Test of a 1 inch Roxar Watercut meter on light condensate with very low water content.

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1 INTRODUCTION

The Oil industry is rapidly moving towards more difficult crude products, as more and more of the easy produce able crude oil will be finished. This leads to new challenges for the whole industry, finding better equipment to coupe with these challenges.

One such trend is in the oil business is moving towards lighter oils or condensates. These will have to be processed and transported under high pressure, to stay liquid. The residue water, more or less saline, in condensates can cause serious corrosion problems in the downstream process equipment and pipelines.

The Roxar Watercut meter have undergone a test on light condensate, with standard density of about 625 kg/m^3, to establish how good the meter is for measuring the very low water content in such products. The ordinary process conditions were 0-650 ppm volume water, while the maximum range was 0-1650 ppm. The test took place offshore on a real condensate line, and was conducted by a large oil company.

A standard Watercut meter was optimized during the installation process for optimization to these process conditions. Also the different contributions to the total measurement uncertainty from the different sensors (microwave, temperature and density) were evaluated, to see if such an installation was possible in the first place.

In-line calibration is crucial on such installations, because it basically will compensate for any biased uncertainty in the measurement system. Establishing the dry oil permittivity under such circumstances is crucial for correct determination of the water content in the meter. Also, sampling several times, then averaging the samples, gives a very good correspondence, better than 50ppm under fairly stable process conditions.

2 THE MEASUREMENT CHALLENGE

2.1. Measurement terms of Water content.

Water content is mostly usually measured in volume percent (%). But for very low water content, it is often wanted to measure the water content in ppm. Since this is rather seldom, the correspondence between these two is not obvious to everyone. To recollect, these are:

1 % = 10.000 ppm
0.1 % = 1.000 ppm
0.01 % = 100 ppm

2.2 The application.

As the easy accessible hydrocarbons more and more are been exploited, the industry will have to turn to more difficult reservoirs to fill the worlds need for hydrocarbons. One set of such more difficult reservoirs are light condensate reservoirs.

Some typical characteristics of a light condensate application are:

- High pressure
- Possibility of flashing
- Stable density
- Stable temperature
- Very low water content (easily separable phases)
- Generally very little problems with scaling

2.3 Permittivity measurement of the condensate and water mixture

The Roxar Watercut meter is designed to measure the permittivity of the content flowing through the meter. The permittivity measured in any resonance cavity is defined by.

$$\varepsilon_{mix} = \left(\frac{f_{vac}}{f_{mix}}\right)^2$$

The meter will then establish the expected permittivity of the dry hydrocarbon fraction in the meter, and the permittivity of the water in the mixture.

These numbers will then go into the famous Bruggeman equation, well established as the correct way of determining the content of one fluid entrained within another fluid with different permittivity. For a hydrocarbon continuous flow with entrained water, this formula will look like:

$$\beta = 1 - \frac{\varepsilon_{mix} - \varepsilon_{water}}{\varepsilon_{oil} - \varepsilon_{water}} \sqrt[3]{\frac{\varepsilon_{oil}}{\varepsilon_{mix}}}$$

In this equation, the establishment of ε_{mix} can be done with a very low degree of uncertainty, and high degree of repeatability.

