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PRACTICAL APPLICATION OF CORIOLIS METERS FOR OFFSHORE TANKER LOADING FROM THE HARDING FIELD

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SUMMARY

The Harding Oil Field is a first application of Coriolis meters for the offshore measurement of 'oil won and saved' and tanker export. A meter skid comprising six inch Micro Motion D600 Coriolis meters and a 24 inch Rosemount Brooks compact prover has been manufactured, tested, installed and commissioned offshore. Coriolis meters were chosen because of the high viscosity of the Harding oil and operating cost savings from hoped for extended meter proving intervals up to 6 months.

The experience from the first three months of field operations and factory acceptance trials are presented in the paper. This shows successful performance of the Coriolis meter and compact prover combination in an offshore custody transfer environment. Stability of meter proving over the first three months is within a band of ±0.2%, which bodes well for the anticipated reduction in frequency of proving. Comparisons between offshore proving on oil and factory calibration on water are within 0.4%, which gives support for the use of Coriolis meters without offshore proving.

1. BACKGROUND

The Harding Oil Field lies in UKCS licence block 9/23b in the Northern North Sea, approximately 320km Northeast of Aberdeen, 190km north of Forties and 35km south of Beryl. It is an Eocene reservoir and was discovered by Britoil (now owned by BP Exploration) in January 1988. The Partners are BP (Operator), Repsol and Ranger.

The Harding field was originally named Forth and changed in 1993 in memory of David Harding CBE former Chief Executive BP Exploration Europe. The field comprises several pools of oil. When initially examined for development, using conventional production platform technologies, it could not be made commercially viable. Radical new approaches were necessary.

The chosen solution for the Harding Development is a novel, large, purpose designed, heavy duty jack-up platform, providing fully integrated drilling, production and quarters (PDQ) facilities. It has been fabricated by Hyundai in Korea. It is fixed to a gravity base tank (GBT) foundation, designed and constructed by a Costain Taywood Joint Venture in London and Hunterston in Scotland. It also acts as storage for the separated crude oil and as a well template.

Oil temporarily stored in the concrete gravity base is exported via a short (2km) 24" pipeline and submerged turret loading (STL) system to shuttle tankers on a batched basis.

These facilities combined with the advantages made possible by significant advances in horizontal well technology turned Harding round from a being at best a marginal prospect into a viable enterprise.

2. METERING PHILOSOPHY AND DESIGN CONCEPT

2.1 Meter Selection

The Harding crude oil is heavy by North Sea standards. It is low in sulphur and wax content, but is particularly viscous at low temperature (600 to 1200 cP). With this high viscosity Harding crude cannot be measured using traditionally approved turbine meter methods. The viscosity was also too high for Faure Herman Heliflu turbine meters, often appropriate for more intermediate viscosity. So first thoughts were to use positive displacement (PD) meters. However these have moving parts, require regular proving, can generate high vibration and tend to require relatively high levels of maintenance.

Coriolis meters appeared to offer an obvious alternative. The mass flow measurement is claimed to be insensitive to viscosity variations and the meters have no rotating parts. They potentially have high inherent stability of calibration and low operating costs. This calibration stability of Coriolis meters offers the potential prize of significantly increased periods between calibration checks.

After careful review of the Coriolis meters on the market it was concluded that the Fisher Rosemount Micro Motion Coriolis mass flow meters met the requirements for the operational ranges of flow rate. Detailed analysis of the measurement and calibration uncertainty was conducted through close working between the BP Harding Development team, BP Research and Engineering, Jordan Kent Metering Systems (JKMS, the chosen skid supplier) and Fisher Rosemount. It was concluded that a viable solution was achievable using Coriolis meters.

2.2 Proving

Proving of mass meters in situ remains a problem because there is, as yet, no direct mass proving system available for an offshore application. The alternative is to prove against a volume prover with a closely associated on line density meter.

Use of alternative routine calibration methods to a conventional pipe prover were considered, with the emphasis being to minimise skid size, weight, and capital cost and to reduce maintenance costs. These alternatives included use of a reference meter with onshore calibration or transportable compact prover combined with reduced frequency of proving.

A Rosemount Brooks 24 inch compact prover in combination with Solartron Type 7835 density meters installed in a conventional fast sample loop were chosen for proving. A particular issue here was whether an acceptable repeatability of proving could be obtained with Coriolis meters and the short proving times (down to one second) that are inevitable with large meters in conjunction with a compact prover. This was first substantiated by pre-purchase testing at Micro Motion facilities in the USA.

2.3 Uncertainty Calculations

Calculations showed that, using a compact prover with a Coriolis meter, an overall measurement uncertainty of ±0.25% on standard volume flow was possible. Mass flow uncertainty was slightly less at ±0.23%, because there is less dependence on density measurement. The largest contribution to uncertainty was a generous allowance of ±0.2% to allow for possible shifts in calibration during the hoped for 6 monthly proving intervals. Tables 1 and 2 show more detail.

Given these uncertainties and the special case of high viscosity, the DTI (GOM) were happy to see Harding as a first application for metering crude oil 'won and saved' offshore using Coriolis meters. A requirement for all parties was that acceptable calibration methods and operating practices were developed to achieve the necessary performance.

2.4 Detail of Metering

The metering concept adopted was to use a single six inch D600 meter (named P) to measure the oil produced to the GBT storage (64,000 barrels per day, tested to 500 t/h) and six, similar meters (named T1 to T6), to measure the oil exported from the storage tank to the offshore shuttle tankers (400,000 barrels per day, tested to 500 t/h per meter). Volume is the primary measurement for tanker loading. The Coriolis meter internal density function and the separate density meter are used for conversion from mass to volume as measured and then to standard volume, using the normal temperature and pressure corrections for oil. The density part of the Coriolis meter is calibrated against the separate density meter which is also used for the mass proving.

Figure 1 shows the configuration of the meters and prover. The density loops are standard fast sample loops containing the Solartron 7835 density meter, flow proportional samplers and an MFI microwave water in oil analyser.

