Are Coriolis Mass meters suitable for Fiscal Liquid Applications?

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Content

1. Introduction

This paper is addressing the use of coriolis meters for liquid applications in the Petroleum industry. It is focusing on the Ormen Lange condensate case as that was the reason for the technical concerns and additional testing that has been done. It is, however, so that the findings and conclusions should be of general nature and thereby be applicable for the use of Coriolis meters for liquid applications.

2. History

The Coriolis principle is relative new as measurement principle. It was in 1979 that the first meters were launced and they were often marketed as the answer to most metering challenges. We have (as we often do) experienced that this was not the truth.

Our Norwegian “gründer” Jon Gjedebo, once told me that he had attended a metering conference in the USA in 1979 or 1980 and there suddenly a speaker presented something brand new. A new metering principle. According to him a really “wake up” message for the audience. Something brand new.

Our conference the NSFMW had its first presentation of coriolis meters in Stavanger in 1987. Dr. Furness was at that time a very enthusiastic spokesman for the coriolis technology. Our inspector Kåre Gran, was by coincidence challenged by Dr. Furness by the question: “What do NPD require then to fully accept the coriolis technology”. The answer was simple but wise: “We want real tests”.

The first coriolis meters installed under our regulation were the Total St.Fergus, condensate meters in the end of the 1980ies. The operation of them were also reported at this conference in 1990, by Trevor Davies of Total. As coriolis meters are still in use for this metering point and also for other newer liquid export measurements from the St.Fergus terminal, it can be concluded that it has been a success.

Later Phillips had an installation at Edda for wet gas. That was not much of a success and was reported at this conference in 1994.

Shell did also use coriolis for a gas application on Draugen, (start 10 years ago) with reasonable success. The heating of the gas is critical to avoid two phase flow.

During the recent years it looks as the confidence in the coriolis meters are growing.

The Ormen Lange project (start up autumn 2007) was designed with coriolis meters for the condensate export. The design is a bank of 3*8” master meters to prove the 5*12” duty meters. A portable compact prover is then regularly used for giving the k-factor for the master meters. This project will be covered in detail in this paper.

The Ormen Lange Coriolis project has previously been presented at this conference in 2006. The presenter then assumed that all challenges were sorted out by the testing during the project phase. The author was in the end riding into the sunset accompanied by sweet music. Operational experience showed later that this was too optimistic.

3. Standardization

API: Measurement of Petroleum Measurement Standards: Chapter 5 – Metering, Section 6- Measurement of Liquid Hydrocarbons by Coriolis Meters (October 2002, reaffirmed march 2008).

AGA: report no 11/API MPMS ch 14.9. Measurement of Natural gas by Coriolis Meter (2003)

ISO: ISO 10790, second edition 1999 with amendment 1 for gas measurement in 2003.

DECC: Guidance notes for petroleum measurement (2003). The coriolis meters are briefly mentioned in section 3.6 and 3.11.

NPD: The coriolis meters are not specifically mentioned but they are in use for fiscal puposes some places after a special case by case handling process. Will be included this autumn.

OIML R-105 Direct mass flow measurement of liquids (1993)(1995)(1999)

Type approvals: Done by various institutes as NMi, PTB or other.

The standards and type approvals are meant to help in the selection, installing and operating the coriolis meters in a best possible way. All concerns are, however, not fully described. It is still pitfalls to be aware of. The technology has during the recent years been improved, new models have been introduced and they are more suited to deliver good linearity, repeatability and stability data. It would, however, be fair to say that the standards are fairly old and are not necessarily reflecting present technology. The same is of course even more the case for the type approval. It is normally not very relevant for the use of the meter. That means that in the "real world" we are very dependant of the knowledge of the vendor and the buyers ability to specify correct the operating conditions. That can of course be a challenge in the oil industry as the number of stages (people involved) in a buying process can be quite high. In addition the operating conditions often changes over time so it is important in the design process to also have an open eye on this aspect.

4. Principle of operation

The principle was first described of the French physician Gustave-Gaspard de Coriolis (1792-1843).

The principle is for general explanation in school books related to the rotation of mother earth.

