6			
1/27/92	TW C02	3,154.3	.76	643.8			
1/27/92	TW C02	3,246.8	.54	644.7			
1/27/92	TW C02	3,290.0	.58	645.0			
1/27/92	TW C02	3,322.5	.35	646.1			
1/27/92	TW C02	3,369.2	.54	645.2			

Figure 3.2.1 : Extraction of the results from the cal. on Tyra West.

Explanation to Figure 3.2.1 :

- flow : Mean flow, mass divided by measured time
- Dev. : Deviation between the Coriolis- and the turbine meter (F_{c-t})
- density : density measured by the coriolis meter
- **Xm** : mean value of the deviation for measurements within a flow range
- **s** : standard deviation for n measurements
- Qmin/Qmax: min. and max. values of flow for n measurements
- Mc : nominel amount measured for one test.
- u(Fc-t) : Uncertainty on Fc-t

The values listed in Figure 3.2.1 are shown grafically in Figure 3.2.2 which represents an "error curve".

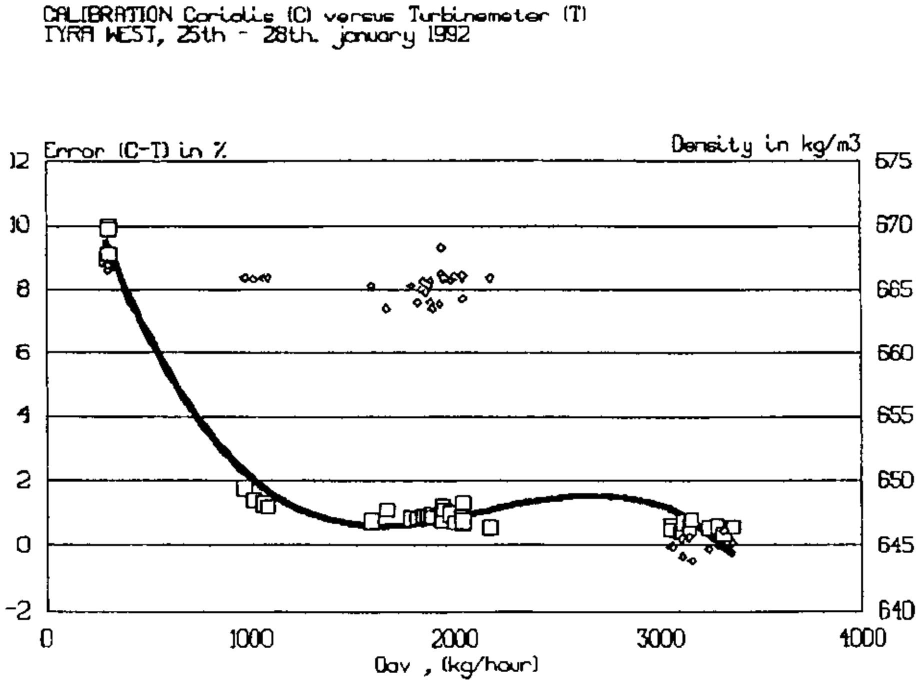


Figure 3.2.2 : "Error curve" , Dev./density versus flow

Figure 3.2.2 shows the deviation between the coriolis meter and the turbine meter (F_{c-t}) as a function of the flow. The measurement points (shown with large rectangles) are joined by a 3 rd degree regression curve determined by the "least square method".

The density has been plotted (with small "diamond" symbols) with the y-scale on the right-hand side. It can be seen that the value for the density at the flow range around 3000 kg/hour is some what lower than for the other flows. This is due to the lower density of the condensate from TW C02 well.

The deviation can be seen to be very constant in the range of 1000 kg/hour to approximately 3300 kg/hour the mean value of the deviation being around 0.9 % ± 0.4 %. This is a good result when the calibration uncertainties are taken into account.

In the range from approximately 1000 kg/hour down to 300 kg/hour the deviation grows to around 9 % . The question that immediately arises is which meter is not measuring correctly: the coriolis meter or the turbine meter. This question will be reflected upon on the next section: Calibration in the laboratoratory.

4. Calibration in laboratory

The calibrations in the Dantest Liquid Flow Laboratory were performed by Lars Mandrup-Jensen (Force Institutes) with the help of Simon Hockenhull.

4.1 Method

The plan was that the metering section consisting of the turbine meter and the mass flowmeter, was to be calibrated against a weighing system.