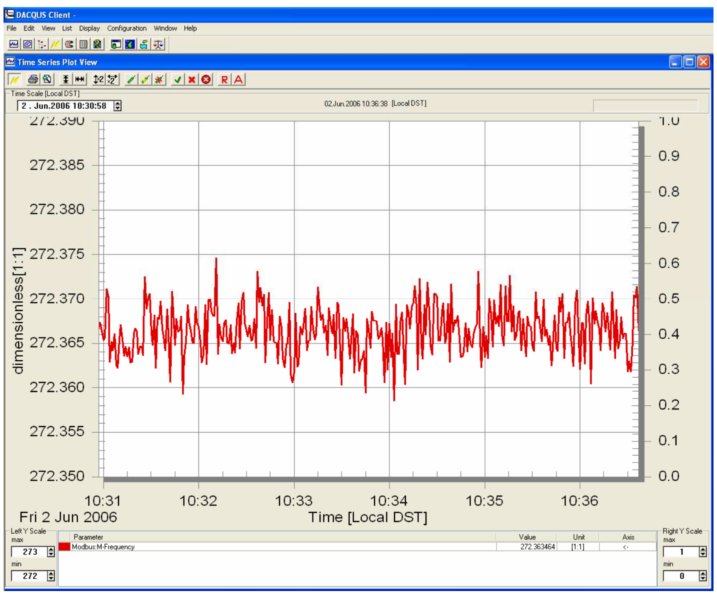

Fig. 1

The chart is logged with a fixed reference. Every point is independent measurements. As we see, the scatter band is maximum ±5 kHz at a measurement frequency of 272 MHz, or proximately ± 20 ppm.

It can be demonstrated with a sensitivity analysis of the Bruggeman equation that the ε_{water} has a non significant influence on the calculations of low water contents, and for this application just as well could be set to a typical number, e.g. 100.

It now remains to establish the permittivity of the pure hydrocarbon fraction. This is the main challenge in a light condensate application, which requires this degree of low measurement uncertainty.

Roxar have earlier done research on how to establish the hydrocarbon permittivity. The main single factor which contributes to the variation of the hydrocarbon permittivity is the hydrocarbon density. [1]

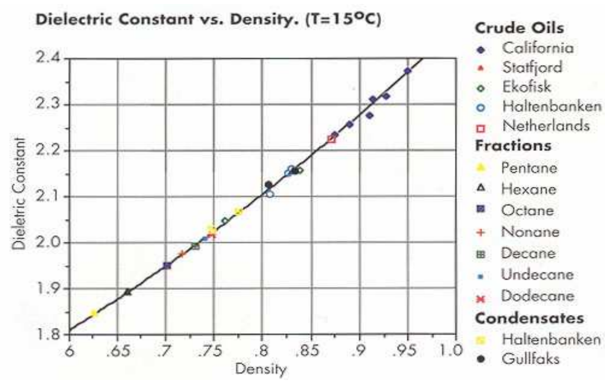

Fig. 2 :

Correlation between density and pure hydrocarbon permittivity (or Dielectric Constant).

Therefore, the most important input to meter, next to the microwave measurements, is a density signal. A reliable density signal is totally crucial for an application like this, and can not be skipped.

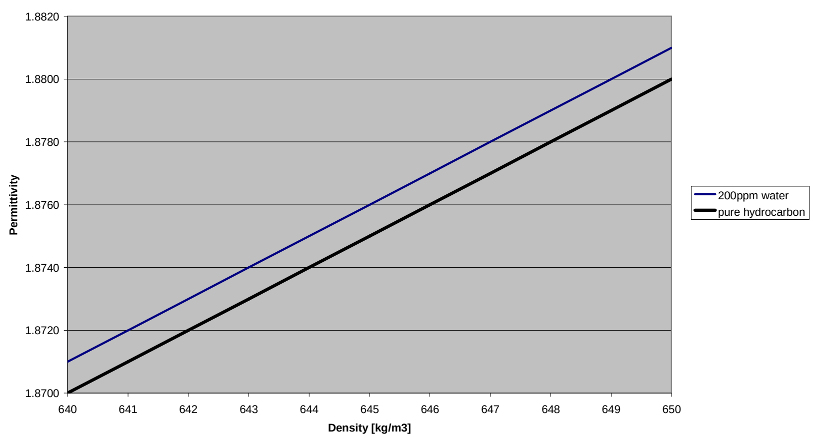

Fig. 3.

Difference in pure hydrocarbon permittivity and 200ppm water mix permittivity

However, there are more factors contributing to the hydrocarbon density. When measuring with the very low degree of measurement uncertainty needed in an application like this, the effects of these other uncertainty contributors must be taken into considerations. A temperature signal will standard be given as a input to the meter. (All Roxar Watercut meters are delivered with a temperature transmitter as a standard.)

Several other effects will also be present to a certain degree. These will have to be cancelled out somehow, and we will soon see how this can be done.

Also, the density signal will have some measurement uncertainty attached to itself. A density input of 1 kg/m^3 would in reality lead to a wrong calculation of the Watercut of about 270 ppm to low, depending slightly on where in the measurement region the measurements are taken.

