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Testing water-in-oil monitors at the Mongstad terminal

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1. Summary

This paper presents an installation developed by Statoil to test and qualify water-in-oil monitors at its Mongstad oil terminal near Bergen.

Results from extensive testing of three different water-in-oil monitors are described. These meters were tested with three different types of crude, which had a water content varying from 0.1 to 10 per cent. Extremely good results were achieved with two of the meters, supplied by Fluenta and Multi-Fluid International (MFI) respectively. These meters are now regarded as qualified for use as devices that give a higher level of accuracy and repeatability than the present method based on laboratory analysis of oil samples.

2. Introduction

Considerable efforts have been devoted by various research institutes and oil companies over the past 10 years to developing better equipment for volume metering of hydrocarbons before and after separation. "Better" in this context means greater accuracy, improved repeatability and a more robust construction. Other important factors when considering an installation include less time-consuming operation, continuous provision of data and a space-saving design.

A multiphase meter, which gives the user continuous flow information on a blend of oil, water and gas, is a good example of such new instruments. Similarly, water-in-oil monitors are devices which could advantageously replace time-consuming off-line analysis equipment such as the Karl Fisher method, and which also provide continuous information about the amount of water in oil at any time. A space-saving configuration would also be beneficial by replacing large and heavy process equipment/metering systems with smaller and more compact units. Examples of this could be the replacement of test separators with multiphase meters. In the longer term, it could also be appropriate to replace large prover stations for calibrating oil metering stations with smaller systems based on mass meters with enhanced long-term stability.

All new equipment entering the market must undergo an extensive qualification process to satisfy users about the functionality of the device and to permit optimisation/improvement by the supplier.

Constructive cooperation between user and supplier is important in this phase, which embraces intensive laboratory and field tests and which often takes longer than desirable. Such collaboration makes it possible to identify teething problems and gives the end-user confidence in the product.

To perform such qualification tests as effectively as possible, Statoil has developed facilities which permit field testing of working products. A flow loop has been constructed at the Mongstad terminal in order to test water-in-oil monitors. Similarly, a flow loop installed upstream of the test separator on Gullfaks B permits multiphase meters to be tested on the different wells. Work is also under way on facilities for testing level meters and for qualifying single-phase mass meters for both gas and oil.

It is gratifying to observe that Norway possesses several highly-qualified companies that have developed advanced metering instruments which hold a market lead in development terms. Over the past year, Statoil has enjoyed constructive cooperation with Fluenta of Bergen and Multi-Fluid International (MFI) in Stavanger. Water-in-oil and multiphase meters developed by both these companies have been thoroughly tested at Mongstad and on Gullfaks B respectively.

3. Test facilities

One question that always arises when assessing test results from new meters is whether process conditions during the tests are representative for later installations. To minimise this uncertainty, it is important to perform the testing under conditions which come as close as possible to those that will prevail in field applications of the equipment.

Examples of test facilities developed in recent years include:

* The K-Lab at Kårstø north of Stavanger: calibration/certification of fiscal gas flow meters

* Con-tech in Stavanger: flow loop for calibrating fiscal flow meters for different types of oil under high pressures and temperatures.

* Gullfaks B: Test facility for multiphase meters.

The test setup at Statoil Mongstad is presented below.

4. Water-in-oil monitors

When metering crude oil, water content is the most difficult parameter to measure with certainty. The actual sampling device is often faulty, and results from the analyses of water content on the ship and by the recipient generally differ fairly widely. This is particularly the case when a large volume of water (from one per cent and up) is accidentally introduced to the oil. A water content this high in oil can result in legal disputes between shipper and recipient that involve very large sums of money on occasion. More accurate and uniform measurement of water in oil could therefore eliminate a major source of uncertainty.

The oil outlet from the separator is another location where Statoil considers it appropriate to install water-in-oil monitors, permitting continuous monitoring of the separation process. This applies particularly to test separators during well testing, where corrections for the water content in the oil are important if the correct protection rate is to be recorded.

4.1 History

Several companies, including Fluenta and MFI in Norway, began to develop oil-in-water meters in the mid-1980s. Statoil has supported Fluenta during the initial development phases and MFI throughout the development of its device. The aim of this commitment has been to develop in-line instruments for fiscal metering of water in oil.