The principle is then for more direct experience, illustrated by a person on a rotating carousel. The person will be influenced by two forces. One radial force from centre of the rotation and one force 90˚ on the radial force in the direction of the rotation (the coriolis force).

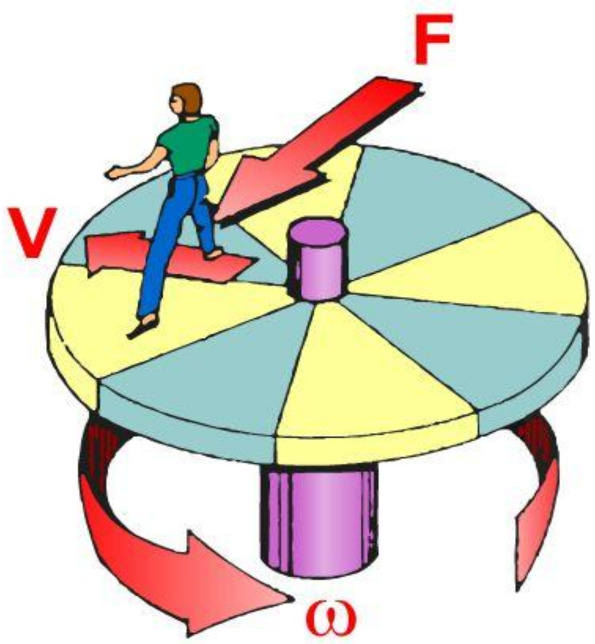


Fig. 1

The persons mass will then be defined by this formulae:

M= The mass of the person

F= The coriolis force

ω = The angular velocity of the carousel v= The person`s radial velocity from the centre of the rotation

It is this effect which is used in the coriolis meters, shown in figure 2.

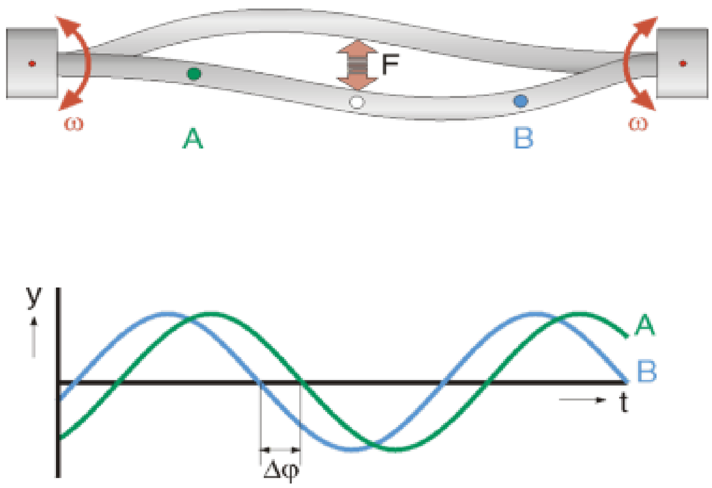


Fig 2

Δφ= Phase shift

A and B= Sensors

t= time

y= Amplitude

Fc= Coriolis force

The coriolis force is forced on the vibrating tube by a drive element. The phase shift is then picked up by the sensors A and B, at the outlets of the tube. When it is no flow, then it is no phase shift, Δφ= 0.

For many people it could then sound simple to produce a metering device based on this principle. But it was not. The first attempts was to use a rotating pipe. This did not work due to mechanical/sealing problems. It was first when a vibrating or oscillating motion was used instead, a break through or commercialization of the technology came. (1979, Micromotion).

5. The use in the North Sea Petroleum Industry

The coriolis meters has been in use for special applications the last 22 years. Total installed them for some small condensate lines in St.Fergus. Phillips installed them on Edda for gas measurement. Shell installed coriolis meters on Draugen by the end of the 1990ies for gas and liquid measurement.

It would be fair to say that this was more to be regarded as pilot installations for small amounts. No technological general acceptance of the metering principle.

Then the Ormen Lange came onstream in 2007, with large condensate meters and a significant economical impact.

Based on an individual technical and economical benefit analysis, it has for a long time been possible to use Coriolis meters for measurements regulated according to the “Regulation related to measurement of petroleum for fiscal fiscal purposes and for calculation of CO_2 tax” issued by the Norwegian Petroleum Dirctorate.