Looking into the datasheet of the different options for density measurement, reveal that they all will have some uncertainty attached to them. However, even if the density out of a coriolis meter has a slightly higher uncertainty attached to it, my experience with coriolis meters is that the measurement uncertainty of this figure, is mainly a biased figure, and that the repeatability of this is very good.

Since most applications will have a need for both a flow meter and a Watercut meter, combining a coriolis meter with a Roxar Watercut meter is a very good combination. In this application it will have three effects: Firstly the client will (obviously) have a flow meter. Secondly the density output from a coriolis meter can be used as an input to the watercut meter to establish the correction of hydrocarbon permittivity. And, thirdly, the biased part of the measurement uncertainty of the density, and most of the effect of all the other contributors to establishment of the hydrocarbon permittivity, will effectively cancel out with an inline calibration of the Watercut meter.

With the Watercut meter correctly inline calibrated, the meter was now ready to measure the water content in the condensate.

3 THE TEST

3.1 The test setup

The meter tested was a standard 1 inch Roxar Watercut meter, equipped with the standard Autozero option. The meter had especially short cables of one meter, and extra attenuators were added, to ensure that cable effects (antenna effects) were minimized. Extra attenuators could lead to very high watercuts that is more then volume % higher than 25% would not be measured, but this is way above all water contents applicable for any application like this.

During commissioning, also a special designed software was tested, but this did not improve the performance of the meter any, and was therefore abandoned. A full data logger (Daqcus) was also provided, to log all data during the test. This would reveal any correlations, and would give us the possibility to fully analyze any moment during the test where we suspect anything odd happening.

The standard commissioning procedure for commissioning Roxar Watercut meters was used as the setup basis of the meter, and a best fit offset value was established as the inline calibration of the meter.

The reference system for the test was a sampler system. The tester had made sure to have the best equipment and personnel available to take samples and analyze them.

3.2 The test results

The test stretched for about a week. Several different well-configurations were tested during this period, to check the meter reactions to these changes.
The results from analyzing the samples and from the Watercut meter, clearly indicates that there is two major clashes of test points, and in addition some scattered results.

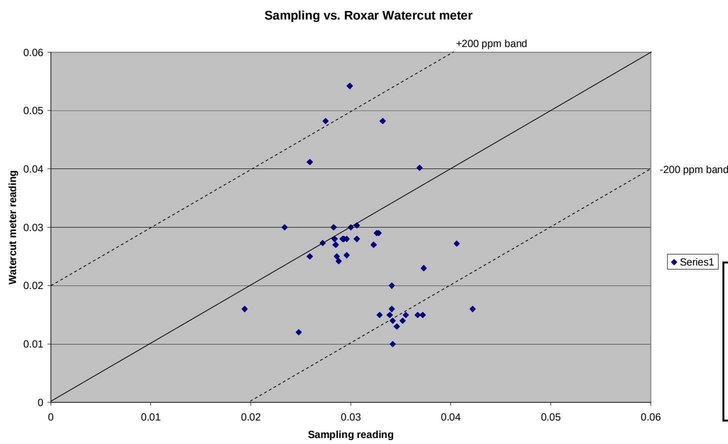

Fig. 4

Linearity of readings of watercut readings vs. sampling

Taking a look at the timeline of the project, vs. the difference in watercut reading, indicates a stable period in the start of the test, then a more scattered intermediate period, then a very stable period in the end of the test. The time the points makes a 'jump', corresponds very good to the tester changing well configurations.

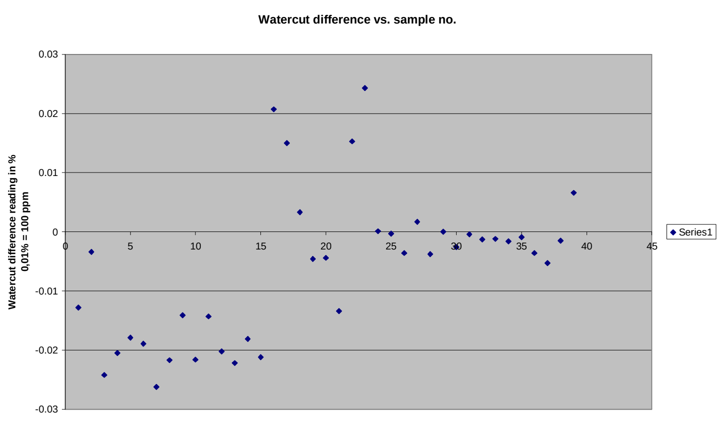

Fig. 5

Difference of watercut reading between the Watercut meter and sampling analyzis.