New issues, to be taken into account in applying the Coriolis meters, included dealing with the potential effects of external vibration, cross coupling vibration causing frequency shift of meters in adjacent streams, mechanical stress, meter orientation and support. The meters were oriented so that flow is vertically upward to avoid any trapped gas pockets in the 'U' bend of the instruments. They are solidly supported at the inlet and outlet and structurally bonded to the relatively large mass of the skid. This is to minimise cross-talk effects between streams and external stress influences. Effects due to external vibration were thought to be unlikely, but provision was made to mount the complete metering skids on anti-vibration mounts should it later become necessary. Field operation has so far not identified vibration as a problem.

2.5 Flow Computers

Flow computers are used in addition to the Coriolis meter field transmitters. This application required some extra functionality and then modification to standard flow computers. Details of the data flow are shown in Figure 2. Mass pulses were chosen as the primary data, because these are necessary for accurate proving. To check the continuous integrity of these pulses, comparisons are made between mass totals and mass flow rates as derived from the pulses and as derived from interrogation of the transmitters via the serial data link. This link is also used to pass on any Coriolis alarm states. The flow computer also applies corrections to the raw readings, in particular for the effect of pressure on mass flow rate.

The control and computer panel for the metering skids was supplied by SpectraTek as part of the JKMS package. SpectraTek chose to use a modified version of their S500 stream computers with two S1000 supervisory computers to manage the skid operation and quantity reporting.

2.6 Determination of Water

MFI continuous analysers are installed to determine water content. It is hoped that, after a period of verification, these continuous measurements will be used in place of traditional sampling and analysis. The flow computers were also modified to perform continuous live calculations of dry oil quantities. This is not a critical application because Harding water content is expected to be low.

3. FACTORY ACCEPTANCE TESTING

All meters were tested on water as part of factory acceptance at JKMS over a flow range of 10:1 from 490 t/h for the D600 meters. The table below shows the nominal test points.

TEST FLOW RATES	
Percent of Design	6 inch D600 Meters
100%	490
60%	294
20%	98
10%	49
PRESSURE	1 to 5 barg
TEMPERATURE	15 to 30 ^{o}C

The results are shown in Figures 3 and 4. Four of the meters were within 0.1% of the factory calibration at all flow rates. Of the other three meters, two were within 0.2% of the factory calibration at all flow rates while the last one was only outside this limit at the 20% flow rate and below.

The differences between the individual tests for a meter at the higher flow rates indicate the separate effects of stability of calibration with time after manufacturer calibration, cross-talk effects from special combination tests and test errors (from water density, prover swept volume and manufacturer mass calibrations). Total variations between tests are within a spread of ±0.1%. This raises hopes that extended calibration stability and proving intervals may be achievable.

For each separate test, the K-factors in a sequence of up to 30 separate passes were determined. The standard deviation for the separate passes is shown for the tanker meters and the production meter in the table below. At the maximum flow rate the pass time was only 1.8 seconds.

Stream	T1	T2	T3	T4	T5	T6	P	Average
Number of Tests	6	7	8	7	7	9	11	
Standard Deviation %	0.09%	0.05%	0.06%	0.07%	0.09%	0.08%	0.09%	0.08

This is equivalent to a 95% confidence limit on a single pass of approximately ±0.16% . This is equivalent to a 95% confidence limit on the average of 10 passes of ±0.05% (0.16 / $\sqrt{10}$). This is acceptable repeatability performance and is marginally better than that inferred from the earlier trials performed by Micro Motion. The averages of two groups of 10 passes should then agree within a 95% confidence limit of ±0.07% (0.05 * $\sqrt{2}$). During the tests such grouped averages were compared and their differences were broadly in line with this.

The above has lead to a modification of the traditional standard turbine meter proof repeatability criteria to one that is more suitable to Coriolis meters in conjunction with compact provers. A prove will be made up of two proof runs each of 10 passes which should give a 95% confidence on the over all mean of the 20 passes of ±0.036%. Proof acceptability for repeatability is that the two runs (each of 10 passes) should not differ from their mean by more than ±0.035%. This limit will have to be reassessed during continuous operation to match the performance as found then with crude oil.

Qualitative observations during testing confirmed the known effect of pressure on the D600 accuracy of about -0.07% per bar. This was allowed for in the test results.

4. OFFSHORE PRACTICAL EXPERIENCE

First production started in May 1996. The production and tanker export meters have been successfully proved and used since then. This paper covers experience up to 5 August 1996. Data are being gathered as a matter of routine and analysis of them is ongoing. The written conclusions must then be seen as first thoughts and potentially subject to change and substantiation. The intention is to provide any up to date, as appropriate, during the presentation at the Workshop in October 96.

4.1 Meter and Proving Performance to Date

The all important performance of the meters and prover together in the field are simply seen by time plots of all the prove K-factors in Figures 5 to 8. For the production meter, proves prior to number 21 had to be discounted because of data entry errors in the flow computers.

There is a clear message that the proves are within a ±0.2% band of the averages for each meter. This is confirmed with the calculated 95% confidence limits shown in Table 3. The conclusion is that the residual scatter, regardless of its source, is small. So in operational terms, proving need not be performed as frequently as was done during this commissioning phase. For the time being proving is being continued once per tanker loading and weekly for the production meters. It can be seen that there is every hope that, given continued similar performance, proving frequencies can be further reduced.

The residual scatter is of limited interest to routine operations but it is of technical interest. There is some evidence of a drift with time (Figure 7 for meter T5 is the most pronounced). The flow curves Figures 9 and 10, show that it is impossible to distinguish between any true flow linearity effect or a time trend. The other meters showed less of any effect.

Temperature has always been above 25°C, so viscosity in excess of 100 cP has not yet been experienced. Operating temperature is in the range 30°C to 50°C. A correction for the effect of pressure on the Coriolis meter tube is continuously applied (0.072%/bar). Export meter pressures are in the range 16 to 25 barg, while production meter pressures are approximately 6 barg.