Until now, water content has been measured using the flow proportional sampler and Karl Fisher titration. The accuracy of this method depends largely on the operator. Whether the water content in a 10-litre oil sample corresponds to the actual water content in the crude passing through the pipeline is also highly uncertain.

4.2 Test objectives

The objective of the test programme was to establish whether any of the three selected meters could qualify to replace the conventional sampler for purchase/sale purposes. The Fluenta and MFI devices were supplemented by a third meter during the initial test phase, but the latter was removed from the programme after yielding unsatisfactory results.

Since all three meters could basically be described as prototypes, it was important to test the following parameters:

- accuracy with different water cuts and types of crude oil
- repeatability with the same water cut
- stability of the instruments in the long and short terms
- sensitivity to variables such as water conductivity, oil density and dielectric constant
- genuine variations in these parameters
- effect of varying air temperatures
- influence of varying temperature, pressure and flow speed
- weaknesses in the instrument, its electronics and its man-machine communication
- possible constraints on the instruments.

4.3 Choice of test facility

Mongstad is the site of a large terminal which takes delivery of crude oil loaded into shuttle tankers on several North Sea fields. Part of this crude is stored in large rock caverns for later export by tanker. Several considerations prompted the choice of this facility as the test site for the water-in-oil monitor:

- It allowed the water-in-oil monitor to be tested with all types of crude handled by Statoil. These oils vary in dielectric constant, density and water conductivity.

- Because the terminal is on land, costs are significantly lower when compared with an offshore test.

- Mongstad is interested in qualifying a water-in-oil monitor for its own use to achieve greater control of such measurements in connection with purchase/sale.

Figure 1 shows a diagram of the actual test rig with the three meters installed.

4.4 The Mongstad test facility for water-in-oil monitors

Crude oil metering station A at Mongstad

The test rig for water-in-oil monitors is linked to crude metering station A at the Mongstad terminal. This is one of two identical units - the other being station B - used when loading and discharging crude oil. During these operations, the crude is transferred between tankers and the terminal's storage facilities.

Both metering stations are equipped with eleven 12-inch lines, giving a theoretical metering capacity of 20 000 cubic metres per hour. In practice, the loading/discharging rate through each station is about 10 000 cubic metres per hour.

Oil from the Gullfaks A/B, Gullfaks C and Statfjord platforms in the Norwegian North Sea can also be circulated from the rock cavern stores, through the metering station and back into storage.

The test rig

The test rig for water-in-oil monitors is a two-inch bypass loop with its inlet and outlet located after the mixer and before the automatic flow sampler at metering station A. The mixer is a motor-driven propeller type installed in a 48-inch pipe after the metering station.

Constructed by Norwegian company Framo Engineering, the test rig is equipped with a frequency-controlled screw pump. A 3/4-inch fresh-water intake, with valve and back pressure valve, has been installed immediately behind the inlet to the test rig. Fresh water from the firewater system is used for injection. The frequency-controlled in-line screw pump is operated by a 4-20 mA signal proportional to the flow rate through metering station A, which means that oil flows through the test rig at the same speed as through the 48-inch line. This isokinetic measurement ensures that results obtained from the water-in-oil monitors during loading/discharging are comparable with those from the automatic sampler.

Static two-element mixers are installed upstream each meter and the sampler probe to ensure that the metered volumes are adequately homogenised.

Fresh-water injection

Initial measurements showed that oil from the Mongstad storage caverns normally contains very little water, about 0.1-0.2 per cent on loading into the tankers. During discharging, water separated out at the bottom of the cargo tanks emerges immediately after the pumps start and can exceed 10 per cent of the flow for a few minutes.

The dielectric constant varied considerably between the three crudes tested. As a result, the MFI and Fluenta meters had to be recalibrated for each type of oil. This calibration must be performed when the water content is stable and below one per cent.

During discharging, the water content of the oil changes so quickly that it proved impossible to take a representative sample at the same time as the instruments were read. After an hour, the water content in the oil was constant and less than one per cent. This meant that the instruments could only be tested during discharging over the lower range - 0.1-0.5 per cent.

In order to test the meters with varying and high water contents, a connection to the firewater system was installed in the two-inch line ahead of the pump. This arrangement permitted the water content to be varied from 0-12 per cent by injection during loading, discharging and recirculation.