We would expect that the change of hydrocarbon composition should give a small different permittivity independent of the hydrocarbon density. This corresponds to the small scatter of points along the density vs. permittivity curve in chapter. 2.1.

Plotting the results as a function of densities measured at the test points, clearly demonstrates a correspondence between the density measured at the test point, and the watercut difference.

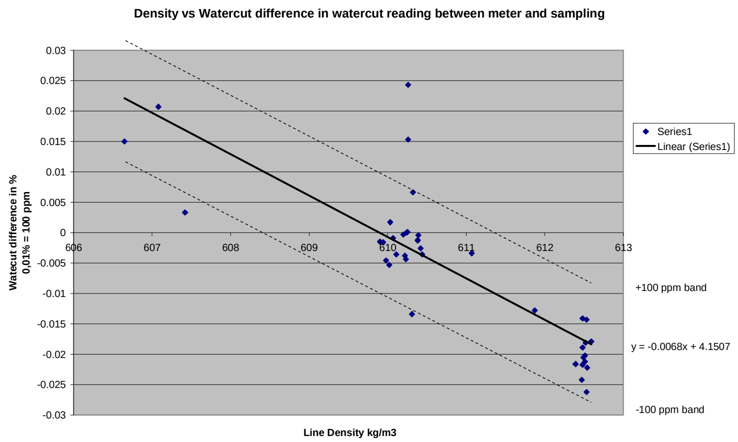

Fig. 6

Density vs. Watercut difference reading between Watercut meter and sampling analysis.

There are mainly two reasons for this:

1 The density correction in the meter is slightly inaccurate in this region for this particular application.

2 The different well configurations in this application will result in different hydrocarbon compositions, creates a pattern which is unique for this application.

The good correspondence between the sampler measurements and the Watercut meter measurements both clearly demonstrates that the sampling was done at very high degree of accuracy, and that the meter is very repeatable. However, in any systems doing repeatable operations (taking repeatable samples), with the possibility of many types of error (including human), it must be expected that one or some few of the sampling results are off. It is therefore impossible to determine if the reason for the few misreading is that the sample result is inaccurate, or the Watercut meter is inaccurate. The only conclusion we can make in such a case is that at least one of the measurements is inaccurate.

4 A PROPOSED SOLUTION FOR THIS MEASUREMENT CHALLENGE

Exploiting the correlation data between the density and the water content difference between the meter and reference indicates that it is possible to impose a correction for this. However, the data from this test exclusively is insufficient to make a general correction in the meter, valid for all applications. Also, improving the Watercut meter, based on data obtained from the meter itself, is not an independent way of improvement.

However, a local correction is possible to do. And, since every application is unique, a local correction method for these types of applications is probably the far best route to go.

A method of determining a correction for the meter has been developed and then implemented into the meter. We have called this method: Local Characterization. The following steps must be followed to implement this method fully into the meter:

1. First the meter must be installed, and measurements started. It should be possible to change well configuration and/or reservoir during this calibration.
2. Run a high number of samples over the full operation area of the meter, and note down the Watercut- and density reading corresponding to every sample.
3. Calculate the watercut difference between the samples and the watercut readings from the meter.
4. Plot the correlation between the density (x-axis) and the watercut difference (y-axis).
5. Find a best fit linear (ax+b) correlation between density and watercut difference.
6. Enter the coefficients ‘a’ and ‘b’ into the Watercut meter. This line will now be the watercut baseline in the meter for this application

The measurement uncertainty will now be the scatter around this line.

In appendix 2 is a numbered example of how to establish a linear correlation between density and permittivity.