This principle was also used by the responsible company for the Ormen Lange development, Norsk Hydro, when they wished to utilize coriolis meters for the condensate export.

6. The Ormen Lange Condensate Case

Design criterias:

a. Loading rate 8000 Sm^3/h

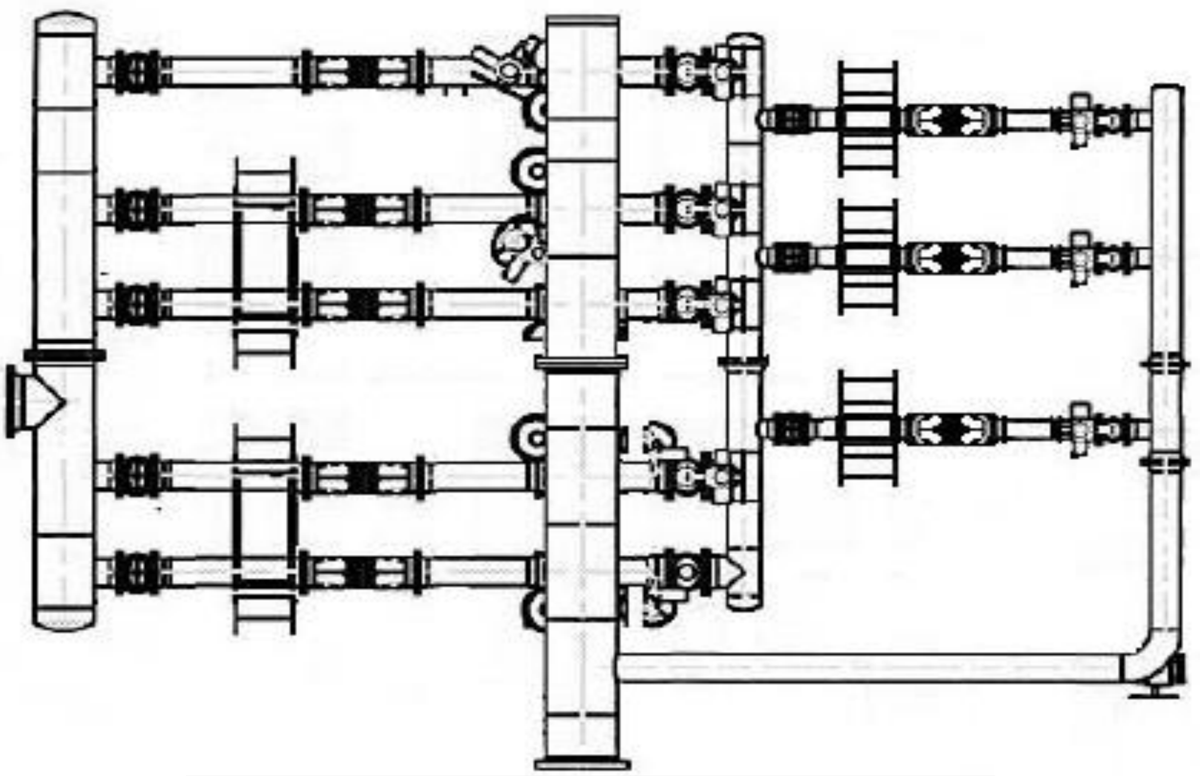
b. On-site calibration of master meters

c. Portable prover capacity is maximum 800 Sm^3/h

d. Volumetric flow primary meters shall have volumetric flow master meters

e. Mass flow primary meters shall have mass flow master meters

f. Maximum meter run line size 12” to ease maintenance



Inlet header, duty meters, outlet header and master meters.

Fig. 3, gives the final design of the Ormen Lange condensate skid.

The calibration rig placed close to the Ormen Lange condensate skid.

It is as shown 5 * 12” duty meters and 3*8” master meters. The master meters should be used on each batch to calibrate the duty meters. The master meters should then at regular intervals be calibrated against the portable compact prover. Same principle as a conventional pipe prover.

As a criteria for the selection of the coriolis concept was an assumption that the lubricating effect of the Ormen Lange condensate was low, so that eventual turbine meters could phase difficulties.