Data collection, trend monitoring

The water cuts reported by the three metering devices were logged once a minute by a Bailey process control system installed in the central control room. The values logged over the previous seven days can be presented as freely-scalable time curves in a freely-selected time window on the screen. The screen picture can be captured to a printer at any time.

In addition to a common time curve, separate time curves can be generated for each of the three meters. It is also possible to obtain the average water cut from the moment when loading commenced, in order to compare this with the result from the sampler. In addition, the total flow rate through the metering station can be presented as time curves on the screen.

Collection of spot samples

Oil samples of 0.9 litres at a time were taken from the two-inch line downstream of a dedicated mixer. The flask was then corked and labelled with the time, the sample number and the values read from the MFI meter while the sample was being taken. Local reading at the actual device was only possible with the MFI meter. Metered values for the other instruments were checked over a radio link with the control room, and recorded in order to be sure that all the meters were stable.

Procedure for Karl Fisher titration

After the oil had been mixed for at least 15 seconds in a dedicated mixer at 20 000 rpm, a sample was drawn into a syringe of a size determined by the water content.

To ensure that the operator was injecting the correct volume, the syringe was weighed before and after injection. Uncertainty in the injected volume was about ± 1.5 per cent. The contents of the syringe were then injected in the titrator. At least two samples were taken from each flask to check repeatability. In the event of poor repeatability, or when titration took a long time, the titration fluid was replaced.

4.5 Requirements for water-in-oil monitors

The MFI water-in-oil monitor was developed by that company in cooperation with oil companies Phillips, BP and Statoil, with Hitec of Stavanger as project manager. During the development, the following standards were established for accuracy:

- ± 0.5 per cent absolute accuracy from zero-one per cent water in oil

- ± five per cent of measured values from 1-12 per cent water in oil.

This requirement was proposed by BP in the UK, which had the greatest experience from research projects relating to water-in-oil sampling and analysis. It has since been applied as a standard in efforts to qualify other water-in-oil monitors for fiscal metering. Reference will be made to this standard later in the paper.

4.6 Reference

The Karl Fisher method is the most widely-accepted current method for determining the water content of oil, and has been used as the reference method in all testing of the various water-in-oil monitors.

A test performed in 1991, in which known amounts of water were injected into a closed loop with a known volume, compared one of the water-in-oil monitors with the Karl Fisher instrument. This experiment showed that the meter gave more accurate results and better repeatability than the analysis-based method.

It is unrealistic to expect the accuracy of an instrument to be better than the reference used as a basis for comparison. The estimated accuracy of the Karl Fisher technique bears a non-linear relationship to changes in the water content of the oil. Setting the accuracy of the Karl Fisher method to equal the requirement for the water-in-oil monitor yields approximately the right result in the zero-five per cent range for water in oil.

The acceptable tolerance for the water-in-oil monitor using Karl Fisher as the reference can then be extended to $\underline{\sqrt{0.05^2+0.05^2} = 0.07\%}$ absolute deviation for zero-one per cent water in oil, and $\underline{\sqrt{5^2+5^2} = 7\%}$ of the measured values over one-five per cent water in oil.

4.5 Test procedure

The main test comprised three rounds of testing with crude from Gullfaks A/B, Gullfaks C and Statfjord respectively. After a few hours of loading/discharging or recirculating, the water content was down to about 0.1 per cent and completely stable. Only minimal changes (± 0.02 per cent) were registered from time to time. The pressure and temperature of the oil was also quite stable.

Once these conditions were established, the meters were calibrated and the tests performed by injecting the desired amount of water into the oil flowing through the test rig. In order to spread different tests with the same water cut over time, the quantity of injected water was constantly varied.

Three samples were taken for each of the three oil types at the following water cuts: 0.1, 0.2, 0.4, 0.6, 0.8, 1.0, 1.5, 2.0, 3.0, 4.0, 5.0, 7.0 and 10 per cent.

During these main tests, all parameters other than water content were kept as constant as possible. In addition to the main test, seven other tests were performed to investigate the stability of the individual meters under different operating conditions. These tests were carried out with stable amounts of oil in the water.

4.8 Test results, Fluenta WIOM 300

Specification

Fluenta's water-in-oil monitor has the following features: a non-intrusive design, full-profile metering and no need for a mixer in normal use. It measures the range from zero to 40/80 per cent water (equalling the transition point for the oil) and comes in diameters from one to 12 inches.

