# DE-170926-01

Evaluation of a radiometric density meter in an export oil application

26.09.2017

Erik Sveinsvoll. AkerBP
Per V. Wærnes. Sensor Technology

## Summary
A clamp-on radiometric density meter type DT-9315 has been tested on export oil at the BP Ula platform from May 28 to October 5, 2015. The test has been executed in comparison with "fast loop"-bypass installed Solartron meter(s). Due to a maintenance shut the efficient duration of the test is 105 days.

The results show that the radiometric meter provides fast and reliable density values with high correlation to the Solartron meters. With exception of short term process disturbances the daily average density difference throughout the test is 0.19 kg/m³. Standard Deviation of the difference is 0.44 kg/m³.

The difference increases with higher or lower flowrates outside a middle range, and temporarily after change of Solartron line. No instability or signal drift of the DT-9315 is observed during the test.

# Table of Contents

## 1.1 Abbreviations

BP (BP Norway AS)
DT (Radiometric density meter, Type DT-9315 from Sensor Technology AS)
Diff. (Measurement deviation between Solartron and DT density meters)
L2 (Fast Loop Solartron line 2)
L3 (fast Loop Solartron line 3)
MV (measured density values, $kg/m^{3)}$.
Records (Logged measurement values)
S-Tec (Sensor Technology AS, Sarpsborg)
Sol (Solartron density meter)

## 1.2 Background

The test was initiated based on demand for a cost effective performance verification of the density metering systems at the ULA platform. In addition there has for some time been discussions, whether (or not) radiometric density meters are capable of complying with the precision and stability requirements of export oil applications. The test has been carried out in cooperation between Sensor Technology AS and BP Norway AS.

## 1.3 Scope

The evaluation has been divided in 2 steps:

1. Workshop Laboratory analysis with a commercial meter
   Objectives:

   A. Evaluation of sensitivity, precision, and repeatability. Calibration of meter.

2. On site evaluation of the same meter on process pipe at the Ula Platform.
   Objectives:

   A. Comparison of the meters MV, evaluation of differences

   B. Temperature dependency

   C. Long term stability

This report is only covering step 2 above.

## 1.4 Measuring principle

The Radiometric Density Meter type DT-9315 (DT) is a “clamp-on” meter, consisting of a source holder and a detector unit. Installed on a process pipe, the radioactive source sends a collimated gamma radiation beam towards the detector, as indicated on figure 1. The detector system converts the residual gamma radiation, not absorbed by media inside the pipe, to an electric pulse signal. The signal is converted to the media density (specific weight).

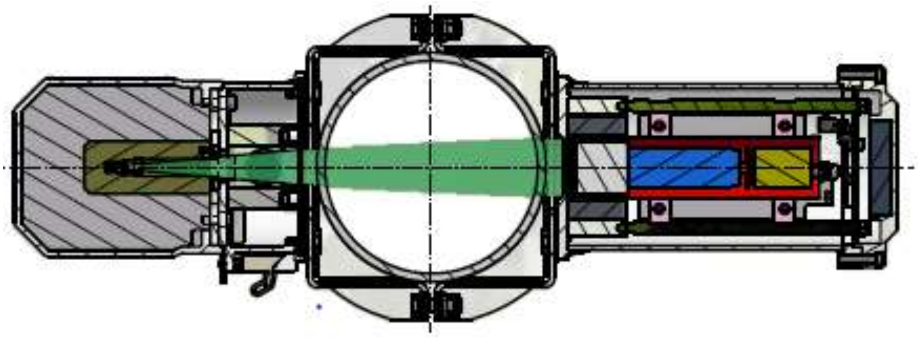

**Figure 1 DT-9315 Density Meter measuring principle**

## 1.5 Equipment under test (EUT)

The DT used for the test is sourced from a batch of regular production units of meters used in top-side and sub-sea multi-phase flow meters. Recorded signals are based on a set-up with time constant of 60 seconds and a signal update rate of 2 minutes.

The DT use a Cesium (CS-137) sealed radioactive source with a half-life of 30.17 years. The unit has automatic source decay compensation. It also has an input for possible temperature compensation of the density (not used under this test).

## 1.6 Flow loop configuration

Piping arrangements are shown in figure 2 below.

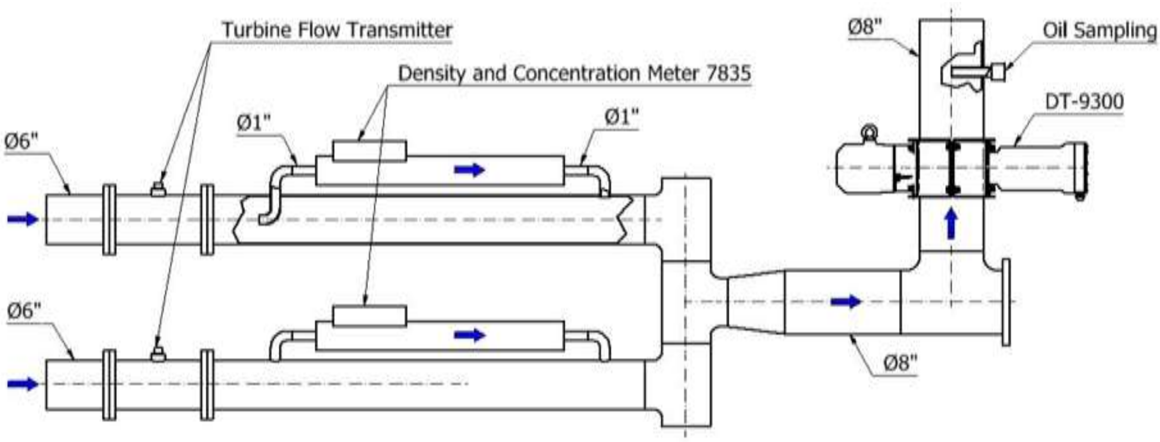


**Figure 2 Flow loop configuration**

## 2.1 Process Log

| | |
|---|---|
| 27/5/2015: | Installation and start-up |
| 28/5: | Calibration. Log start at 15:00, Sol L2 |
| 3/6 @21:00: | Changed to Sol L3 |
| 3/6 @22-23:00: | Sol in manual mode |
| 13/6 at 10:00: | Sol in Manual mode for 1 hour |
| 27/6: | Sol stopped for ESD test |
| 2/7: | Changed to Sol L2 |
| 2/7-3/8: | Maintenance shut. DT remains powered during the shut |
| 3/8: | Start Sol L2 |
| 4/8: | Changed to Sol line 3 for 6 hours |
| 15-16/8: | Temporary shut down for 2 days |
| 2/9: | Changed to Sol L3 |
| 5/9: | Changed to Sol L2 |
| 3/10: | Changed to Sol L3 |
| 06/10: | Test termination. Dismantling of the DT |

## 2.2 Installation and calibration

The DT was clamped to the 8 inch production pipe after pipe repaint in the mounting position, see figure 2. Signal and power cables (24V) were led to a safe area cabinet. Signal cables were connected to a logging computer. DT signals were transferred wireless to S-Tec as 2 minutes average values. Sol-signals were forwarded to S-Tec as written report tables of hourly average line density values, based on signal output updates pr. minute. Process temperature data and volume flow-rate were reported as hourly averages.

**Figure 3 DT on process pipe**

The DT was delivered with a calibration curve from precedent laboratory evaluation, based on oil sample from the export pipe in question. The oil was forwarded to S-Tec by BP after laboratory analysis. Calibration was established by comparing measured density values under temperatures from 20 to 60°C, extended to a linear measuring range from 640 to 830 kg/m$^3$ (4-20 mA).

The initial results at start-up showed that the DT had an offset to the Sol L2 density by approx. 25 kg/m$^3$. This is within the variations expected by the random variations in inner diameter and pipe wall thickness of the standard pipe in question (documented in the precedent laboratory evaluation at S-Tec). As it was inconvenient to insert a known oil sample or other known liquid into the pipe under operation, it was decided to carry out a single point calibration of the DT using the actual Solartron L2 MV as reference. Installation, start-up and calibration adjustment was carried out by Hans Wilhelm Ro (S-Tec) and BP technicians.

For avoidance of doubt it should be emphasized that the above calibration is the only adjustment carried out on the DT throughout the testing period. It has been in operation and transferring signals during the total period, including the maintenance shutdown in July.

# 3 Results

Overall results includes:

Hourly records

- Line density Sol L2&L3
- DT density
- Difference Sol-DT
- DT internal Temperature
- Process temperature
- Gross Volume flow-rate

Daily records

- Line density Sol
- DT density
- Difference Sol-DT
- Standard Deviation of difference Sol-DT based on hourly variations

Hourly records are averages of 1 minute readings from Sol and 2 minutes readings from DT.

## 3.1 Exclusions

The following dates are excluded in the comparison evaluation:

| Date | Cause |
|---|---|
| 17.06.2015 | Instable Sol MV |
| 27.06.2015 | Sol shut during ESD test |
| 03 - 04.08.2015 | Instability at start-up after maintenance shut |
| 15 - 16.08.2015 | Line shutdown |

Some short time further exclusions are discussed under section 4.
Detailed results and observations follows.

## 3.2 Correlation and variance

In order to reduce effects of process variations, correlation evaluations are based on result difference (Diff) between Sol and DT (MV Sol-MV DT) density MV's. It follows that the Diff is negative if MV DT has the highest value of compared MV's. Correlation between Sol and DT based on daily average density values is shown in figure 4.