When it comes to selection of vendor of coriolis technology only one vendor at that time could deliver meters with this size. (And the size of the vibrating loop is really large, some thermal challenges could may be have been foreseen). The vendor also sold in the meters as being not sensible for vibrations in structure and surrounding pipe due to the way the vibrations were picked up was somewhat different from other vendors.

Fig 4, Coriois meters mounted at a test stand. Take notice of the coriolis loop size

A huge test sequence was established in cooperation between the Ormen Lange project/Norsk Hydro/Shell/NPD. This to ensure that meters were capable of delivering when put in service. The sequence went on for several years from visiting sites, testing and retesting at Trapil and final flow calibration at a FMC construction site in Greece. Several weaknesses with the meter algorithms related to the coriolis effect, compensation of environmental and density effects were picked up and corrected during this sequence.

The tests, however, were as tests normally are, not covering the operational range (outside conditions as well) as the meters were intended to cover at Ormen Lange. It is easy to say afterwards that the testing was not realistic enough to bring all effects that could occur into broad daylight.

The Operator was arguing that it was not a qualification run for technology which was going on. The tests which were done should then be regarded as a compromise between the viewpoints of the Operator, the package vendor, the equipment vendor and NPD.

After the meters were put in service it was soon seen that they did not have that stability as fiscal meters should. This lead to several claims on condensate being shipped out from the Ormen Lange terminal and frequent recalibration of the 3 master meters to investigate and possibly solve the technical difficulties. It did not work out, as the KF deviation between the installed coriolis meters and the reference could on some tests be 1% and above. All random depending mainly on what environmental temperature effects which were in place during the testing sequence.

Finally in summer 2010 a decision was taken to check three manufacturers coriolis models at a traceable laboratory and specifically focus on the weaknesses we had seen on Ormen Lange.

The test procedures were ready by the end of 2010, and the test itself were run in January 2011.

7. The Intertek flow test laboratory

Figure 5, shows the Intertek flow loop.

It consists of:

- Pump
- Heat exchanger

- Compact prover
- Meters to be calibrated
- Pressure accumulator (Oil/Nitrogen)

The capacity of the rig is:

Flow: 400 m3/h,

Temperature: Up to 90˚C/Pressure: Up to 100 Barg

The uncertainty of the set up is very much dependant of the uncertainty of the Compact Prover unit. It is in principle the same type of unit which is used for calibrating provers. The volumetric uncertainty is calculated to 0,036% according to the principles laid down in JCGM 100 (2008) (earlier GUM 1995) and the NFOGM, Handbook of uncertainty calculations.

Vannkalibrering		**Meterfaktor**		**Rørnormal volum**	
cp temp	23,9°C	cp temp	37,7°C	meter temp	37,7°C
stem temp	18,0°C	stem temp	25,9°C	meter trykk	3,0BAR
can temp	23,8°C	meter temp	37,7°C	prover temp	37,5°C
cp trykk	2,0BAR	cp trykk	3,0BAR	prover trykk	2,1BAR
		meter trykk	3,0BAR		

Fra 5.1

dCTDw =	0,000050	,	S1 =	28,8675135	E-4	,	S1^2 =	83 333	E-10	
dCTSm =	0,000005	,	S2 =	2,8867513	E-4	,	S2^2 =	833	E-10	U1^2 =(E-6)
dCTSp =	0,000003	,	S3 =	1,7320508	E-4	,	S3^2 =	300	E-10	62,4671
dCPLp =	0,000005	,	S4 =	2,8867513	E-4	,	S4^2 =	833	E-10	
dCPSp =	0,000001	,	S5 =	0,5773503	E-4	,	S5^2 =	33	E-10	U1 = (%)
Rd =	1,76 ml	,	U6 =	29,26326556	E-4	,	U6^2 =	85 634	E-10	0,00790
A1 =	1,00ml	,	U7 =	9,622504486	E-4	,	U7^2 =	9 259	E-10	
A2 =	4,00ml	,	S8 =	33,33333333	E-4	,	S8^2 =	111 111	E-10	
A3 =	0,0058%			57,73502692	E-4	,	A3^2 =	333 333	E-10	