Mongstad test

Before a test round started, the meter was calibrated for the correct type of crude by entering its dielectric constant. This can be done automatically by putting in the meter in a calibration mode and entering the exact volume of water, or manually be entering the constant.

A total of 98 tests were performed during the three rounds. The results from four of these were outside the adjusted requirement (0.07 per cent absolute accuracy for zero-one per cent water and seven per cent of the measured value for one-five per cent water), while results from 21 tests were outside the original standard of 0.05-5 per cent.

Figure 2 gives an example of a test round, where the measurements are shown in a deviation diagram. Table 1 presents the results of the test round with Gullfaks C crude. The upper part of the table shows the absolute deviation between meter and laboratory analysis for zero-one per cent water in oil, while the lower section presents deviation from the measured value when the water content exceeds one per cent. The lowest values are not official test results since the uncertainty associated with the Karl Fisher method becomes high for a water content exceeding five per cent. Each test is numbered in the order it was performed.

The Fluenta meter drifted a little between one oil cargo and another from the same field, and therefore had to be recalibrated for each cargo. Whether this drift was due to variations in ambient temperature or the sensor/electronics is not known.

Fluenta has developed a water-in-oil monitor which gave very good results in an extensive test. Replacing traditional BS&W metering methods with this device would be advantageous in environments with a reasonably stable ambient temperature.

Statoil has installed a Fluenta WIOM 300 on its Gullfaks A platform. Placed in a bypass line ahead of the oil metering station, this meter has performed very satisfactorily since it came on line in August 1992. The meter is compared at regular intervals with samples, and a good match has been found. But the tests performed so far with the meter have not been sufficiently detailed to permit any conclusions about its accuracy and long-term stability.

4.8 Test results with the MFI Watercut Monitor

Specification

The MFI device comes in two versions - one measuring water content from 0-12 per cent and the other covering the range from 0-40/70 per cent water, depending on the type of oil involved. The meter can be delivered in all diameters from two inches and up, and will provide full-profile measurement.

Testing

Before starting a test round, the meter was calibrated for the right type of oil by entering its dielectric constant. This can be done automatically by putting the meter in a calibration mode and entering the exact amount of water, or manually by entering the constant. In addition, water conductivity must be entered with an accuracy of ± 50 per cent.

A total of 98 tests were performed in the three rounds. All results from these tests are within the modified requirement (0.07 per cent absolute accuracy for zero-one per cent water and seven per cent of the measured values for one-five per cent water). Four of the tests yielded a result outside the strictest standard of 0.05 per cent-five per cent.

Figure 3 gives an example of a test round, where the measurements are shown as a deviation diagram. Table 2 presents results for the test round with Statfjord crude. The upper part of the table shows the absolute deviation between meter and laboratory analysis for zero-one per cent water in oil, while the middle section presents deviation from the measured value when the water content exceeds one per cent. The lowest values are not official test results since the uncertainty associated with the Karl Fisher method becomes high for a water content exceeding five per cent. Each test is numbered in the order it was performed.

The MFI meter is stable from cargo to cargo, and remains apparently unaffected by variations in its surroundings.

MFI has developed a water-in-oil monitor which gave extremely good results in an extensive test. Since these tests, MFI has improved the operator communication - the only weakness of the device exposed during testing. Replacing traditional BS&W metering methods with this meter would be advantageous.

Statoil intends to install an MFI meter on the Gullfaks B test separator. This device will be used to measure the exact water content in the crude after separation, and help to improve the accuracy of reference measurements on the test separator. This meter will then be tested for long-term stability. Statoil is also planning to install meters for the export metering stations on both Statfjord A and the Veslefrikk field in the Norwegian North Sea.

4.9 Conclusion, water-in-oil monitors

The Mongstad test has demonstrated that both Fluenta and MFI have developed water-in-oil monitors which could advantageously replace existing methods based on sampling and subsequent laboratory analysis for purchase/sale metering. Both meters are accurate and are easy to operate. Reservations focus not so much on the meters as on the electrical characteristics of the medium in which they are to measure.

The dielectric constant varies from one type of crude to another. Measurements from Mongstad have also revealed that this constant can vary from one cargo to another supplied by the same field by a factor corresponding to as much as ± 0.05 per cent water in oil.