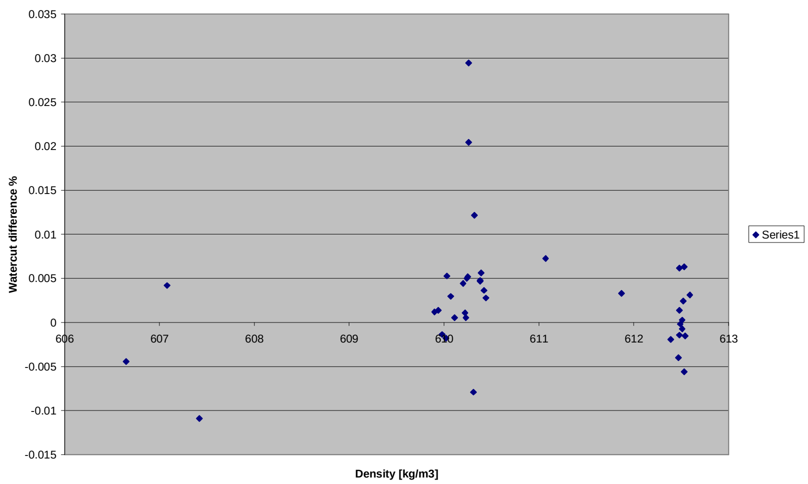

Figure 6

Watercut difference between sample analysis and Watercut meter reading, back-calculated from test results.

Roxar have now implemented this method into the Watercut meter software, and it is available as an option with a new meter. Further, since this method is implemented as a software change only, it is possible to upgrade existing meter with new software with this functionality included.

There is however some uncertainties attached to this method. If the application consists of three or more distinct hydrocarbon compositions, there is a possibility that these three can not be aligned to a line fit. A best fit approach will however reduce the measurement uncertainty greatly, but some additional uncertainty around this must be expected in cases where the different hydrocarbon does not fit linearly.

5 CONCLUSION

Condensate applications, close to a reservoir but after separation, are known to be very stable processes. The water content is generally very low, since water separates fairly easy from the condensate. Also, any process changes are generally slow, due to the fact that the condensate has had time to settle down and mix in the separator tank.

On an application of light condensate with very low water content, it is possible to achieve very low measurement uncertainty with the method 'local characterization' implemented into the Watercut meter. The method is basically an advanced way of inline calibrating a meter, and taking into considerations local effects of different hydrocarbon compositions.

The method will cancel out local effects on the special offset of the local hydrocarbon composition, as well as small local differences from the general correction of the density versus the hydrocarbon permittivity.

It is assumed that the hydrocarbon composition from one reservoir is stable throughout the lifetime of the reservoir. Therefore, the calibration will only have to be done once. Based on the foregoing assumption, it should be valid throughout the lifetime of the reservoir.

6 ABBREVIATIONS

ppm	parts per million	(No unit)
T	temperature	ºC
CCFR	Center Cylindrical Fin Resonator	
CFR	Cylindrical Fine Resonator	

7 NOTATION

β	Watercut (as a number between 0 and 1)
ε_{oil}	Permitivitty of pure hydrocarbon
ε_{mix}	Permitivitty of fluid through the meter
ε_{water}	Permitivitty of water
f_{vac}	Resonnance frequency in vacuum
f_{mix}	Resonnance frequency in mix

8 REFERENCES

[1] ROXAR, Roxar Watercut meter, Operation and Maintenance Manual.

[2] Klaus Kupfer & Ebbe Nyfors,Electromagnetic Aquametry, ISBN 3-540-22222-7

[3] Ebbe Nyfors, Cylindrical Microwave Sensor for Measuring Materials under Flow, ISBN 951-22-4983-9

APPENDIX 1

The Roxar Watercut meter used in the test, was a model called: Centre Cylindrical Fin Resonator (CCFR). This is a variant of the more general Cylindrical Fin Resonator (CFR). The only difference is that the CCFR will have a small cylinder on the top of the fin, which is in the centre of the pipe.

The fin has two functions in the meter:

1 It creates a resonance cavity in the measurement section of the meter.
2 It reduces the cut-off frequency of this pipe section by approximately 63%, enabling microwaves to travel freely in the pipe section with the fin, while the microwaves will have a to low frequency to escape up or down the pipe.