4.2 Repeatability of Compact Prover Runs

The acceptance criterion for a "good" prove is that the averages of two sets of 10 passes do not differ from their mean by more than 0.07%. This is a relaxation of the figure derived in the factory acceptance tests. Table 4 shows that the average repeatability for each meter was below this tolerance and that four of the seven meters never exceeded the limit. There is evidence that this tolerance could be reduced, particularly because conditions are likely to be more stable after commissioning. This is being reviewed as more data are gathered.

4.3 Absolute Comparisons Against Factory Tests on Water

From a commercial perspective, it is the meter performance as proved against the compact prover offshore on oil with the swept volume from the offshore water draw that is relevant. It is technically interesting to compare the offshore proved K-factors on oil with those from the skid factory acceptance trials and the original Rosemount Micro Motion factory calibration at Veenendaal (calibration K-factor = 36716 pulses/tonne). This is shown in the table below and graphically in Figure 11 (negative % means factory calibration K-factor higher).

Difference From Factory Calibration on Water							
Meter	T1	T2	T3	T4	T5	T6	P
FAT - Water	-0.04%	-0.07%	-0.05%	-0.04%	0.06%	0.06%	-0.16%
Field - Oil	-0.33%	-0.41%	-0.43%	-0.41%	-0.26%	-0.33%	-0.85%

These data are all corrected back to a common pressure of 0 barg using the Micro Motion supplied factor of 0.072%/bar (the K-factors quoted in Table 3 are referenced back to 29.6 barg and 6.5 barg for the tanker and production meters respectively). At 29.6 barg the K-factors are 2% lower without this correction. A 17% increase in this correction factor would be sufficient to reduce the average difference for the field results to zero. The uncertainty in this coefficient is unlikely to be much better than this. The larger difference for the production meter could be due to trace gas break-out immediately after separation, though this is far from proven. However there was also a larger deviation for this meter at the factory acceptance trials, so some installation effect is another possibility.

The important conclusion is that, for the more important export meters, the size of the difference from original factory calibration is only 0.4%. This gives substantiation to the use of Coriolis meters with factory calibration on water only and no offshore calibration on oil, provided an uncertainty of say 0.5% is acceptable. To substantiate a lower uncertainty, a satisfactory explanation for the residual difference is required. Possible effects to be considered are:

- Error in density measurement (calibration and temperature) - some effect here likely.
- Residual pressure or temperature effects on the Coriolis meter.
- Installation effects offshore (pipe stresses etc.).
- Effect of viscous oil rather than water on Coriolis meters.
- Effect of viscous oil rather than water on compact prover.
- Difference from reverse direction water draw with "downstream" prover.
- Error in water draw of compact prover (unlikely - factory/offshore agreement).

The relative merits of these possibilities, and indeed other suggestions should provoke much discussion.

5. CONCLUSIONS

It is too early to finalise conclusions on the all important offshore experience. To date this has shown successful performance of the Coriolis meter and compact prover combination in an offshore custody transfer environment. Stability of meter proving over the first three months of operations has shown all meter proving to be within a band of ±0.2%, which bodes well for the anticipated reduction in frequency of proving. The intention is to increase proving intervals progressively up to once every six months as operating experience justifies this.

Comparisons between offshore proving on oil and factory calibration on water are within 0.4%, which gives support for the use of Coriolis meters without offshore proving.

In project terms, the adoption of Coriolis technology combined with working very closely with the skid supplier JKMS, the flow computer supplier SpectraTek and Fisher Rosemount has resulted in a significant reduction in capital costs. The expectation remains that significant savings are to be realised on Harding during operations, compared with the once per tanker loading proving and maintenance overheads associated with more conventional high accuracy metering methods.

Acknowledgements

The authors wish to thank the Harding team, in conjunction with SGS Redwood, for providing the experience and data upon which this paper was based.

MAIN SOURCES OF UNCERTAINTY		MEASUREMENT UNCERTAINTY	
		MASS %	VOLUME %
Swept Volume		0.05	0.05
Prover Density	0.5 kg/m^3	0.06	0.06
Liquid Temperature/Pressure Corrections			
Prover Densitometer	0.5 deg C	0.05	0.05
Prover		0.05	0.05
Meter			
Repeatability of prove with meter		0.04	0.04
Calculations		0.00	0.00
TOTAL K-Factor		**0.11**	**0.11**

Table 1 - Uncertainties - Proved K-Factor

MAIN SOURCES OF UNCERTAINTY		MEASUREMENT UNCERTAINTY	
		MASS %	VOLUME %
Prove (from above)		0.11	0.11
Allowable deviation between proves		0.20	0.20
Meter Densitometer - Header (Schlumberger)			
Including drift between cal.	0.5 kg/m^3		0.06
Liquid Temperature/Pressure Corrections			
Meter Densitometer	0.5 deg C		0.05
Meter (for standard volume)	0.5 deg C		0.05
Coriolis Meter Pressure Corr.	10% of corr.	0.04	0.04
Calculations		0.00	0.00
TOTAL		**0.23**	**0.25**

Table 2 - Uncertainties - Metering

K-Factor Stability over Time				
Meter	Average all proves p/t	Difference from Average all tanker %	Standard Deviation all proves %	95% Confidence Limit %
T1	35827	0.03%	0.09%	0.19%
T2	35796	-0.05%	0.07%	0.14%
T3	35792	-0.06%	0.08%	0.16%
T4	35798	-0.05%	0.07%	0.15%
T5	35850	0.10%	0.10%	0.21%
T6	35827	0.03%	0.09%	0.18%
P	36234	1.17%	0.06%	0.12%
Average	35815	< All Tanker		

Table 3 - Prove K-Factors to 5 August 96

Proof Repeatability - Two Sets of Ten Passes					
Meter	Maximum Difference from Mean (+/-)				
	Average	Max	Total Count	Number Greater Than:	
				0.070%	0.035%
T1	0.03%	0.10%	31	3	9
T2	0.02%	0.07%	26		5
T3	0.06%	0.40%	25	6	10
T4	0.03%	0.14%	26	3	9
T5	0.02%	0.05%	25		3
T6	0.02%	0.06%	26		4
P	0.02%	0.05%	66		6