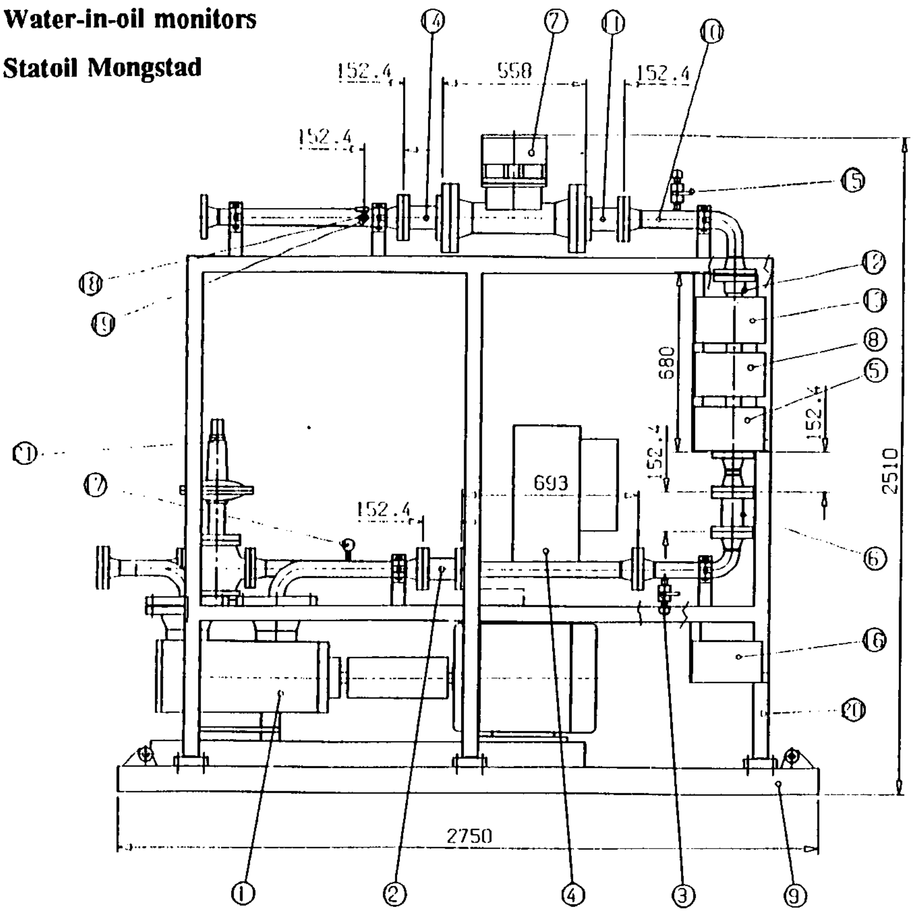
These water-in-oil monitors must be approved by the Norwegian Petroleum Directorate if they are to replace today's samplers for purchase/sale of oil. This approval can only be achieved by documenting good long-term stability and little day-to-day variation in the dielectric constant. Statoil is planning to install the MFI water-in-oil monitor at several of its installations.

The long-term stability of the meters has not been adequately tested or documented by the Mongstad tests.

Test Facility for

Water-in-oil monitors

Statoil Mongstad



1 - Pump	
2 - Static mixer	
3 - Ball valve	
4 - MFI water-in-oil monitor	
5 - Junction box	
6 - Static mixer	
7 - Fluenta water-in-oil monitor	
8 - Junction box	
9 - Frame	
10 - Piping	
11 - Static mixer	
12 - Water-in-oil monitor	
13 - Junction box	
14 - Static mixer	
15 - Ball valve	
16 - Junction box	
17 - Pressure gauge	
18 - Sampler probe	
19 - Ball valve	
20 - Frame	
21 - Safety valve	