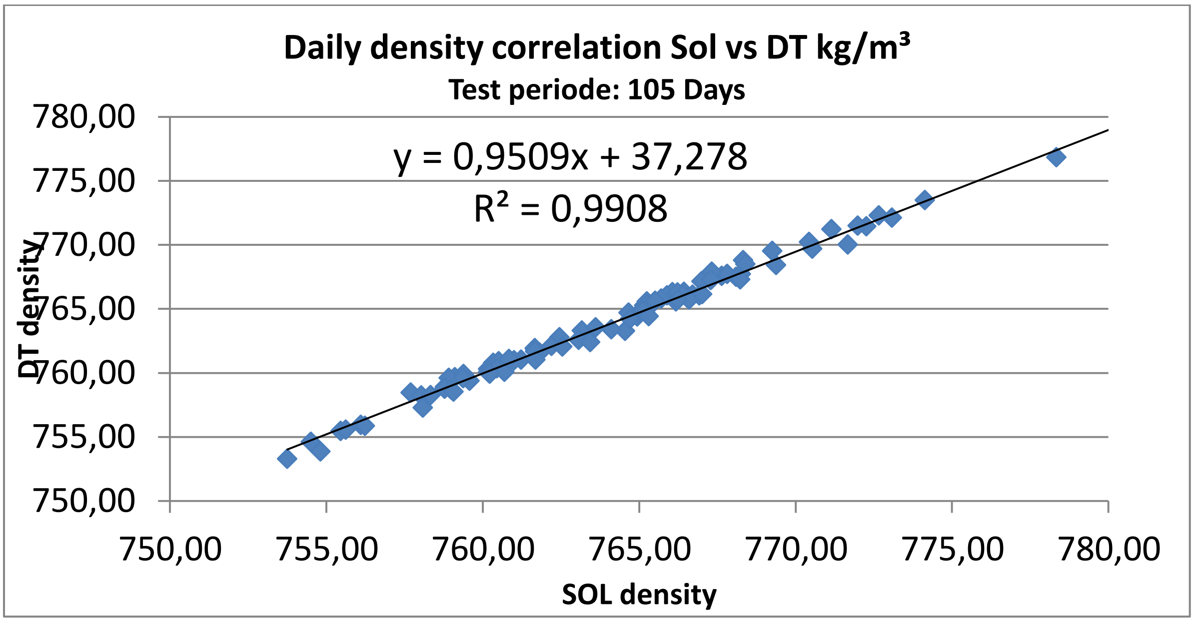


**Figure 4 Sol and DT Correlation**

## 3.3 Diff vs. density

Daily diff vs. Density is shown in figure 5.

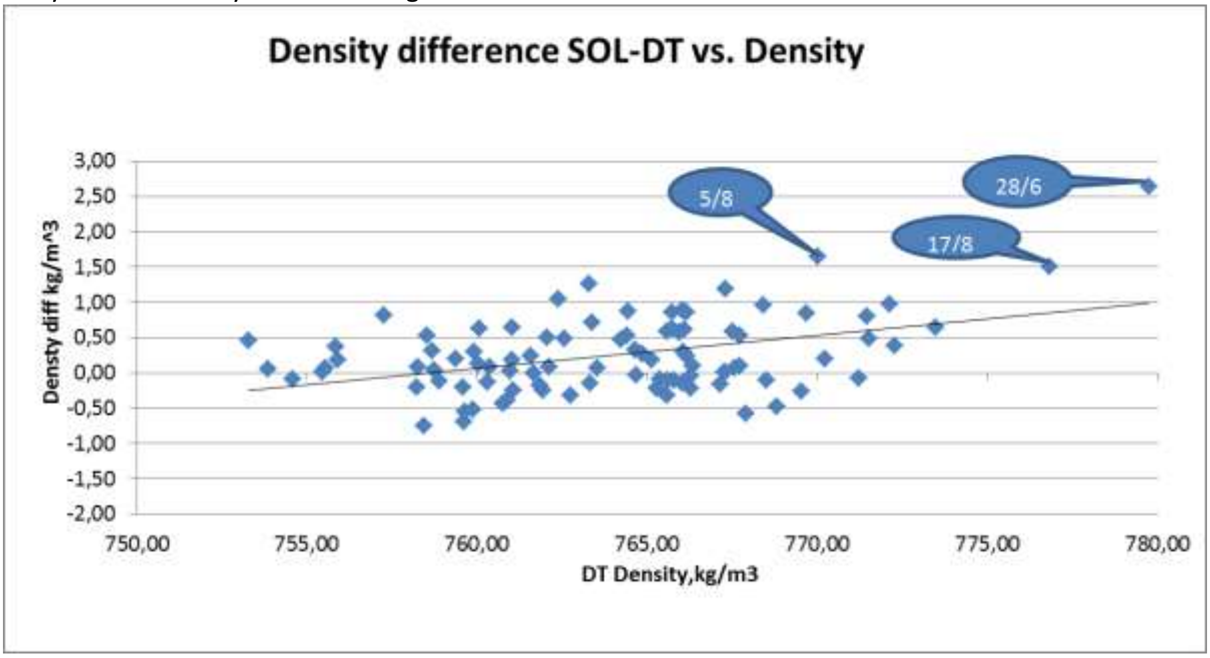


**Figure 5**

The trend-line indicates increased diff with increased density.
This may have following separate or combined causes:

- The trend-line is erroneous due to process dependent reasons for the few high density records.
- The Sol is over- reading density at increased densities.
- The DT is under-reading density at increased densities.

This issue is further considered under detailed results below. It should be observed that the 3 bulleted dates are significantly pulling the curve upwards. Increased Diff is dominantly observed during instable process conditions (Water intrusion and high/low flowrates).

### 3.4 Diff with elapsed time

Recorded diff vs. time is shown in figure 6.
The outliers in bullets are considered under section 4, detailed results and observations.

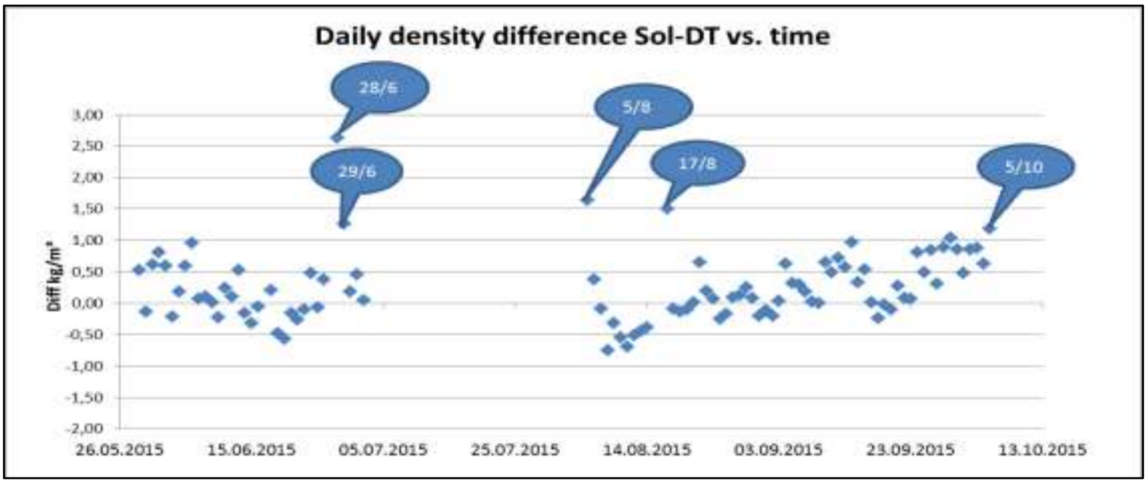


**Figure 6**

The graph indicates increased Diff with time during the test in second half year.
Increased Diff implies that Sol MV is higher, respectively the DT MV lower for a given compared time sample. It should be noted that an aging deviation of the DT dominantly will appear as increased density with time, as the count rate of detected photons will decrease (lowered sensitivity). As standard a zero-point calibration (empty pipe) is used for control/calibration of any DT ageing related deviations in addition to source decay. As this has been impossible during the actual test, a comparison has been made on daily averages of equal density values, measured early and late in the test period. The results are shown in table 1.

**Table 1**

| Date | SOL density [kg/m³] | DT density [kg/m³] | Measured DT count rate [Hz] | Calculated decay count rate [Hz] |
|---|---|---|---|---|
| June 11 | 766.40 | 766.16 | 202 663 | |
| Sept. 27 | 766.38 | 766.08 | 201 313 | 201 291 |

The DT density values are based on the count rate at the single point calibration to the SOL density at test start, compensated for the decay in source activity with elapsed time.
Decay compensation of the meter is based on the equation:

$$F_t = F_0 \cdot 2^{-\left(t/T_{1/2}\right)}$$

Where: $F_t$= count rate at time t, in this case Sept. 27 average
$F_0$= count rate at time of start, in this case June 11
$T_{1/2}$= Isotope half- life. For Cs-137: 30.17 years (11 019.6 days)
t= Time between $F_0$ and $F_t$. In this case 108 days

The observed deviation between measured and calculated count rate is 22 Hz (0.01 %). This indicates that there are no significant aging effects besides source decay, or change of scaling inside the DT process pipe. The Diff is 0.3 kg/m³ in the dates above. This is well within the Standard Deviation of Diff of daily averages for the test period. Evaluation of flow rate effects shows that the high Diff's at end of the test period is caused by stable high flowrate.

## 3.5 Standard deviation of Diff.

Standard deviation is an accepted measure of stability. The daily standard deviation shown below is based on hourly Diff records within each given date. The average standard deviation value over the test period is 0.47 kg/m$^3$, including results from dates with high deviation (bulleted in figure 7). The test proves that Standard Deviation is somewhat misleading as a stability variance measure of the instruments, as short term process instabilities have a significant impact on the measured values. In production allocation these short term measurements would presumably be deleted, when density values are affected by water ingress, flow interruptions etc.

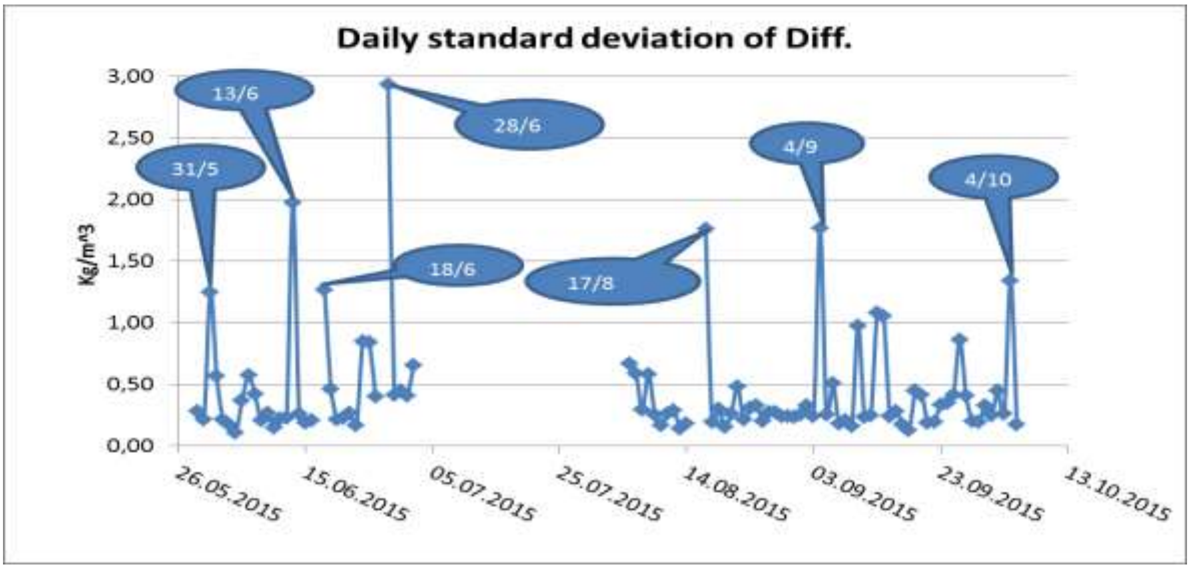


**Figure 7**

There is no significant change in standard deviation of Diff with time throughout the test period, under stable process conditions. Results from the bulleted dates with large deviation will be addressed under detailed results below.