The fin resonator will have two antenna probes. One probe is placed exactly opposite the fin, the other exactly 90 degrees to the fin [2].

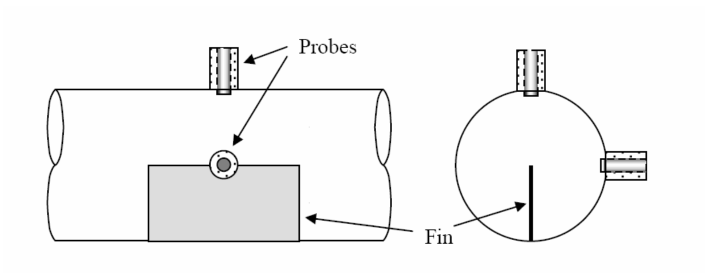

Fig. 7

Principal measurement sketch of a fin resonator.

The Microwaves will be transmitted into the pipe through one of the antennas. The microwaves will then form an electromagnetic wave pattern in the complete area of the pipe. The pattern is rather complex, but we can look at some microwave patterns of some simple microwave modes in the meter [3].

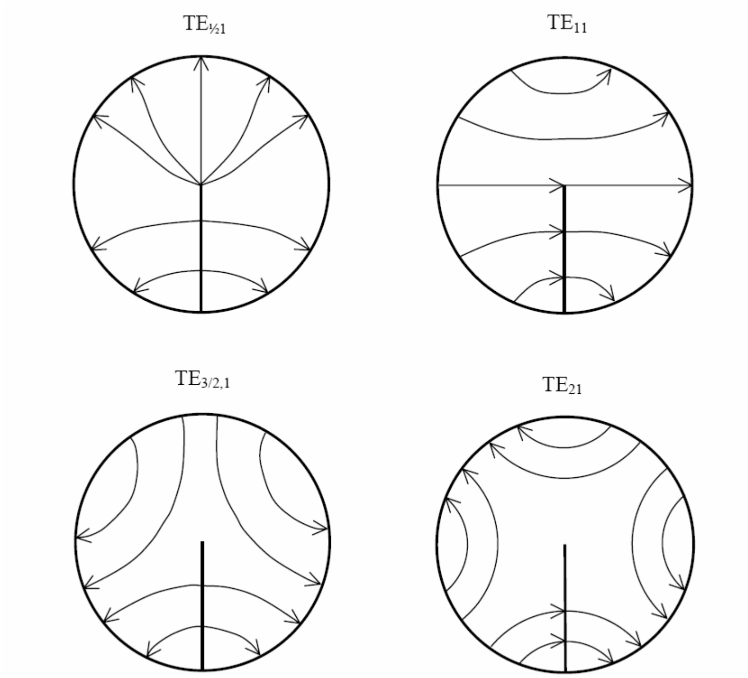

Fig. 8

Four different mode patterns of microwave patterns in the meter

The important thing to notice is that the microwaves will cover the full bore of the meter, thus all water passing through the meter will be measured. Also, the wave pattern is fairly uniform at resonance. Thus, a gradient of water content in the watercut will not influence the measurements particularly.

The Bruggeman equation, as implemented in the Watercut meter, is valid for oil continuous flow with water droplets which in size is less than 1/10 of the pipe diameter. Droplets sizes greater than this, could cause the measurement uncertainty to increase.

In case of full separation, the meter will still measure this water, but a higher degree of measurement uncertainty must be expected.

For the lowest degree of measurement uncertainty, a fairly good mix should exist in the meter. The meter should be vertically installed to ensure that no free water (water fully separated from the oil) can be present in the meter.