Fig. 1

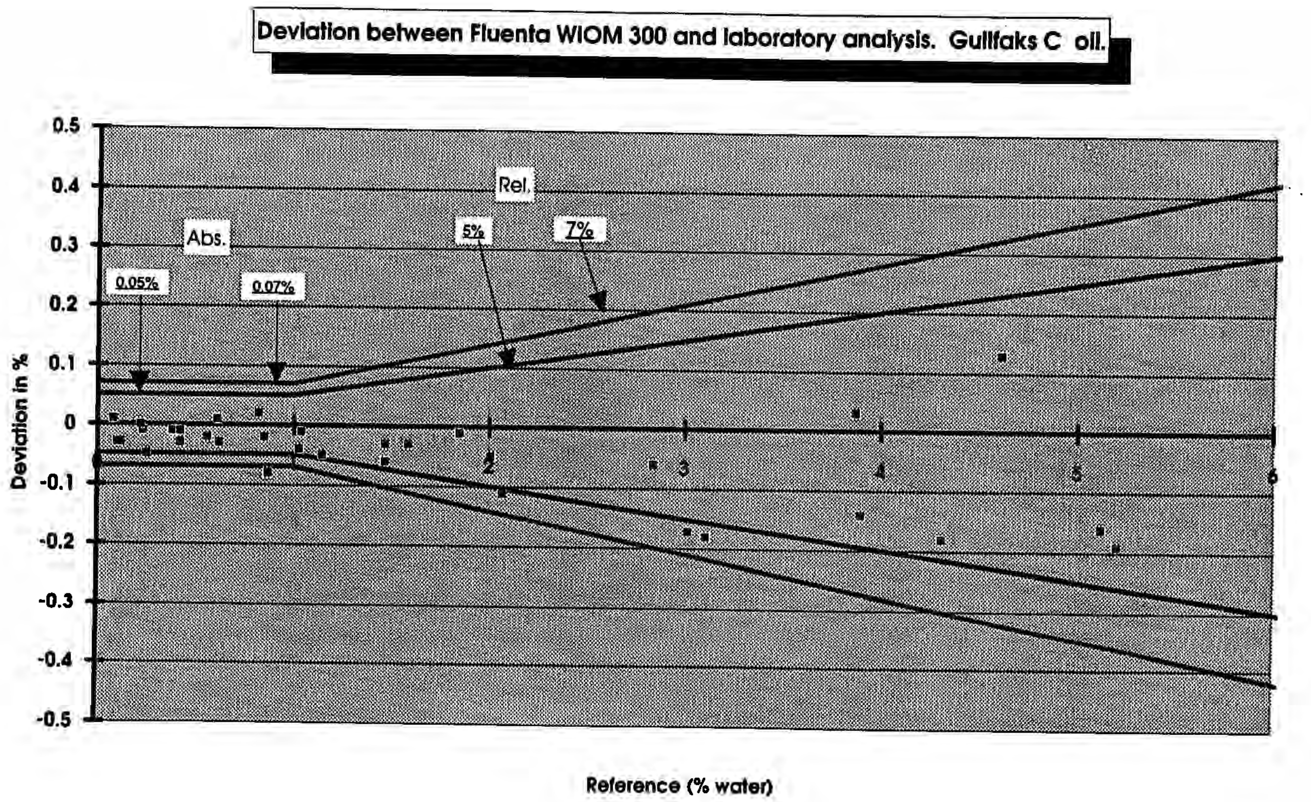

Deviation between Fluenta WIOM 300 and laboratory analysis. Gullfaks C oil.
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
Deviation in %
Rel.
Abs.
5%
7%
0.05%
0.07%
2
3
4
5
6
Reference (% water)