Table 4 - Repeatability of Proves to 5 August 96

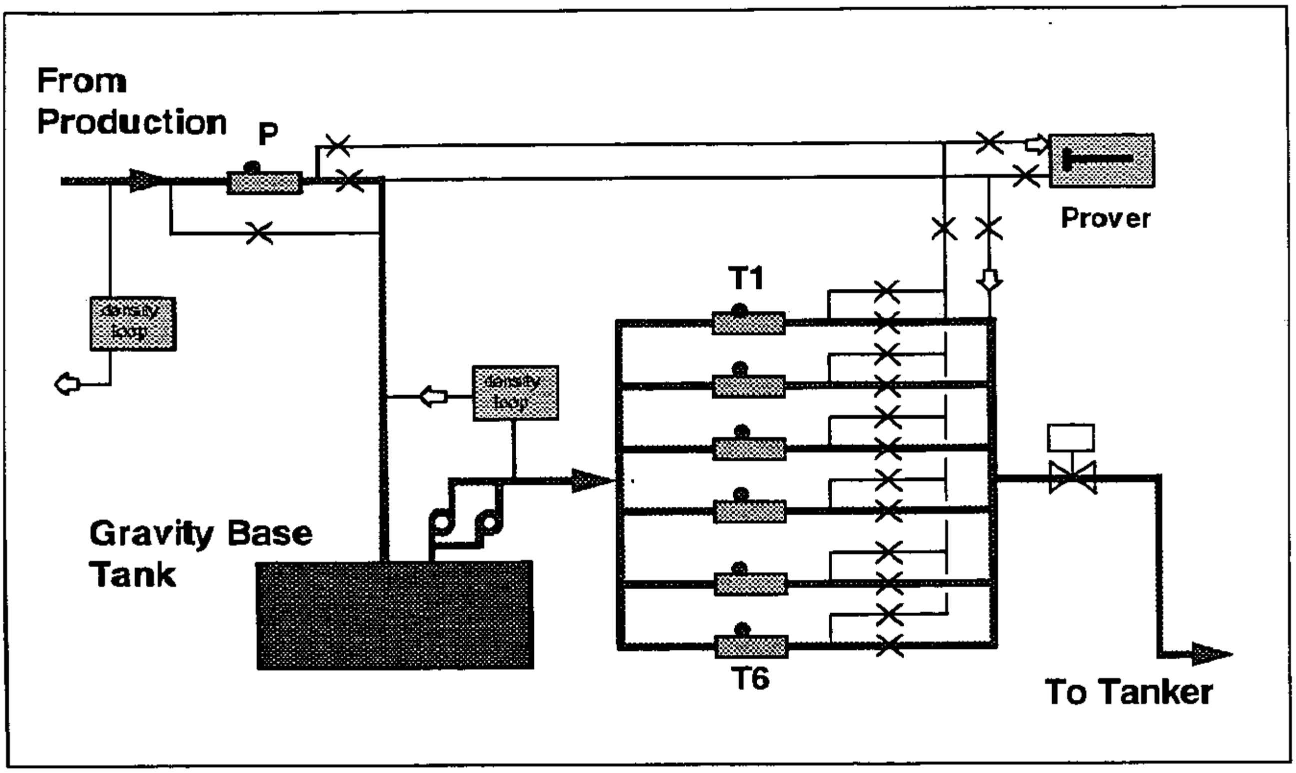


Figure 1 - Configuration of Meters and Prover

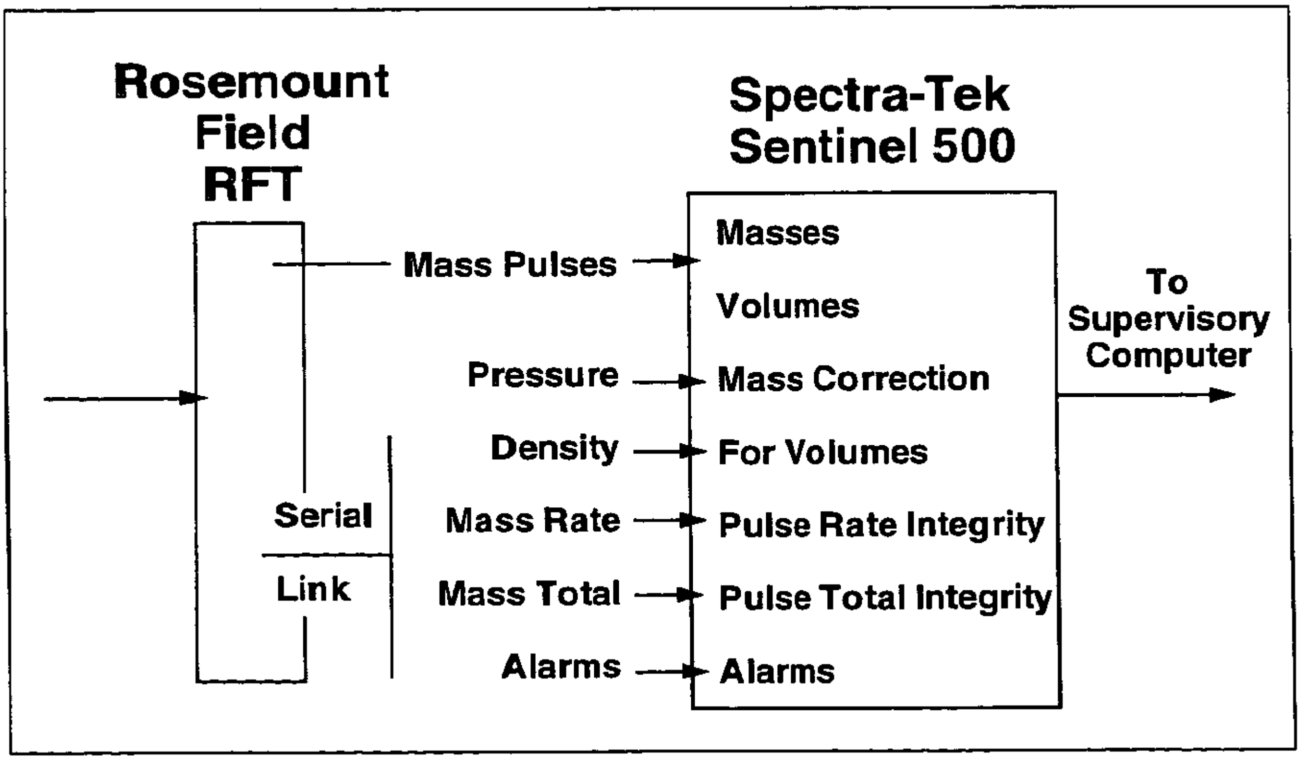


Figure 2 - Flow Computers and Data Flow