Fra 5.2

U1 =	0,00790361			79,0361252	E-4	,	U1^2 =	624 671	E-10	
dCTL =	0,000169	,	S9 =	97,5721955	E-4	,	S9^2 =	952 033	E-10	
dCPL =	0,000018	,	S10 =	10,3923048	E-4	,	S10^2 =	10 800	E-10	U2^2 =(E-6)
dCTSp =	0,000003	,	S11 =	1,7320508	E-4	,	S11^2 =	300	E-10	200,6805
dCPSp =	0,000001	,	S12 =	0,5773503	E-4	,	S12^2 =	33	E-10	U2 = (%)
rd =	1,76 ml	,	U6 =	29,2632656	E-4	,	U6^2 =	85 634	E-10	0,01417
A3 =	0,0058%	,		57,7350269	E-4	,	A3^2 =	333 333	E-10	

Fra 5.3

U2	0,014166	,		141,6617372	E-4	,	U2^2 =	2 006 805	E-10	
dCTL =	0,000158	,	S9 =	91,2213425	E-4	,	S9^2 =	832 133	E-10	U3^2=(E-6)
dCPL =	0,000018	,	S10 =	10,3923048	E-4	,	S9^2 =	10 800	E-10	318,3505
dCTSp =	0,000003	,	S11 =	1,7320508	E-4	,	S9^2 =	300	E-10	U3 = (%)
dCPSp =	0,000002	,	S12 =	1,1547005	E-4	,	S9^2 =	133	E-10	0,01784
A3 =	0,0058%	,		57,7350269	E-4	,	A3^2 =	333 333	E-10	

SUM USIKKERHET SQRT(U3^2) = 0,01784 %

USIKKERHET I KALIBRERT VOLUM: U = K2 U = 0,036 %

8. The test specification

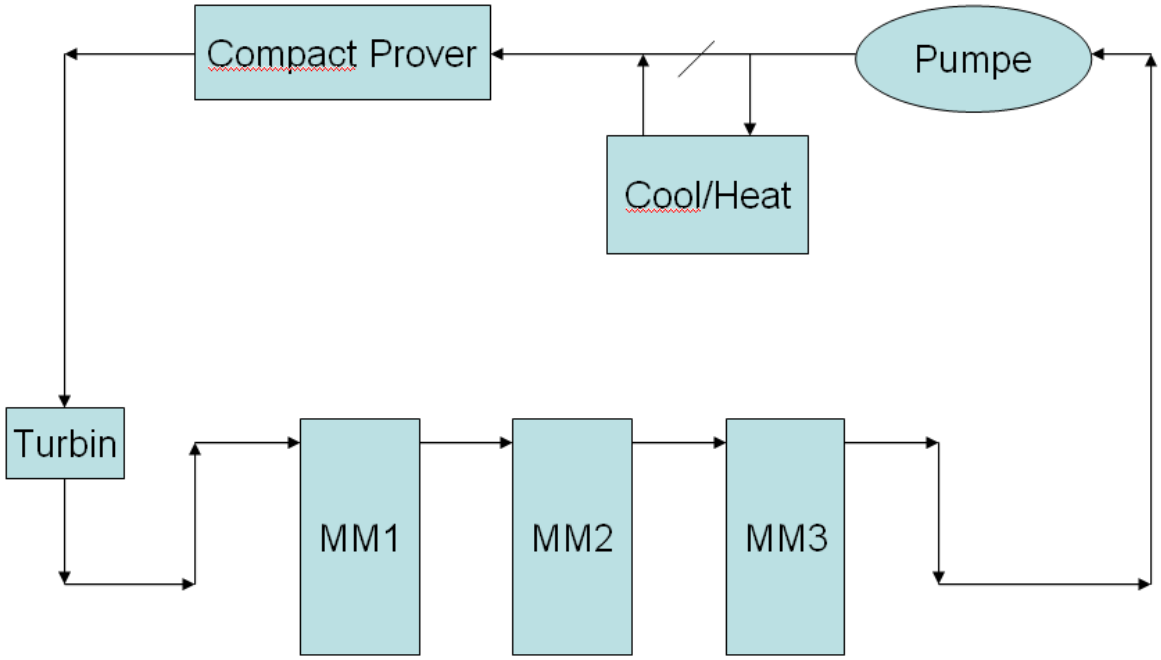
Phase one (in the flow lab)