Fig 2

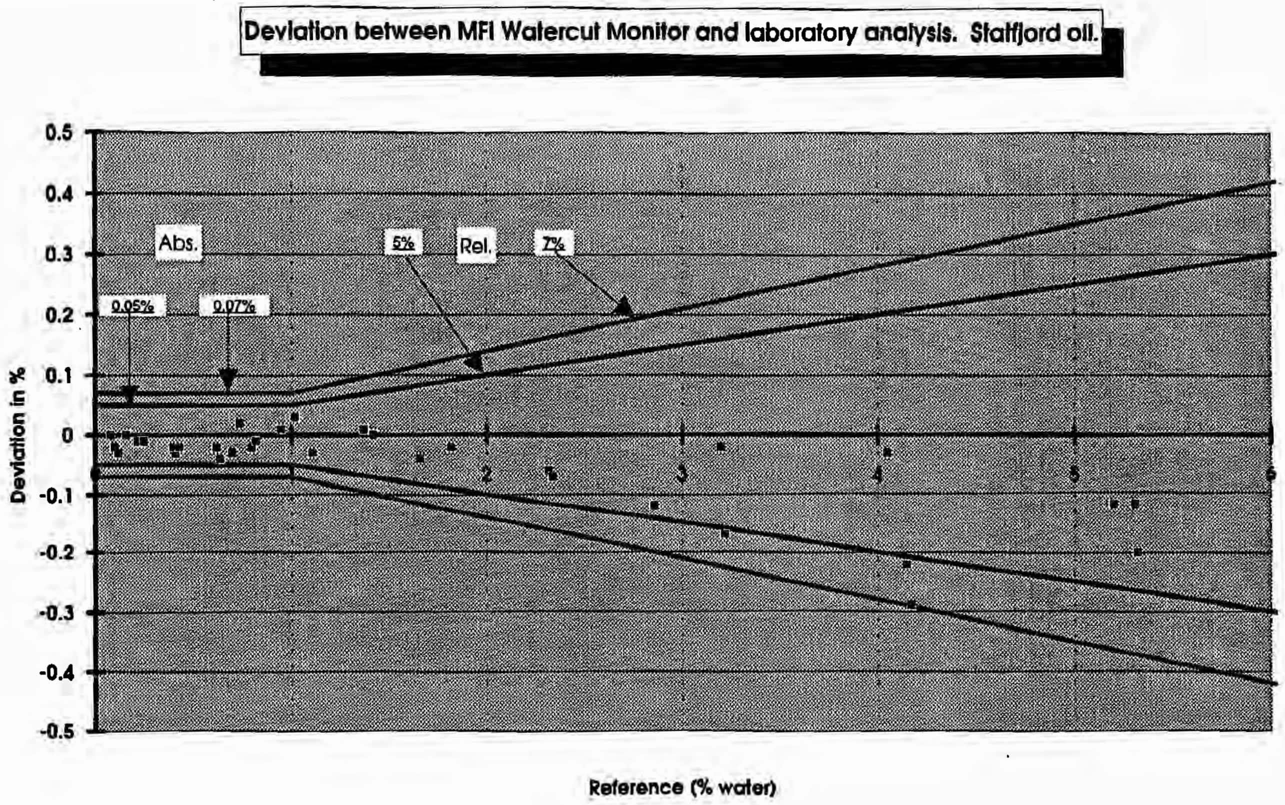

Deviation between MFI Watercut Monitor and laboratory analysis. Statfjord oil.
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
Deviation in %
Abs.
0.05%
0.07%
5%
Rel.
7%
2
3
4
5
6
Reference (% water)

Fig. 3

TESTING WATER-IN-OIL MONITORS AT THE MONGSTAD TERMINAL

OIL TYPE: GULLFAKS C **DENSITY: 859.5 kg/m3** **DATE: 26.1.93**

INJECTION OF FRESH WATER **SIX HOURS OF RECIRCULATION BEFORE START OF TEST**

Test no.	Time	Fluenta % water	Lab. analysis % water	Deviation lab./ MFI	Oil temp. (oC)	Ambient temp. (oC)	Line pressure (barg)	
1	15:43	0.07%	0.10%	- 0.03%	23.4	-3	5.3	
26	19:17	0.08%	0.08%	0.00%				
39	19:57	0.09%	0.12%	-0.03%				
4	15:57	0.20%	0.25%	-0.05%	23.6	-3	5.3	
25	19:15	0.22%	0.23%	-0.01%				
28	19:24	0.22%	0.22%	0.00%				
5	16:00	0.37%	0.38%	-0.01%				
22	19:05	0.39%	0.42%	-0.03%				
27	19:20	0.41%	0.42%	-0.01%	23.8	-6	5.1	
3	15:55	0.59%	0.62%	-0.03%				Absolute deviation
24	19:12	0.54%	0.56%	-0.02%	23.7	-6	5.1	
31	19:31	0.62%	0.61%	-0.01%				
2	15:50	0.83%	0.85%	-0.02%				
23	19:08	0.79%	0.87%	-0.08%				
30	19:28	0.84%	0.82%	0.02%				
6	16:03	0.99%	1.03%	-0.04%				
20	18:56	1.10%	1.15%	-0.05%				
29	19:27	1.03%	1.04%	-0.01%	23.7	-6	5.2	
8	16:10	1.44%	1.47%	-2.04%				
21	19:00	1.41%	1.47%	-4.08%				
32	19:33	1.56%	1.59%	-1.89%	23.8	-6	5.2	
7	16:07	1.96%	2.01%	-2.49%				
19	18:53	1.96%	2.07%	-5.31%				
33	19:36	1.84%	1.85%	-0.54%				
9	16:14	2.93%	3.11%	-5.79%	23.7	-4	5.2	
18	18:50	2.85%	3.02%	-5.63%	23.8	-6	5.2	
34	19:40	2.78%	2.84%	-2.11%				
10	17:25	3.90%	3.87%	0.78%	23.7	-5	5.2	Relative deviation
16	18:05	3.76%	3.90%	-3.59%				
38	19:55	4.13%	4.31%	-4.18%				
11	17:34	4.74%	4.61%	-2.82%				
17	18:10	4.96%	5.12%	-3.13%				
37	19:53	5.01%	5.20%	-3.65%				
12	17:37	6.90%	6.89%	0.15%	23.6	-5	5.3	
15	17:59	6.68%	6.85%	-2.48%	23.6	-5	5.1	
36	19:50	6.76%	6.99%	-3.29%				
13	17:43	8.90%						
14	17:50	9.64%						
35	19:45	9.38%			23.8	-6	5.2	