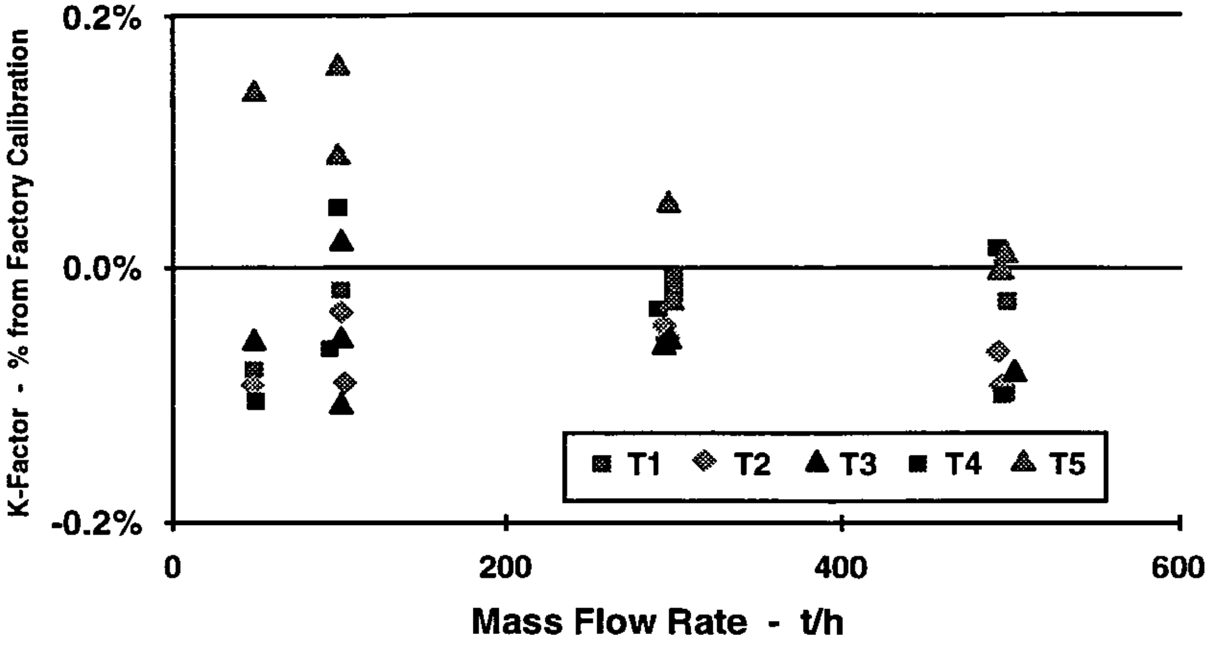


Figure 3 - Acceptance Tests on Water - Meters T1 to T5

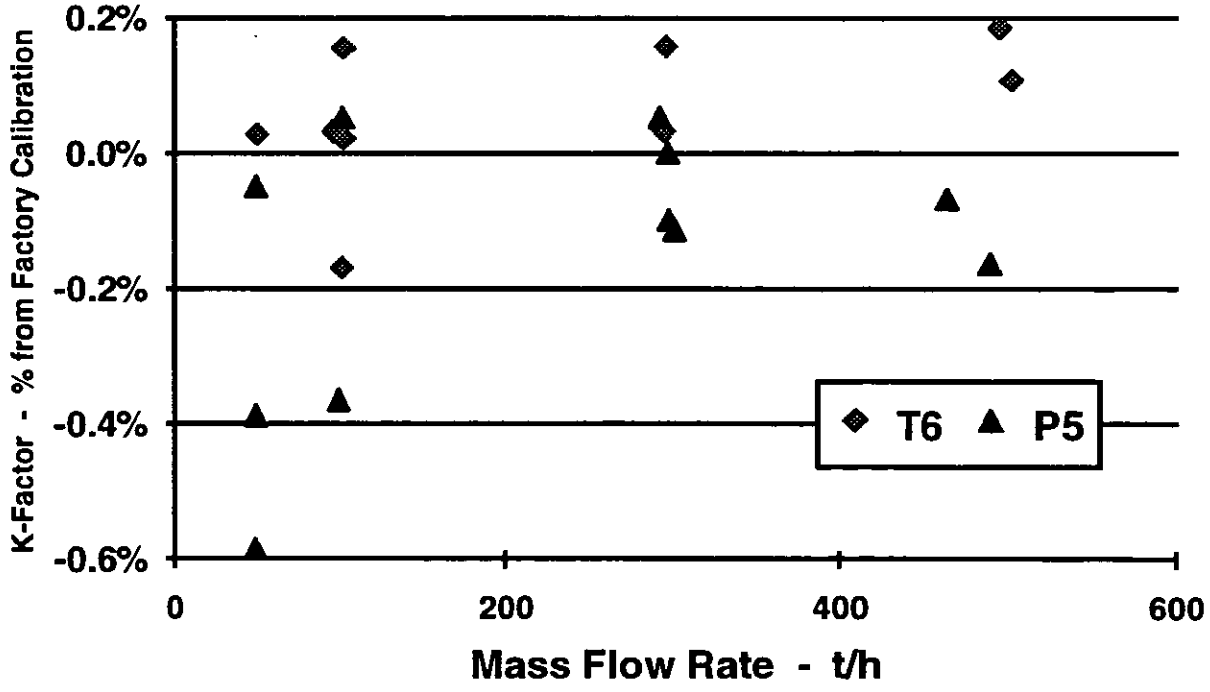


Figure 4 - Acceptance Tests on Water - Meters T6 and P