a. All mass meters will be installed in series with proper support skid for each meter to prevent stress to the meter. Calibration liquid will be near Ormen Lange condensate. The meters will be zero calibrated on the working condition after temperature and pressure has stabilized. The zero will be checked and registered regularly but no calibration will be done on a later stage in the test.
b. Good representative sample will be taken from the loop to establish density of the flowing condensate.
c. After the meters have been Zero calibrated at the decided operated pressure and temperature the test can begin.

Procedure will be as follows for each condition:
1. Pre calibration of the turbine meter by using a Compact Prover
2. Three repeats of comparison between the master meter (calculated to mass) and the mass meters (all at the same time) over a set period to achieve necessary resolution.
3. Post calibration of the turbine meter by using a Compact Prover

d. Following condition will be checked:
1. 20°C – 10 barg
2. 25°C – 10 barg
3. 30°C – 10 barg
4. 35°C – 10 barg
5. 40°C – 10 barg
6. 30°C – 5 barg
7. 30°C – 10 barg
8. 30°C – 15 barg

e. To prove the stability of the meter even with a environmental change we will introduce each meter with a blower giving approx 20°C above the liquid temperature to se if the K-Factor change. One meter at the time will be checked by isolate the effect to only one meter at the time.
f. Linearity check can only be done to a limited range on the meter. Max flow rate are 400m3/h so a check from 200 – 400m3/h will give an indication of the meters performance.
g. From the tests mention above the conclusion could be drawn if the meter should go further to phase two at Aukra. Suppliers will be informed of the achieved results.
h. Test loop setup (fig 6)



Figur 6

A short version of the test requirements:

- Check the meter performance during liquid temperature change. 20-25-30-35-40˚C. Pressure 10 Barg.
- Check the meter performance during liquid pressure change. Liquid pressure 5-10-15 Barg. Liquid temperature 30˚C.
- Check the meter performance during meter warm up period. Liquid temperature 30˚C. Pressure 10 Barg.
- Check the meter during environmental temperature change (Warm air influence). Liquid temperature 30˚C. Pressure 10 Barg.
- Linearity test. Liquid temperature 30˚C. Pressure 10 Barg. Flowrate 200-400 m3/h.

Calibration procedure:

Pre KF on Master Meter – Comparison between Master meter and all three Coriolis Meters simultaneously- Post KF on Master meter.

To calculate mass from volume the density were established in the beginning of the test. Ko and K1 improved by checking and analyzing density at 15 ˚C and 40 ˚C.

All meters were tested at the same time and with the same conditions.

9. **Results**

a) **Liquid temperature change 20-40˚C = KF within a band of 0,1%**

Meter 1: 1,60 % : Not OK

Meter 2: 0,071%: OK

Meter 3: 0,239%: Not OK

b) **Liquid pressure change 5-15 Barg = KF within 0,05%**

Meter 1: 0,021%: OK

Meter 2: 0,024%: OK

Meter 3: 0,056%: Not OK

c) **Meter from start up (cold to warm) = KF within a band of 0,05%**

Meter 1: 0,175%: Not OK

Meter 2: 0,025%: OK

Meter 3: 0,052%: OK

d) **Change outside temperature by blowing warm air = KF within a band of 0,05%**