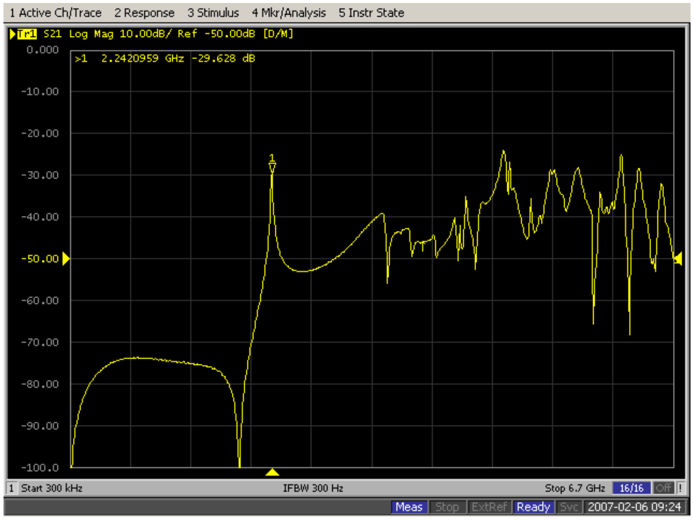

Fig. 9

Plot taken with a Network Analyzer of a 2 inch fin sensor filled with air. On the x-axis is frequency. On the y-axis is received power divided on transmitted power, including 20dB antenna attenuators.

APPENDIX 2

A numbered example of the implementation of the 'Local Characterization' method.

This example will follow the method in the 6 steps described in chapter 4.

1. We assume that the meter is installed, and production has started.
2. In this exampled 30 samples are done, varying the meter conditions over the full range of what is expected of this application. Data is filled in column 1 through 3 in the table.
3. Column four is calculated as the difference of column 1 and two.

Watercut meter	Sampling result	Density	Watercut difference
0.045	0.049	645.9	-0.004
0.053	0.055	642.4	-0.002
0.033	0.032	640.7	0.001
0.079	0.088	644.8	-0.009
0.021	0.017	642.9	0.004
0.048	0.073	649.9	-0.025
0.062	0.058	639.8	0.004
0.055	0.059	647.2	-0.004
0.064	0.053	640.7	0.011
0.094	0.075	640	0.019
0.086	0.067	641.1	0.019
0.061	0.083	649.2	-0.022
0.05	0.048	639.9	0.002
0.044	0.05	645.8	-0.006
0.049	0.055	644.1	-0.006
0.073	0.08	646	-0.007
0.085	0.081	645.7	0.004
0.099	0.104	646.3	-0.005
0.012	0.035	649.4	-0.023
0.054	0.042	639.8	0.012
0.077	0.067	641.2	0.01
0.072	0.063	642.4	0.009
0.083	0.078	642.3	0.005
0.031	0.045	648	-0.014
0.029	0.037	645.1	-0.008
0.076	0.069	642.2	0.007
0.084	0.092	645.3	-0.008
0.045	0.053	648.8	-0.008
0.067	0.056	641.9	0.011
0.092	0.088	643.2	0.004

4. Column three (density) vs. column four (watercut difference) is plotted in a plot.
5. A best fit line (ax+b) to the data is established.

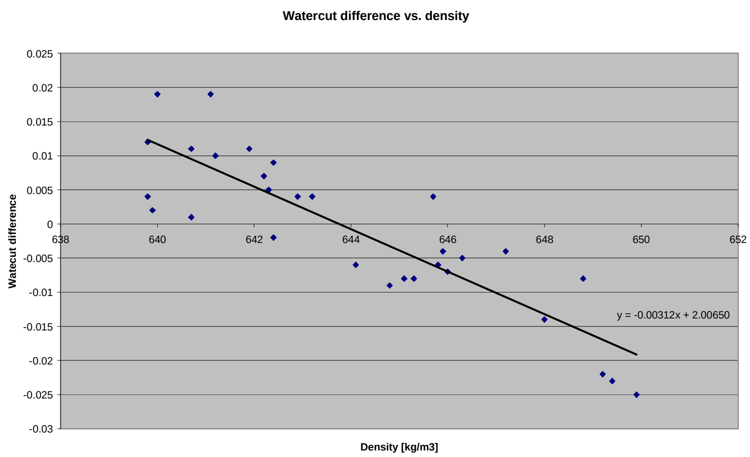

Fig. 10

Density vs Watercut difference between sample analysis and Watercut reading plot.

6. The coefficients ‘a’ and ‘b’ from the line are now entered into the Watercut meter.

The meter is now calibrated with the ‘local characterization’ method for the range of this application.