### 3.6 Sensitivity correlation

The following graphs (figure 8 & 9) shows the density sensitivity correlation between the 2 meters under stable process conditions.

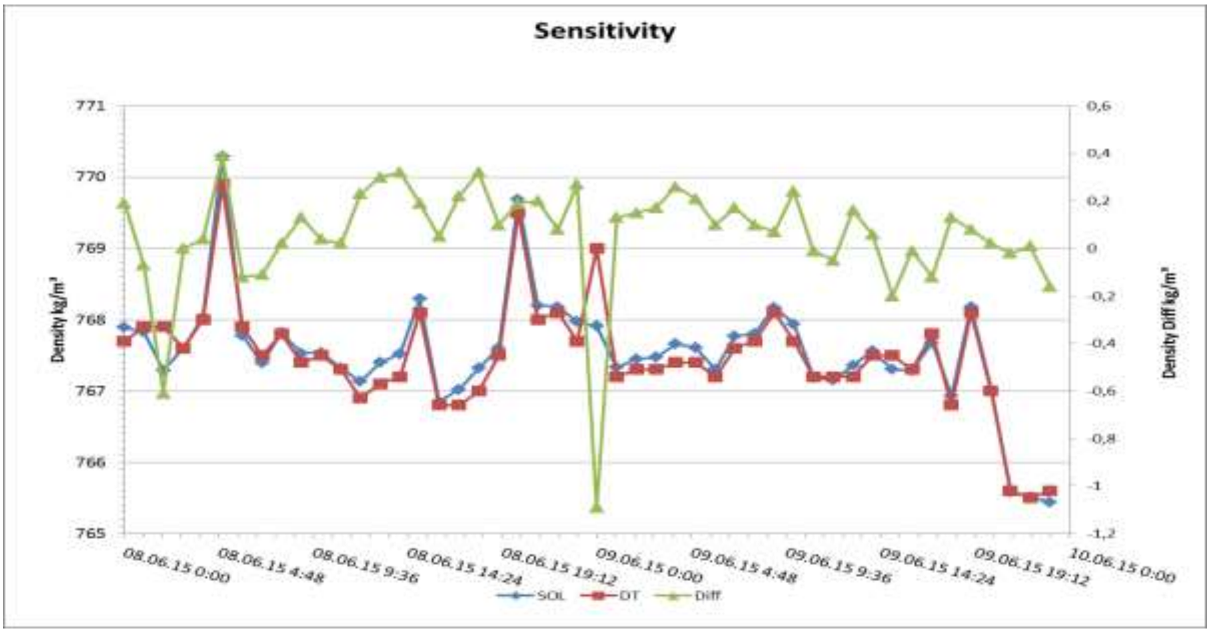


**Figure 8**

The DT shows repeatable detection of hourly density changes corresponding to those of the Sol units, with few exceptions. The standard deviation of Diff for the 48 hours above is 0.24 kg/m³ and the average Diff is 0.06 kg/m³. It is evident that the DT is measuring a density increase at 0:00 on June 9 without any similar response from the Solartron L3 meter.
Average DT density is 767.485 kg/m³ and Solartron 767.544 kg/m³.

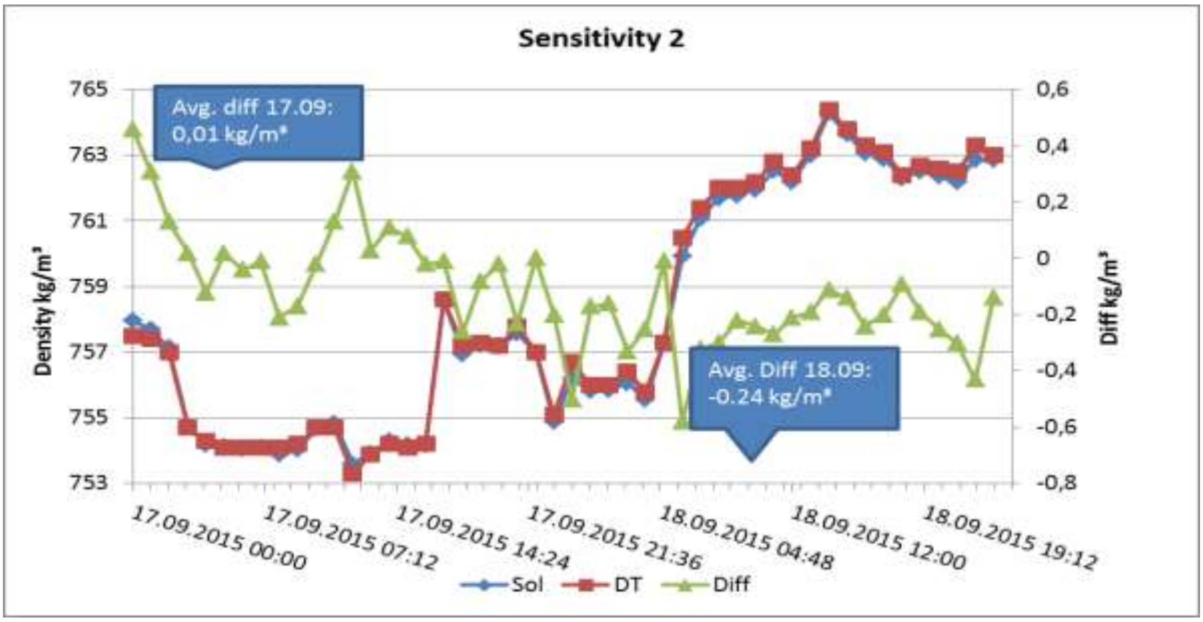


**Figure 9**

It should be noted that the figure 9 results above are recorded more than 2 months later than the previous figure 8 graph, maintaining similar results. Standard deviation of Diff is 0.20 kg/m³. The density varies from 754 to 764 kg/m³, and the DT MV's are slightly higher than corresponding Sol L2 at the higher density values.

### 3.7 DT Internal Temperature sensitivity

The DT is clamped on the process pipe, measuring the density at the prevailing process conditions (line pressure and temperature). No insulation or shield for reduction of temperature of the DT detector has been installed.

Temperature sensitivity has traditionally been a concern related to radiometric meters. During the test internal temperature inside the electronic enclosure has been recorded, and hourly averages are listed in the attached table 1. Differences in density measurements vs. internal temperature are shown in figure 10.

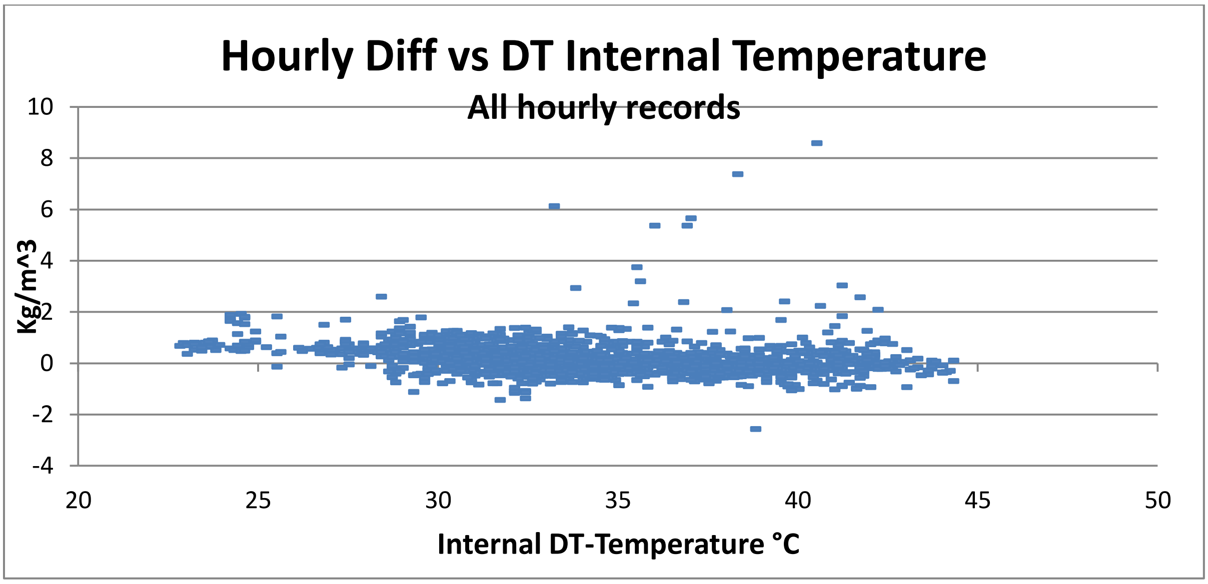


**Figure 10 Temperature sensitivity**

There is no significant effect of temperature over the range from 20 to 45 °C.

## 3.8 Density records at change of Sol line

Results from change of Sol meter (fast loop line L2 and L3) are listed in table 2.
The column "Diff from" and "Diff to" represents the average Diff at the 12 hours prior to line change (diff. from), and the first 12 hour average diff after change (Diff to).
The changes are evidently step changes.

12 hour averages are used in order to avoid short term process disturbances.

**Table 2 Solartron line change differences**

| Date | Time | Line Change | Diff. from [kg/m$^3$] | Diff. to [kg/m$^3$] | Change [kg/m$^3$] | Comments |
|---|---|---|---|---|---|---|
| 03.jun | 21:00 | L2 to L3 | -0.22 | 0.14 | 0.36 | Increased SOL density |
| 02.jul | 16:00 | L3 to L2 | 0.735 | -0.51 | -1.22 | Decreased SOL density |
| 04.aug | 09:00 | L2-L3/L3-L2 | | | | Instable process conditions, 2 changes in 6hrs |
| 02.sep | 15:00 | L2-L3 | -0.38 | -0.03 | 0.35 | Increased SOL density |
| 05.sep | 13:00 | L3-L2 | 0.36 | 0.31 | | No significant change |
| 03.okt | 07:00 | L2-L3 | 0.62 | 1.01 | 0.39 | Increased SOL density |

The results indicates that the SOL L3 density is higher the L2. Changing from line 2 to line 3 consistently shows an increase of 0.4 kg/m$^3$. It should be observed that the DT was calibrated against Line 2 density.