Tab. 1

TESTING WATER-IN-OIL MONITORS AT THE MONGSTAD TERMINAL

OIL TYPE: STATFJORD **DENSITY: 832.9 kg/m3** **DATE: 27.1.93**

INJECTION OF FRESH WATER **THREE HOURS OF RECIRCULATION BEFORE START OF TEST**

Test no.	Time	MFI % water	Lab. analysis % water	Deviation lab./ MFI	Oil temp. (oC)	Ambient temp. (oC)	Line pressure (barg)	
2	14:40	0.9%	0.12%	- 0.03%	18.8	0	5.3	
18	15:24	0.08%	0.10%	-0.02%	18.4	-4	5.4	
35	16:28	0.08%	0.08%	0.00%	17.6	-4	5.4	
9	14:58	0.24%	0.25%	-0.01%				
17	15:22	0.21%	0.22%	-0.01%				
34	16:22	0.16%	0.16%	0.00%				
8	14:57	0.38%	0.41%	-0.03%				
16	15:17	0.38%	0.40%	-0.02%				
32	16:17	0.41%	0.43%	-0.02%				
6	14:52	0.67%	0.70%	-0.03%	17.9	0	5.3	**Absolute**
15	15:15	0.60%	0.62%	-0.02%				**deviation**
33	16:19	0.60%	0.64%	-0.04%				
7	14:55	0.76%	0.74%	0.02%				
13	15:10	0.78%	0.80%	-0.02%				
30	16:12	0.81%	0.82%	-0.01%	17.8	-3	5.3	
5	14:49	1.08%	1.11%	-0.03%	18.8	0	5.4	
14	15:12	0.96%	0.95%	0.01%				
31	16:14	1.05%	1.02%	0.03%				
4	14:47	1.62%	1.66%	-2.41%				
12	15:05	1.38%	1.37%	0.73%				
29	16:10	1.42%	1.42%	0.00%				
3	14:45	2.26%	2.32%	-2.59%				
11	15:03	2.27%	2.34%	-2.99%				
28	16:07	1.80%	1.82%	-1.10%				
1	14:35	3.05%	3.22%	-5.28%	18.6	0	5.4	
10	15:01	2.47%	2.86%	-4.20%	17.9	-3	5.4	
27	16:03	3.18%						
22	15:43	3.93%	4.15%	-5.30%				**Relative**
26	15:57	3.88%	4.17%	-6.95%				**deviation**
39	16:43	4.02%	4.05%	-0.74%	17.4	-4	5.3	
21	15:40	5.12%	5.32%	-3.76%				
25	15:55	5.08%	5.20%	-2.31%				
38	16:40	5.19%	5.31%	-2.26%				
20	15:36	7.38%	7.14%	3.36%				
24	15:50	6.77%	6.95%	-2.59%				
37	16:37	6.88%	6.61%	4.08%				
19	15:33	9.34%			18.2	-2	5.3	
23	15:45	9.03%						
36	16:32	9.25%						

Tab. 2

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.