Meter 1: 0,108%: Not OK

Meter 2: 0,024%: OK

Meter 3: 0,115%: Not OK

e) **Linearity check**

Meter 1: 0,388%

Meter 2: 0,059%

Meter 3: 0,017%

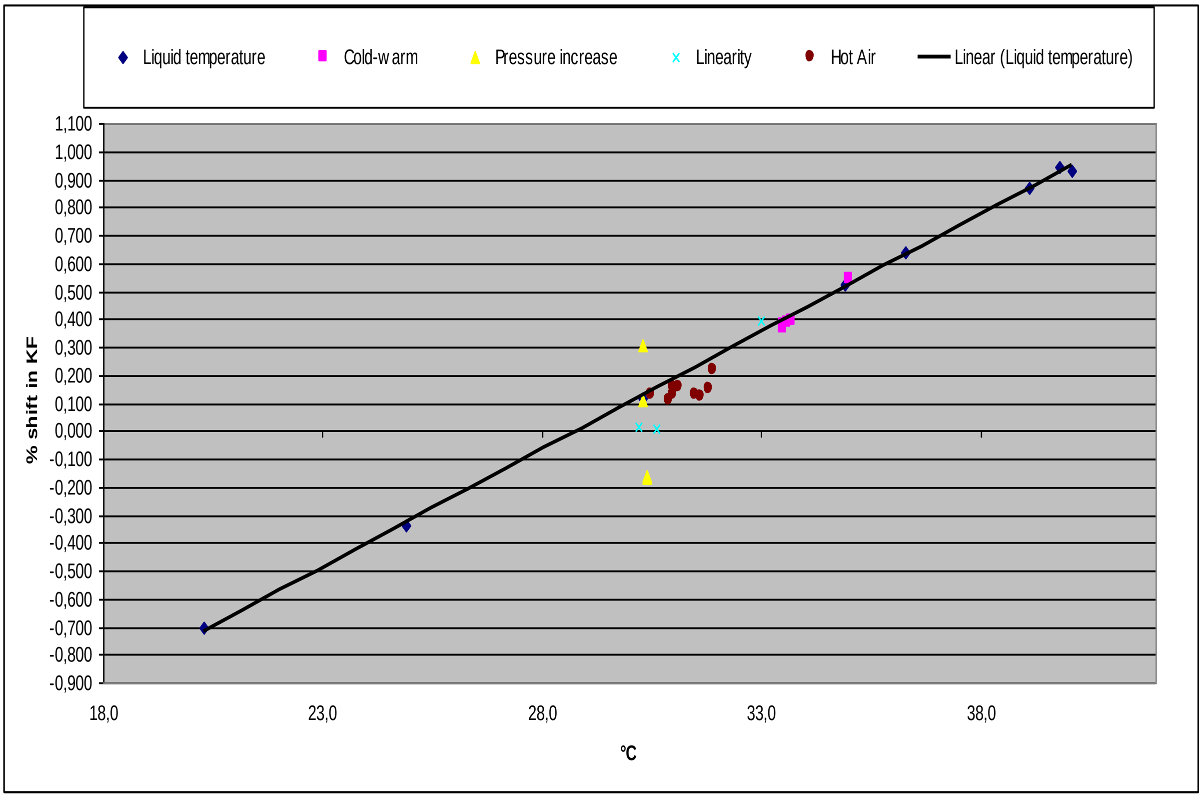
From these results it can be concluded that Meter 1 (originally installed in the field) did deliver poor results. Meter 2, did fulfill the requirements on all items. Meter 3, was slightly outside on some areas, but gave excellent results on the linearity check.

Meter 3 was retested this summer and the result from this testing were excellent and it can then be regarded same as meter 2 to fulfill all requirements.

It should be mentioned that technical staff from the vendors of meter 2 and 3 gave very active support during the test and helped solving technical matters on the test site. Without this follow up during the tests both meters would have had difficulties. It shows the importance of knowledge among the people responsible for the follow up activities.