The result from the June 3 and July 2 changes are shown on the following graphs (fig 11 & 12).

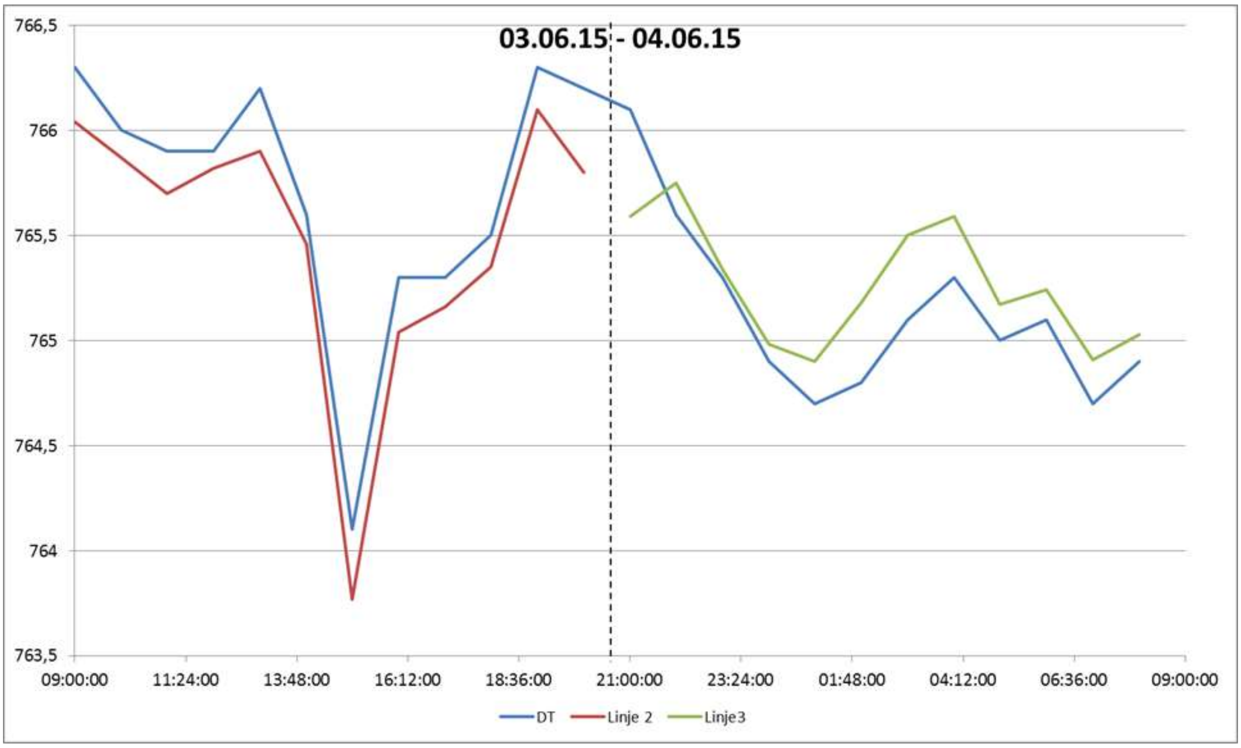


**Figure 11 03.06.15 – 04.06.15 Change of Sol line**

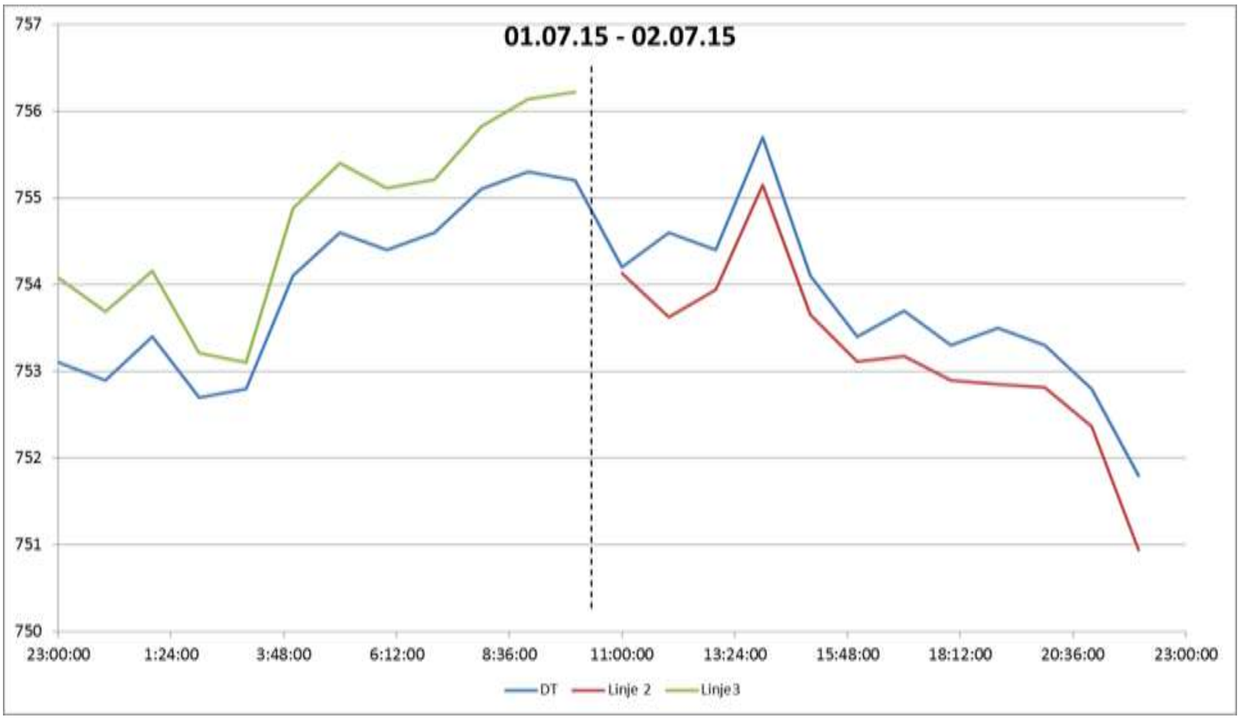


**Figure 12 01.07.15 – 02.07.15**

As the DT is showing no step-change at the Sol line changes, the observed Diff change must be caused by a difference in Solartron by-pass line layout, or by maintenance related variations affecting calibration of the Sol.

## 3.9 Flow rate dependency

Effect on Diff at variable flow-rates were not included in the initial evaluation, and not considered in section 3 above. Later completion of flow-rate data shows that the diff increases both at low and high flow-rates.

Flow rate variations before and after the maintenance shut are shown in figure 13 & 14 below:

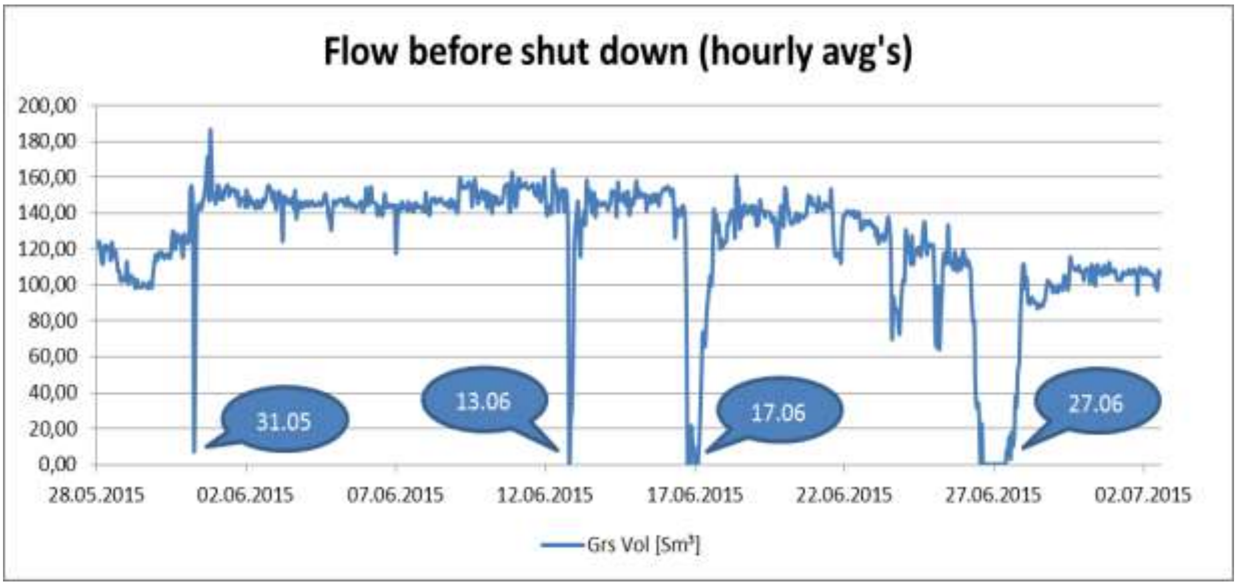


**Figure 13 Flow before shut down 03.07.15**

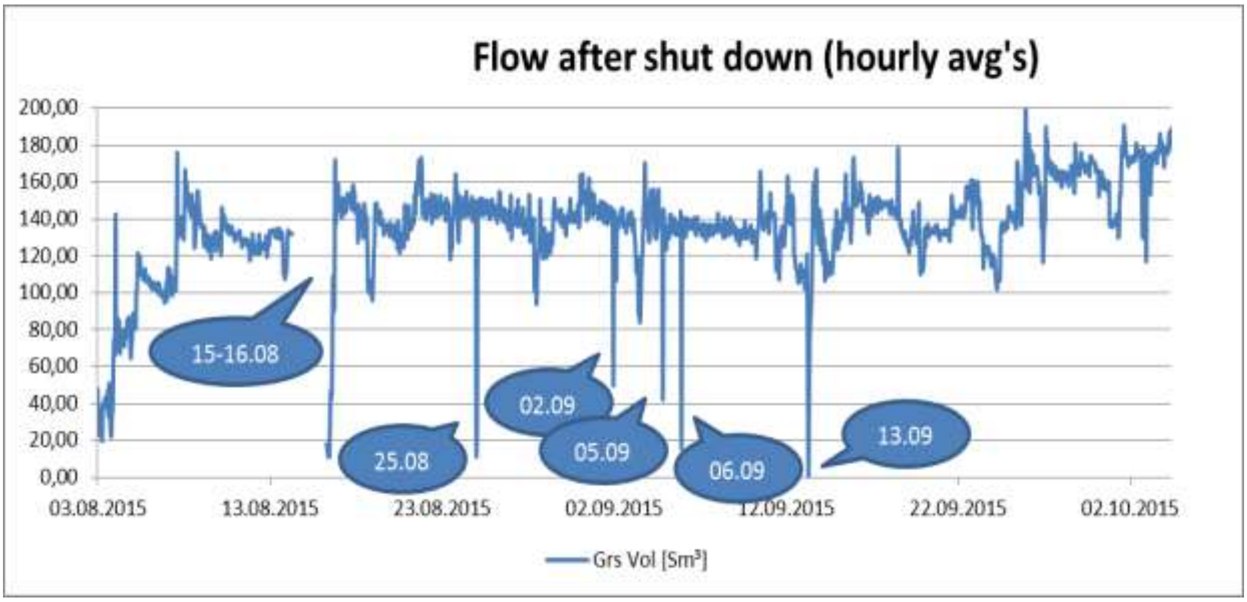


**Figure 14 Flow after shut down 03.08.15**

Figures are showing significant irregular flow disturbances of which several has led to large diff's listed in bullet points in section 3.4 & 3.5

It should be observed that hourly data on diff and flow-dependency below includes values which are listed as exclusions in the previous sections.

The figure below (15) shows the moving averages of diff at different flow rates for SOL line 2 and line 3.

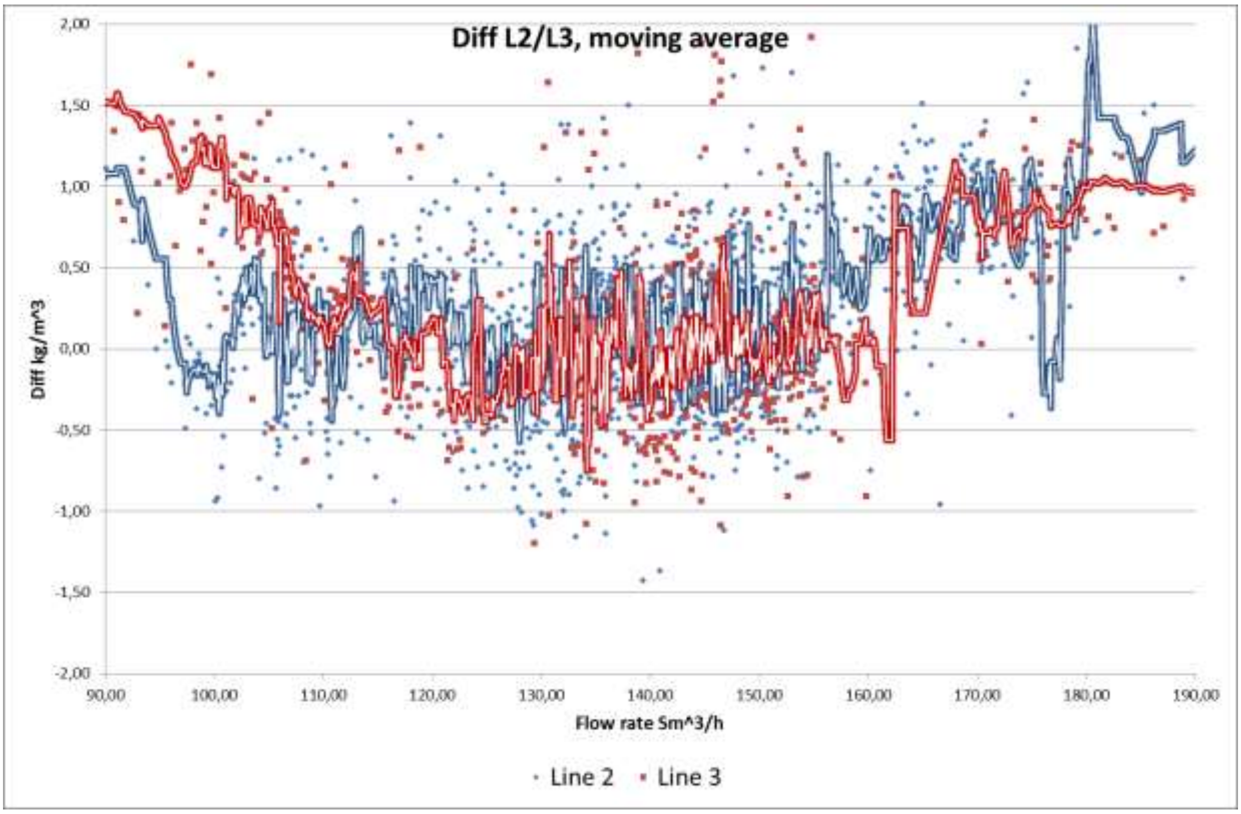


**Figure 15 Diff, moving averages**

The figure clearly describes dependency between diff and flow-rate at both high and low flow Line 3 shows overall higher diff's, in particular at low flow range.

At high flow-rates both lines are showing increased diff's

Based on the figure above the flow-rate is split into:

Low Flow range : 90-115 $Sm^3/h$

Dominant Flow range : 115-155 $Sm^3/h$

High Flow range : 155-190 $Sm^3/h$

Flow rates below 90 $Sm^3/h$ are not considered due to process disturbances.

Table 3 below shows the average diff and standard deviation of diff for the 2 Solartron lines according to this range separation.

**Table 3**

| Flow Interval [m³/h] | Line 2 | | | | |
|---|---|---|---|---|---|
| | **AVG DIFF [kg/m³]** | **STD DIFF [kg/m³]** | **Number of Hourly samples** | **Hourly Samples diff <0** | **Hourly Samples diff >=0** |
| 90-115 | 0.11 | 0.54 | 169 | 43 % | 57 % |
| 115-155 | 0.07 | 0.48 | 1068 | 46 % | 54 % |
| 155-190 | 0.72 | 0.60 | 196 | 9 % | 91 % |
| **Flow Interval [m³/h]** | **Line 3** | | | | |
| | **AVG DIFF [kg/m³]** | **STD DIFF [kg/m³]** | **Number of Hourly samples** | **Hourly Samples diff <0** | **Hourly Samples diff >=0** |
| 90-115 | 0.61 | 0.58 | 121 | 12 % | 88 % |
| 115-155 | 0.00 | 0.48 | 529 | 54 % | 46 % |
| 155-190 | 0.59 | 0.52 | 83 | 14 % | 86 % |

Averaged SOL 2/3 diff throughout the test period at dominant flow-range is 0.07 and 0.00 kg/$m^3$. At low flow line 2 shows an average diff of 0.11 kg/$m^3$ against 0.61 kg/$m^3$ from line 3.

However both lines show similar diff's at high flow rates.
Standard deviation of diff at all flow rates are approx. 0.5 kg/$m^3$.

This demonstrates stable process conditions and that the variances are caused by flow-dependency of Solartron.

# 4 Detailed results and observations

The following sections are covering "bullet" marked deviation dates in section 3.

## 4.1 31.05 to 03.06 Effect of process instability

Density records and DT internal temperature is shown in the graph below, figure 16.

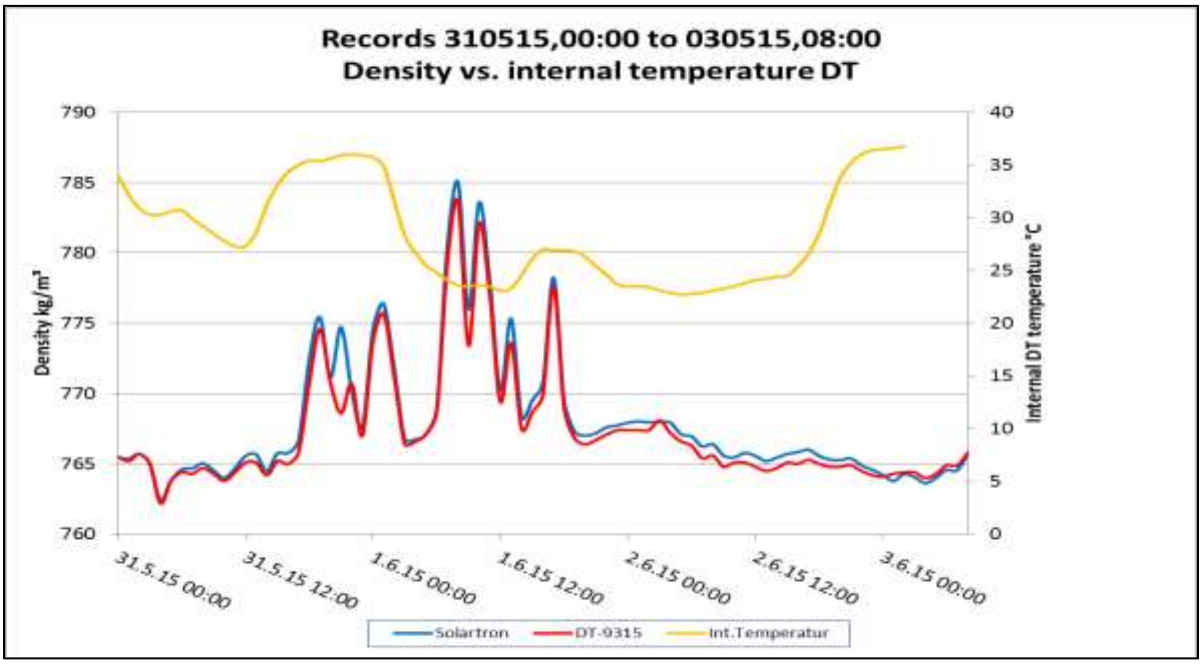


**Figure 16 31.05 to 03.06**

The graph shows no effect on density MV from DT internal temperature variations. Process instability appears from 31.05 at 15:00 to 01.06 at 19:00. Density and Diff is shown in figure 17. The staggering density peaks may be caused by water ingress or flow variations.