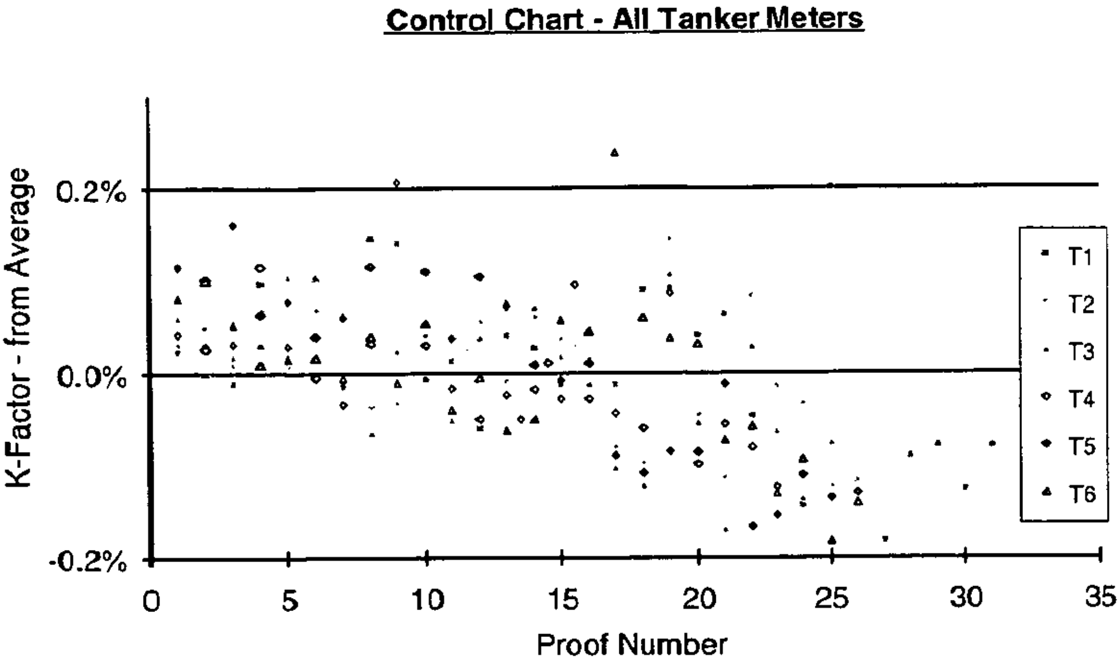


Figure 5 - Proves for All Tanker Meters (to 5 August 96)

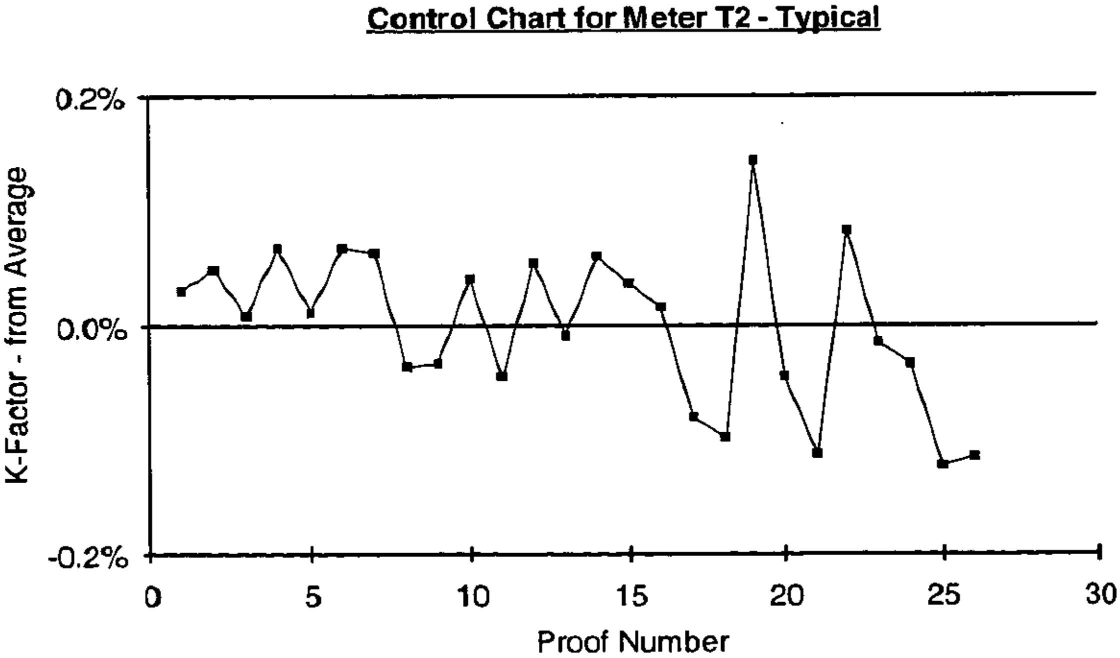


Figure 6 - Proves for Tanker Meter 2 (to 5 August 96)