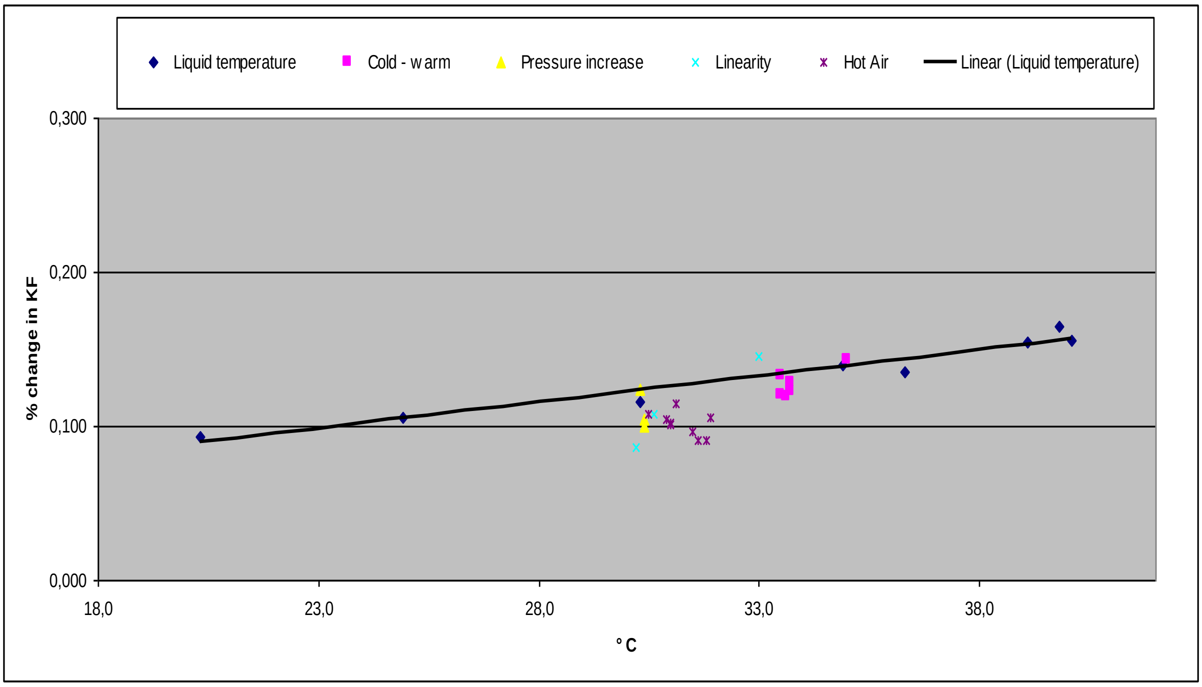
Meter number 2, has after the test been installed in series with the reference meters on Ormen Lange and it has continued to deliver acceptable results, when compared against the portable reference unit.

Fig 7. Worst achieved results



Shift in K-factor, 1,6% due to temperature change of 20 ˚C

Fig 8. Best achieved results



Shift in K-factor, 0,07% due to a temperature change of 20 ˚C

10. Conclusion

Fiscal metering employing "new" technology is never easy. Some coriolis meters based on recent design are capable of doing the job, but they have to show their capacity in tests as are referred to in the Intertek test set up or similar.

The density will have to measured accurately as it influences the comparison against the reference meter and often also the coriolis effect. Pressure and Temperature is therefore also important parameters.

All the three meters tested are sensitive to pressure, but the effect was found to be linear and could be compensated for.

Environmental effects as cold weather/winds or hot weather/direct sun will influence the meter. The meter should document robustness against these effects and should also be protected against them by proper insulation og sun protection/air condition.

The viscosity effect is also a parameter that could influence especially on high viscous fluids and should be documented.

The importance of field calibration under real conditions can never be underestimated.

A careful examination to avoid installation effects and to ensure correct installation should always be done.

The recent development in electronics have contributed to the improved quality of the Coriolis meters. Recent testing at NEL have shown that the meters now are able to respond fast enough to rapid changes in the natural frequency. We see that these facts have been adopted by the industry and it is quite clear that more projects than before are now proposed to us with Coriolis meters as the fiscal meters.

The NEL Guidance note: Installation and Set-up of Coriolis Mass Flow meters (August 2010) (free download from the NEL web site) gives a number of good recommendations when installing a Coriolis meter, and it also mention a number of pitfalls.

11. The Norwegian Petroleum Directorate (NPD) Measurement Regulations

We are now in the process of including the Coriolis meters into the measurement regulations, the table in section 8.

The requirements is proposed to be:

Gas:

Linearity: ± 0,70% in the working range

Repeatability: 0,40% (band)

Oil:

Linearity: ± 0,20% in working range

Repeatability: 0,05% (band)

In addition a requirement for documenting the stability of the meters for the relevant operating conditions will be included (by operating condition we mean both the fluid specifications and the environmental conditions). This will not be something which should necessarily be done every time but as a reference test for a meter design.

12. References

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