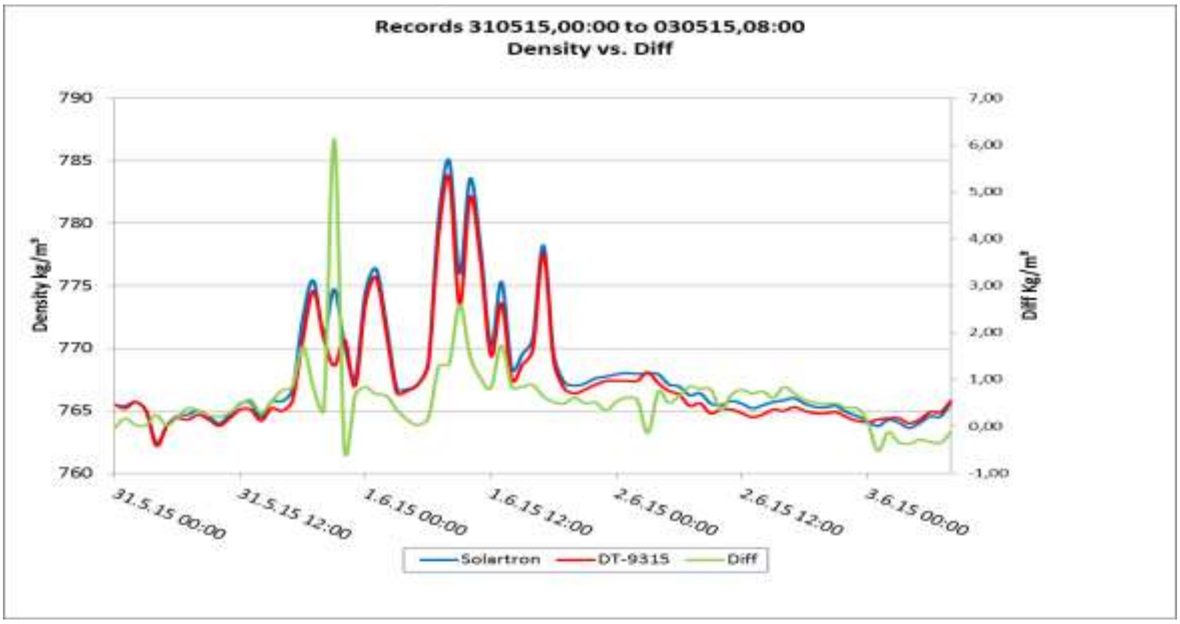


**Figure 2 31.05.15 00:00 to 03.05.15 08:00**

One hour sample time stamp 31.05 21:00 has a Diff exceeding 6 kg/m³.

This coincides with virtually no flow as shown below (Figure 18).

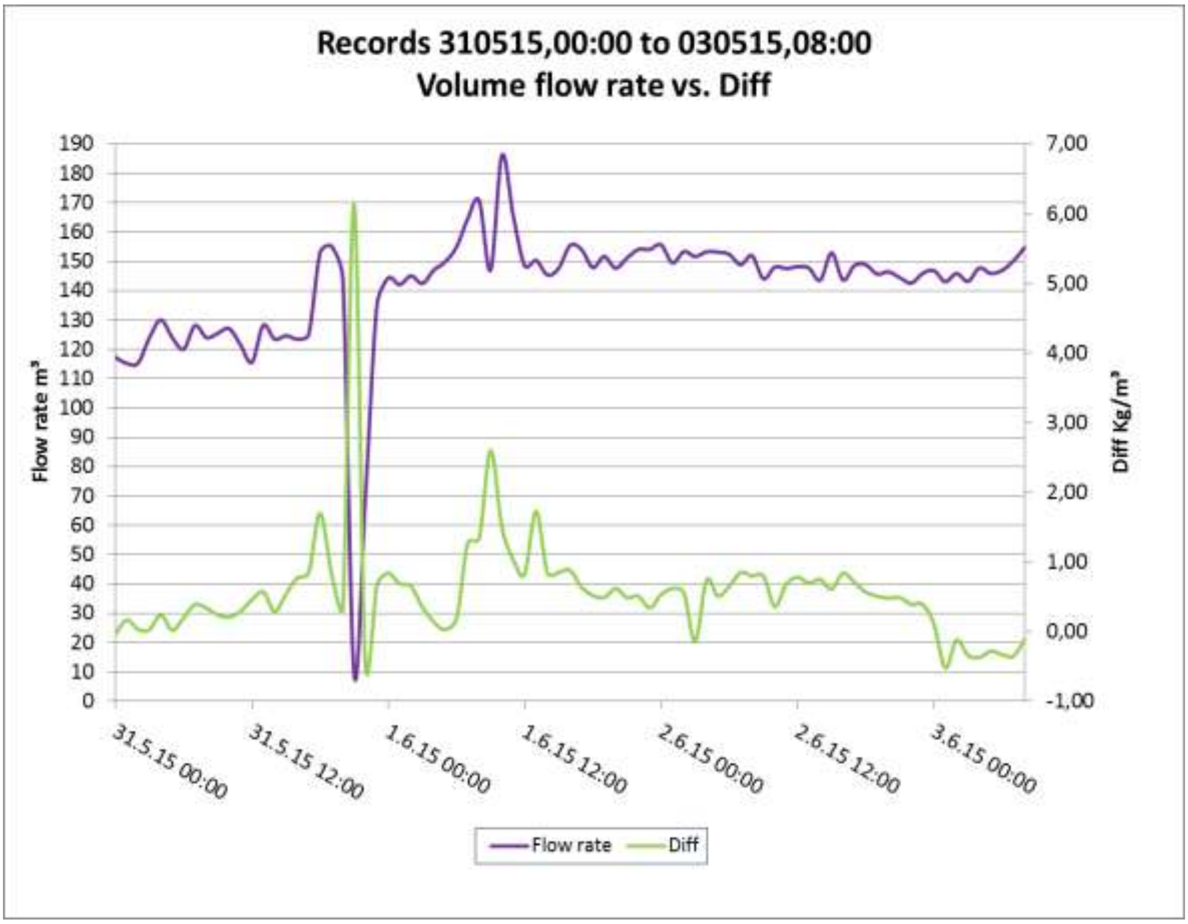


**Figure 18**

This record is excluded in the following overall correlation calculations. For the time sample in question the exclusion will reduce the standard deviation of Diff from 0.81 to 0.51 kg/m$^3$.

## 4.2 13.06 Effect of process instability

The graph below, figure 19 shows a step change, increasing the density of about 30 kg/m³.

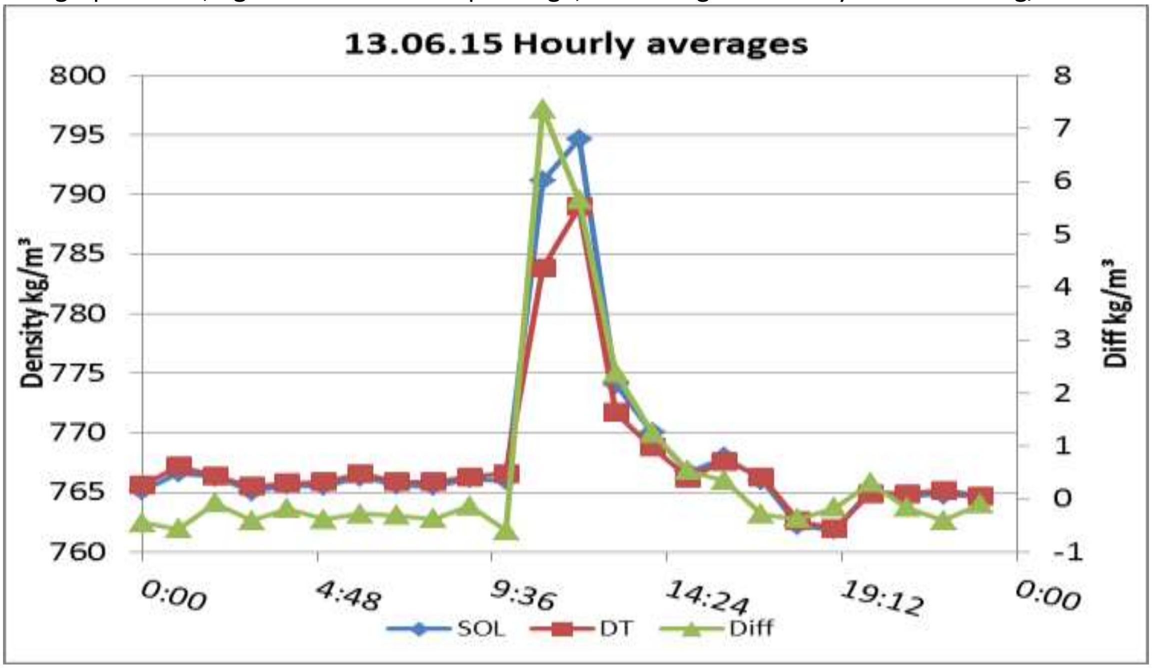


**Figure 19**

A possible reason is water ingress. The density values are calculated based on 2 minutes samples shown in figure 20. For the hour from 10-11 the BP report is listing no flow and Sol in "manual". In the following overall correlation calculations the record from 10:00 to 14:00 is excluded. For the date in question this will reduce the standard deviation of Diff from 1.97 to 0.3 kg/m$^3$.