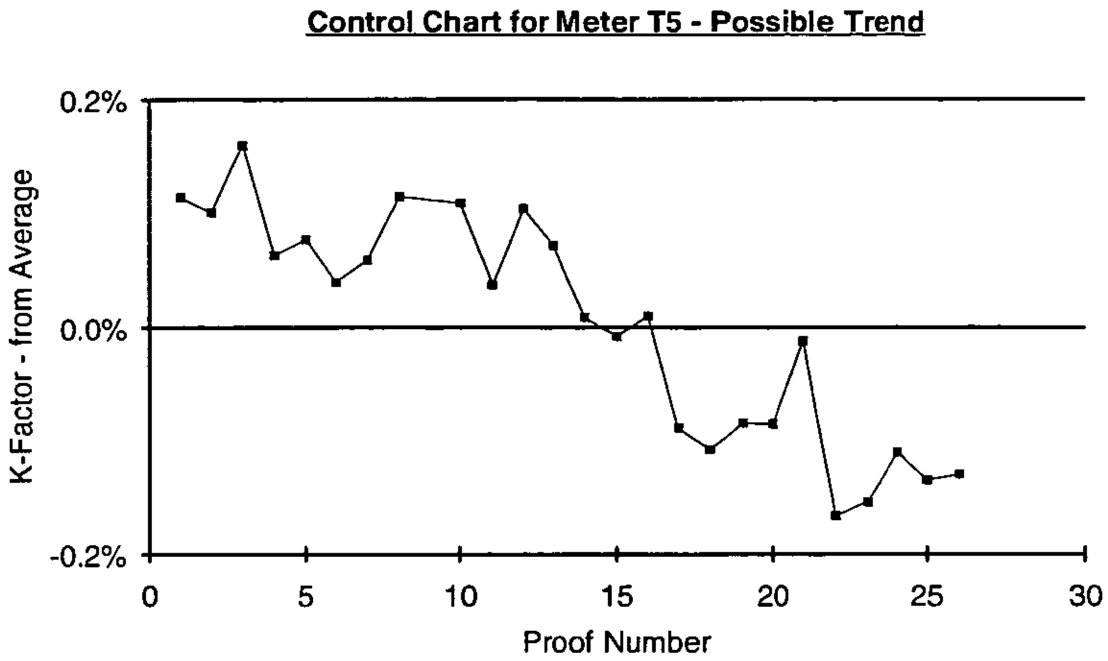
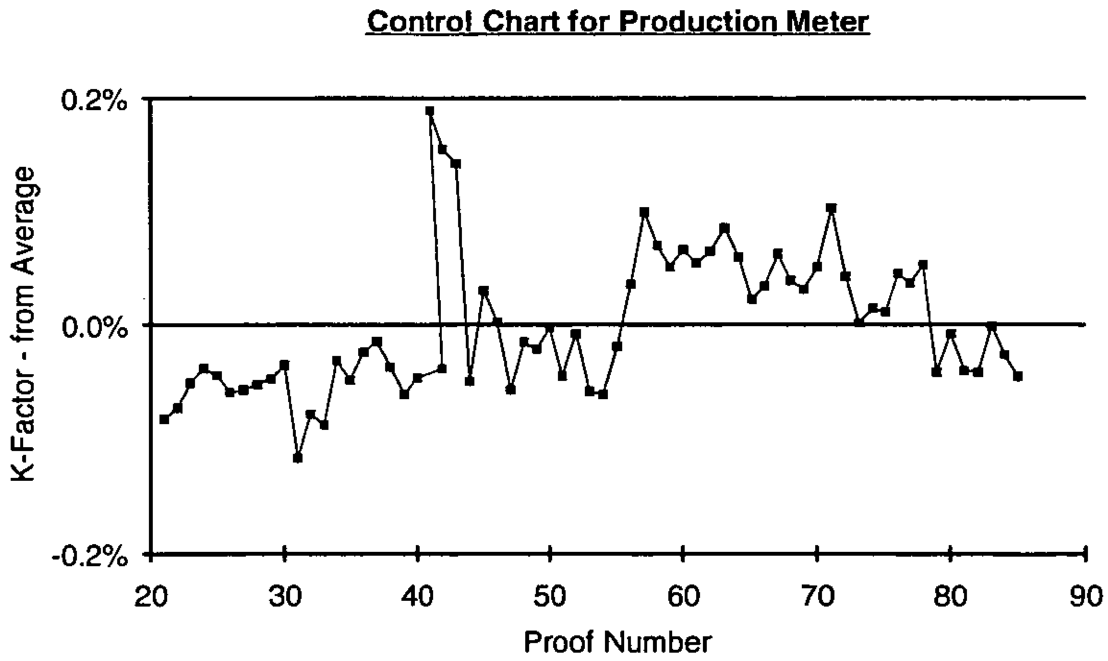


Figure 7 - Proves for Tanker Meter 5 (to 5 August 96)



Proves prior to number 21 had to be discounted because of data entry errors in the flow computers.

Figure 8 - Proves for Production Meter (to 5 August 96)