But as the turbine meter was damaged when it arrived to the laboratory (probably during the transportation off-shore to the laboratory), calibration of this meter was not possible in the laboratory.

The mass flowmeter was calibrated against the weighing system using mineral turpentine (≈ kerosine) with a density of appr. 770 kg/m^3 at 20 °C. The principle applied is standing start and standing stop and an amount corresponding to minimum 30 seconds calibration periode has been measured.

The error for the mass flowmeter (F_{c-v}) is determined as:

$$F_{c-v} = \frac{M_c - M_v \cdot BCF}{M_v \cdot BCF} \cdot 100\ (\%) \qquad [4.1.1]$$

where: F_{c-v} = Error in percent for the mass flowmeter
M_c = Total mass of the mass flowmeter in kg
M_v = Display of the weight in kg
BCF = bouyancy correction factor, nom. = 1.0014

The uncertainty of F_{c-v} is estimated to be better than ± 0.2 % .

4.2 Results

The results from the calibration of the mass flowmeter against the weighing system is shown in the table below. **Xm** is the mean value and **s** is the standard deviation.

Cal. Nr.	Flow [kg/h]	Fc-v [%]	**Xm** [%]	**s** [%]
1	223	-0.33		
2	303	-0.25		
3	310	-0.38	-0.29	0.06
4	312	-0.19		
5	315	-0.32		
6	316	-0.25		
7	1284	-0.48		
8	1292	-0.44		
9	1295	-0.46		
10	1306	-0.45	-0.46	0.02
11	1307	-0.42		
12	1307	-0.42		
13	1309	-0.49		
14	1313	-0.48		
15	2527	-0.51		
16	2537	-0.51		
17	2557	-0.49	-0.52	0.02
18	2561	-0.54		
19	2588	-0.54		

Figure 4.2.1 : results from the calibration of the mass flowmeter against weighing system.

The mean value of the error in the flow range of 223 to appr. 2600 kg/hour is **-0.42 %** with an unlinearity of **± 0.11 %**, which at least regarding the unlinearity is within the specifications.

Comparing these results with the off-shore calibration results (see figure 3.2.1 and figure 3.2.2) it can be seen that it was the turbine meter that was in error in the low flow range. This is in accordance with theory and practise of the calibration curve of a "normal" turbine meter.

Besides the above calibrations the mass flowmeter has been calibrated using pulsating flow. The flow was turned up and down every 10 seconds a total of ten times during a calibration. 5 repeat measurements have been performed, in which the mean value of the error was measured to be -0.48 % with a standard deviation of 0.02 % . Therefore no significant difference from the calibration with non-pulsating flow.

5. Conclusion

The Coriolis meter has been tested off-shore against a turbine meter, and acceptable results were obtained. The turbine meter and the Coriolis meter compare well down to 1000 kg/hour. In the flow range under 1000 kg/hour the deviation between the meters grow as the error of the turbine meter grows. This is to be expected from a normal turbine meter.

In the laboratory the Coriolis meter has been calibrated against a weighing system and there the meter has shown good repeatability but an off-set of approximately -0.42 % . The Coriolis meter was found not to be significantly sensitive to pulsations.

In the following will be given some benefits and non-benefits in using Coriolis meters off-shore, which have been deduced from the calibrations performed in this project off-shore and in the laboratory :

Benefits:

- Good measurement uncertainties in a large measuring range.
- Small sensitivity towards pulsations
- Measures the density and temperature of the fluid continuously
- Will not be damaged by particles in contrast to turbine meter

Non-benefits:

- Safety risk in the case of fatigue fracture, as the fluid then will flow uncontrolled (in contrast to turbine meter)
- Sensitive to air in the fluid
- Possible sensitivity to vibrations in the fundament

On the basis of the results from the performed calibrations the Coriolis mass flowmeters are evaluated to be possible alternatives to conventionally applied metering systems off-shore.

The performed calibrations have although not tested the Coriolis meters under every possible condition and therefore this project is intended to be followed by a more complete investigation. Such an investigation could besides uncovering all benefits, also involve several manufacturers of meters, long term tests especially to test the possibility of fatigue fracture, variation in the content of particles and air in the fluid and possible vibrations of the fundament.

References

[1] Paper presented at the North Sea Flow Measurement Workshop, a workshop arranged by NFOGM & TUV-NEL

Note that this reference was not part of the original paper, but has been added subsequently to make the paper searchable in Google Scholar.