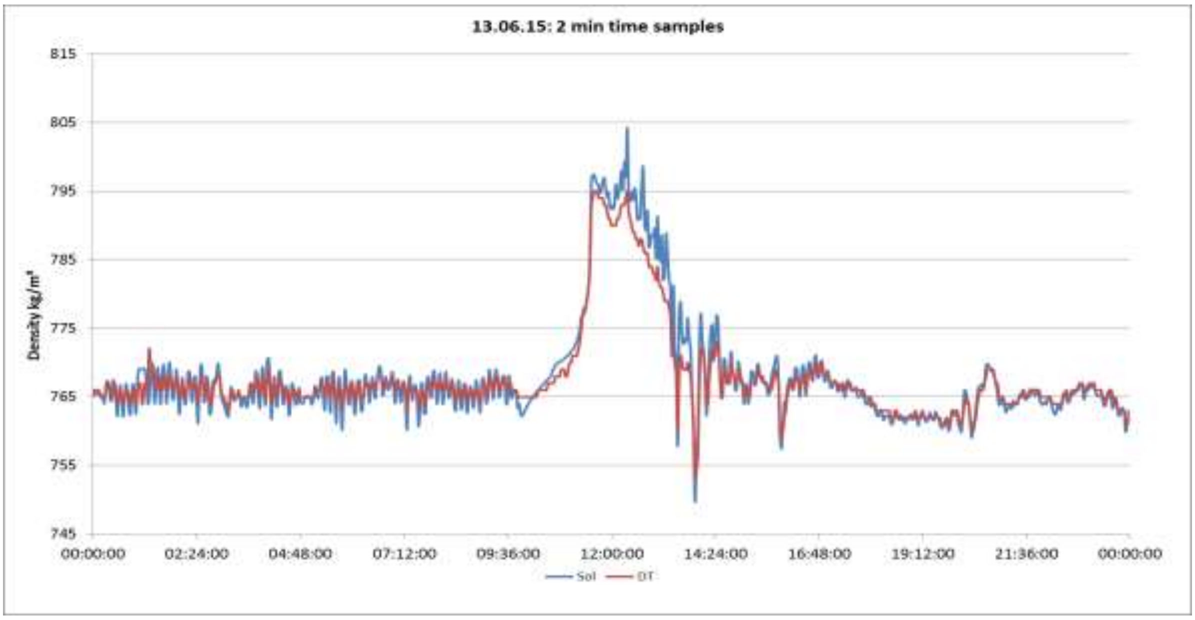


**Figure 20 2 min time samples**

It should be noted the Sol has a time lag in reaching stable conditions after the incident, compared to the DT.

## 4.3 17-18.06 Effect of process instability

The graph below (fig 21) shows a similar process disturbance as above, section 4.2. Records from June 17 are excluded due to fallout of the Sol signal on 3 occasions. Sol is over-reading the DT for the first 6 hours after the process is regaining balance, until stable conditions are established.

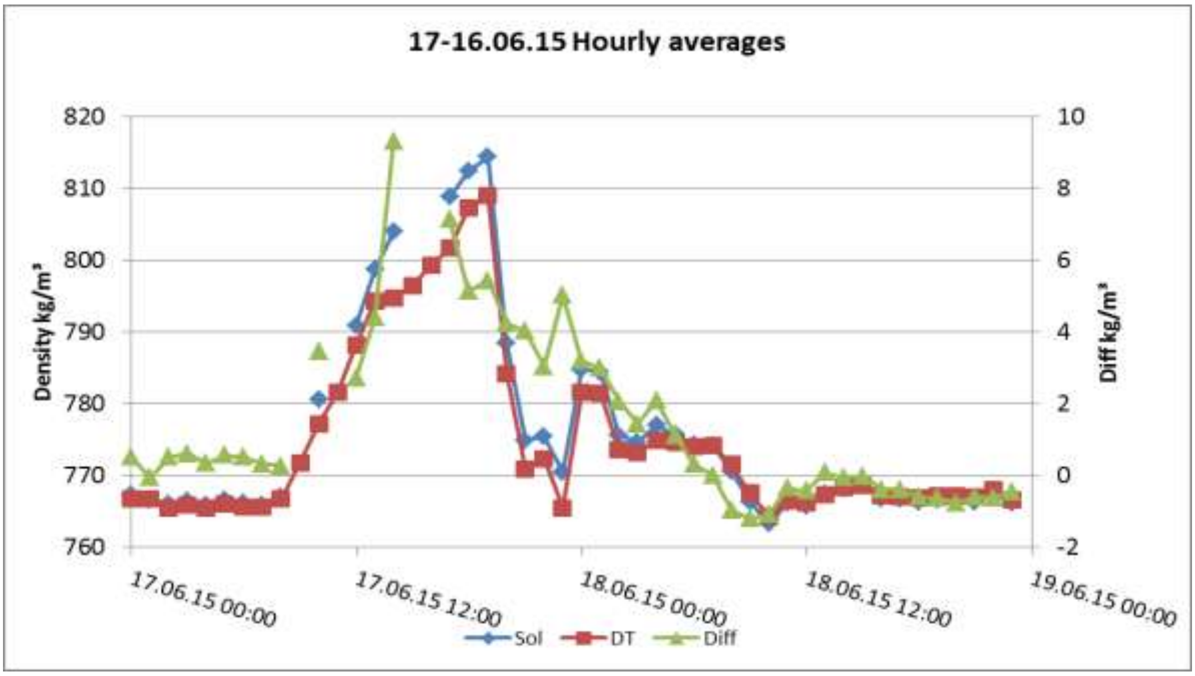


**Figure 21**

## 4.4 28.06 Results after start-up, temperature dependency

On 27.06 the Sol is shut due to ESD testing of instruments. The DT is operating, showing an average density of 805 kg/m³. After start-up at 00:00 the flow remains unstable until 13:00 (figure 22). This is documented by trend from both meters, however with significant Diff.

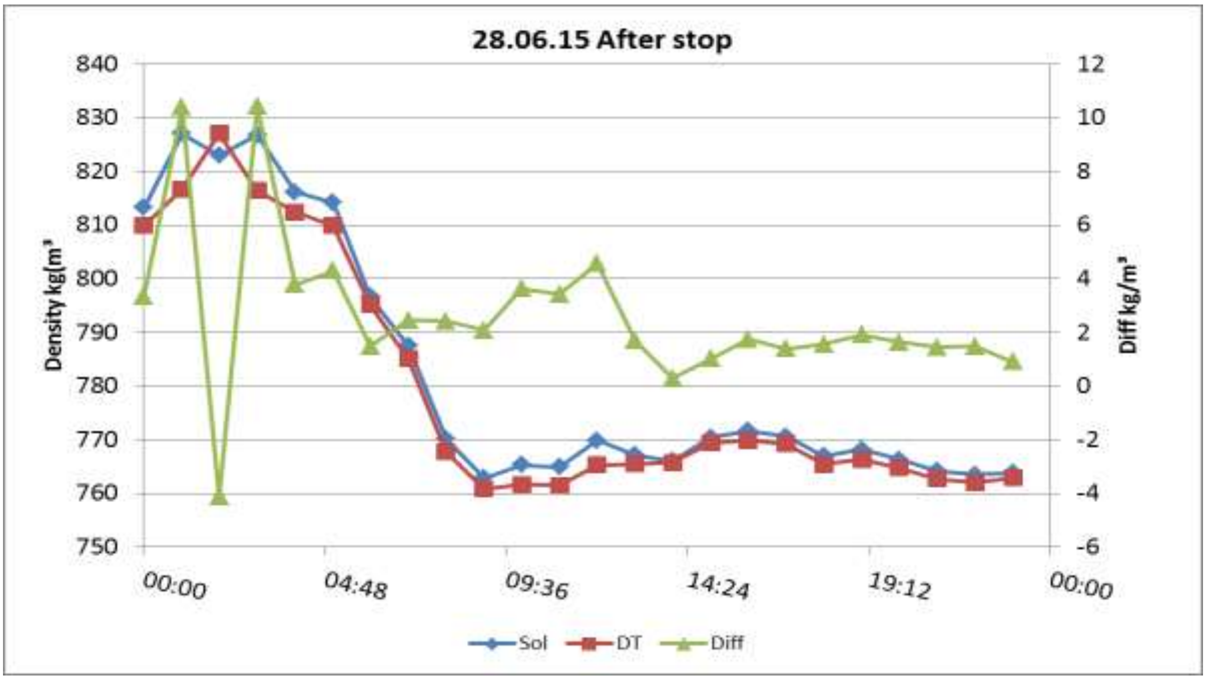


**Figure 22**

The instability is confirmed by process temperature variation, as shown below (figure 23). The graph indicates high correlation between temperature and density under process transition. There is however a delay as the MV stability of both meters seems to be established at temperature above approx. 50 °C. The results indicate that this is achieved approx. 3 hours after the temperature is measured. It should be observed that the initial process temperature is around 20 °C, indicating a large water fraction.

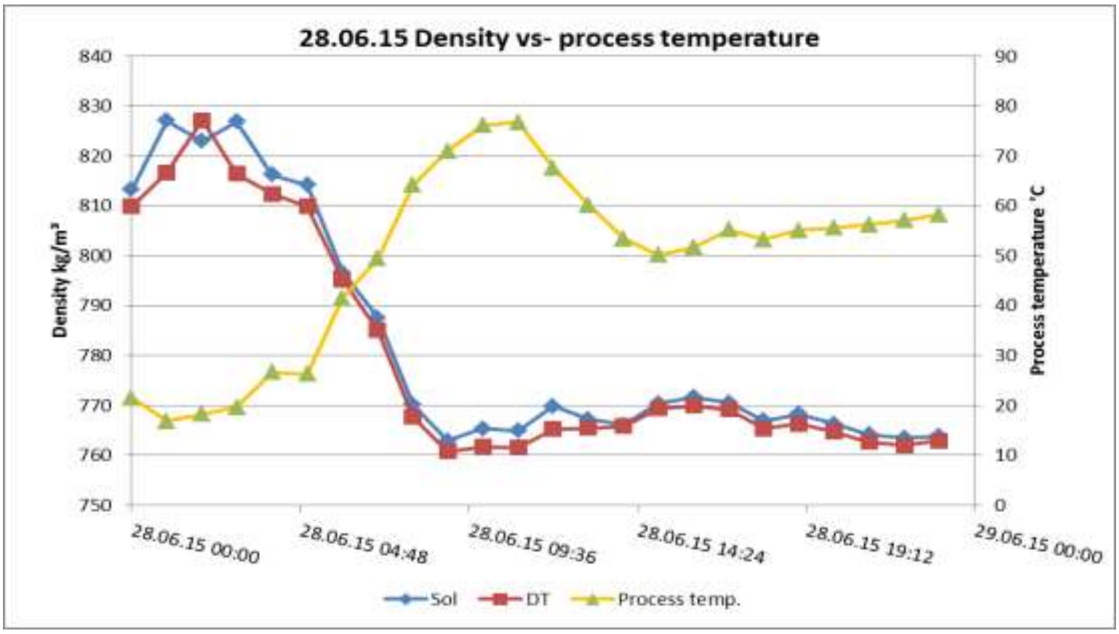


**Figure 23**

Another interesting observation in conjunction to the ESD shutdown is that it represents a Diff shift:

Diff average 19 - 26.06 : -0.06 kg/m³
Diff average 28.06 - 02.07 : 0.88 kg/m³ SOL L3
Diff shift : 0.94 kg/m³
Diff average 01 - 03.07 : -0.48 kg/m³ SOL L2

The last value is described in section 3.8 (line shift). Process conditions are stable during this period. The recorded change in Diff can only be caused by differences between SOL lines performance, see the figure below (24).