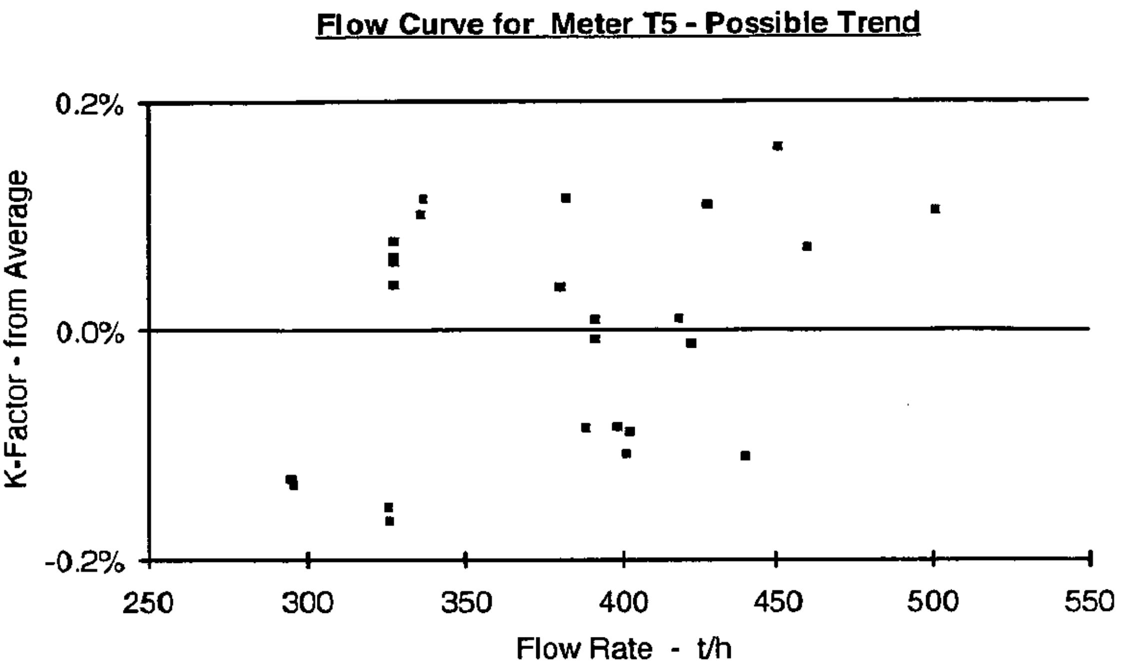


Figure 9 - Flow Curve for Tanker Meter 5

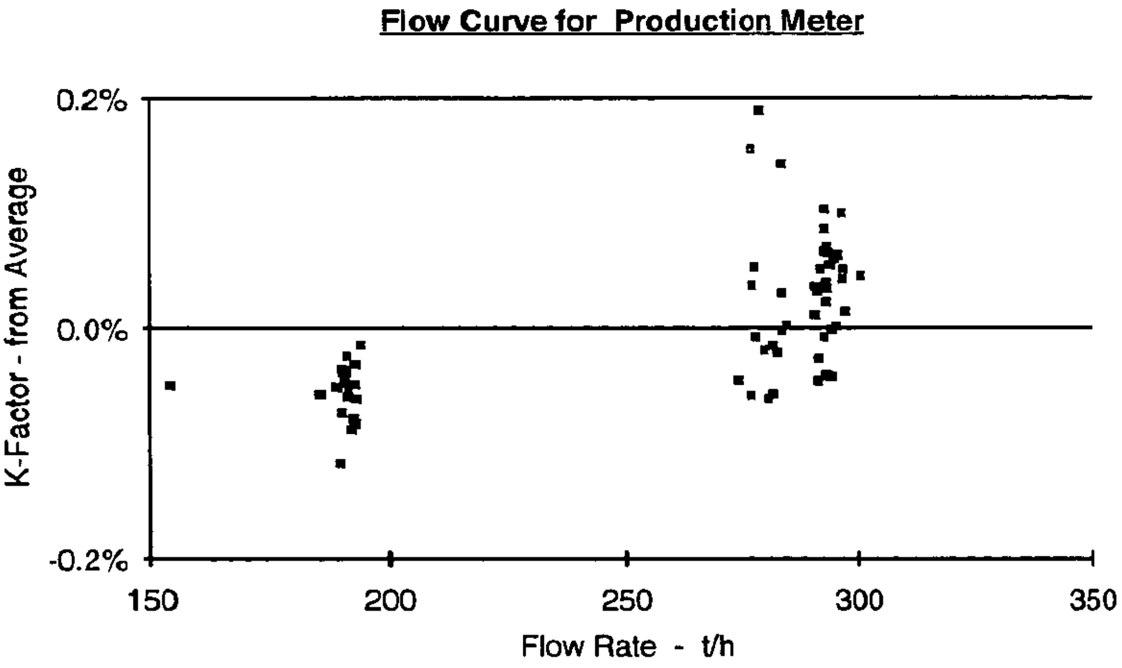


Figure 10 - Flow Curve for Production Meter

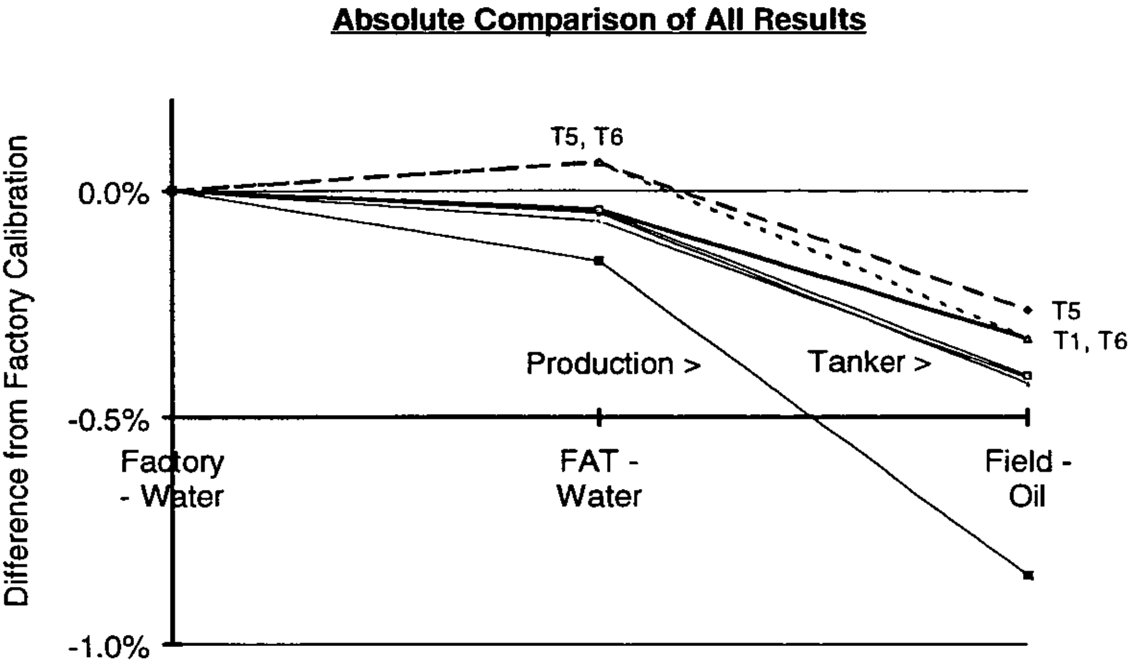


Figure 11 - Comparisons Back to Factory Calibration

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.