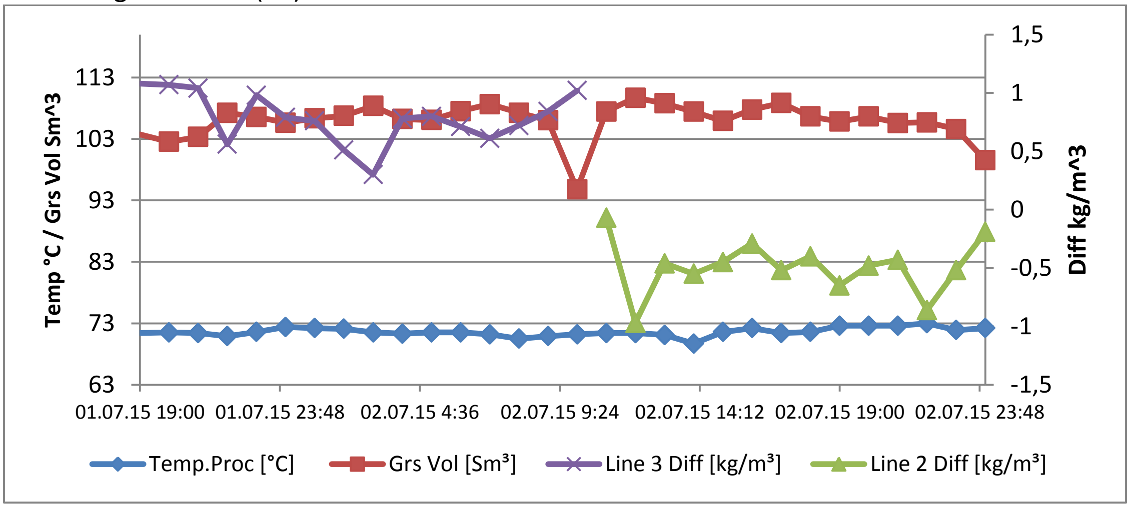


**Figure 24**

## 4.5 17.08 Deviation after start-up

The flow line is apparently closed during August 15 to 16 until 23:00. The DT shows stable density. The metering results after start-up is shown in the graph below (figure 25).

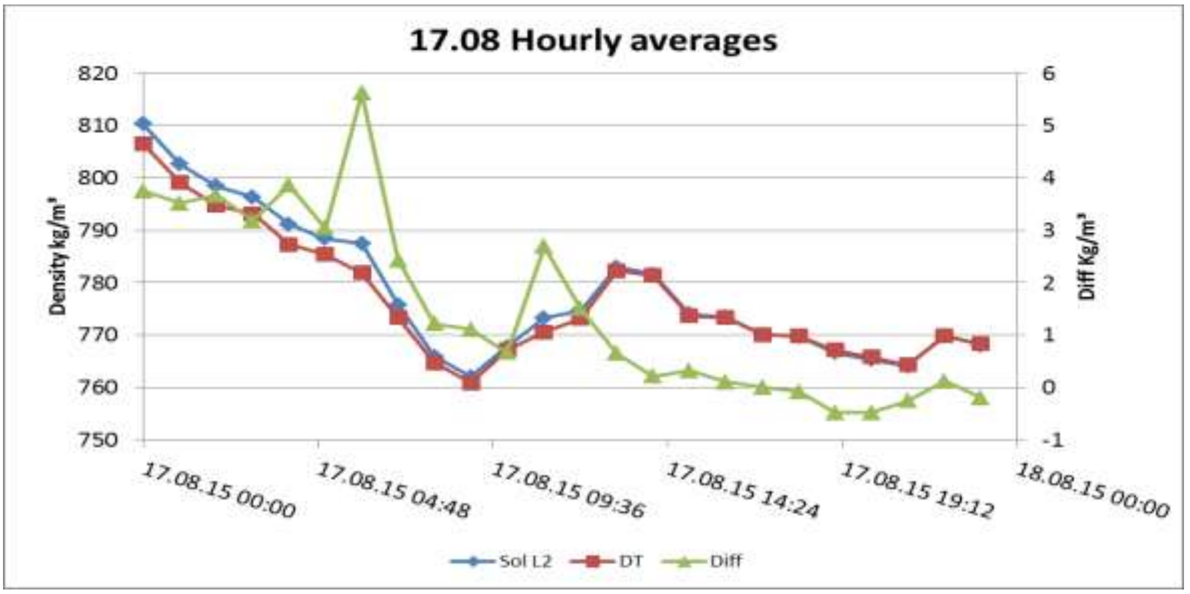


**Figure 25**

Starting with a high water fraction and low flow, the Diff is 2.8 kg/m³ for the first half of August 17 against 0.01 kg/m³ for the second half. Standard deviation is 0.34 kg/m³ for the second half against 1.76 kg/m³ for the full day. Figure 26 below show diff and flow throughout 17.08.

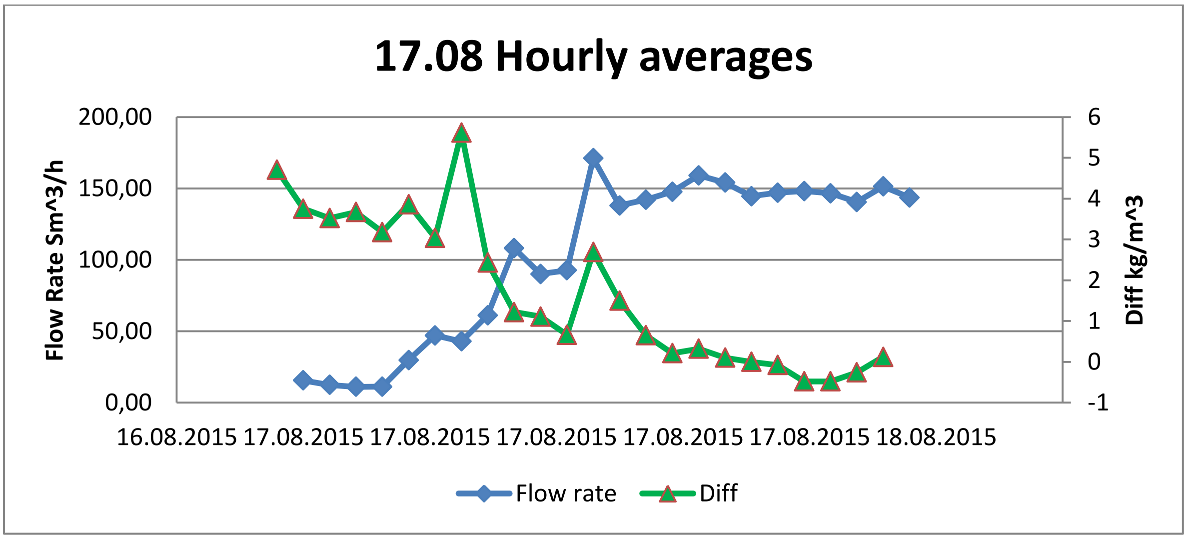


**Figure 26**

## 4.6 Step changes

Some step changes under normal process conditions are observed. This is also described in paragraph 4.4 above. For the period after the summer shut the following record are:

Diff average 23.08-06.09: 0.08 kg/m³ SOL L2 + L3
Diff average 10.09-16.09: 0.61 kg/m³ SOL L2
Diff average 17.09-23.09: 0.01 kg/m³ SOL L2 Dominant flow range
Diff average 24.09-05.10: 0.78 kg/m³ SOL L2 + L3, High flow range

The changes are shown in figure 26 below. The reasons for differences between the first 2 periods are complex. It may be noticed that the period 23.08 – 06.09 contains several process disturbances, both on flow and process temperature. Data from 04.09 are deleted due to process instability effects.

Diff deviation between the 2 later periods is compliant to the flow (fig 27) pattern described in section 3.9, with flow- rate deviations between high and dominant range of 0,72 and 0,61 kg/m³, for line 2 and 3 respectively. Compared to the difference 0,78-0,01 kg/m³ above, the increased diff during the latter part of the test is caused by increased flow rate. It is as such an over-reading of density by the SOL lines.


**Figure 27**

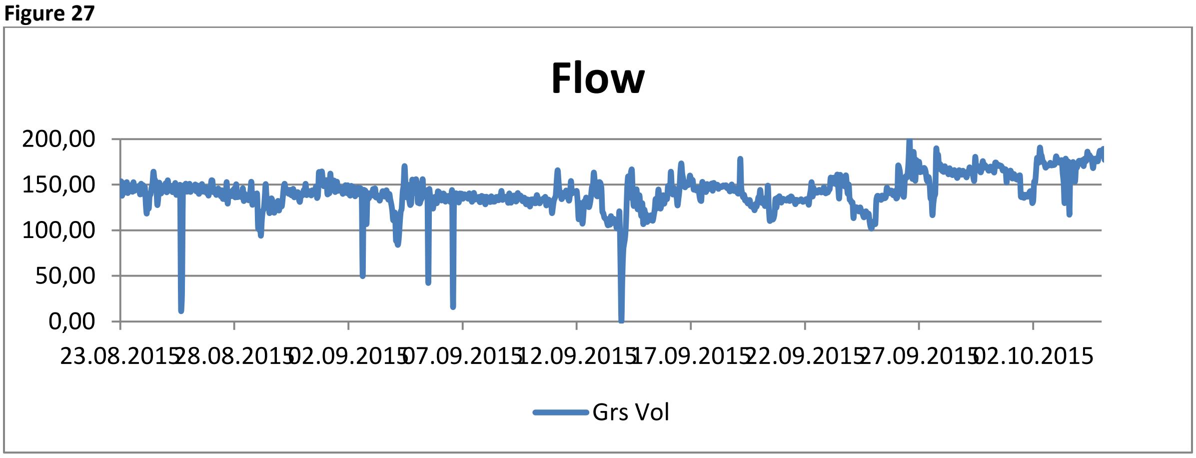


**Figure 28**

## 4.7 Overall results excluding process instabilities

Excluding records from time stamps with unstable process conditions described in section 4 and "bulleted" in graphs section 3, the overall results for the test period is:
Average daily Diff: 0.19 kg/m³ Standard deviation of daily Diff: 0.44 kg/m³

# 5. Discussion

## 5.1 Effect of water

Paragraph 4.2 above describes the changes by intrusion of water. The step change from a stable density level of 766 kg/m³, with high correlation between the 2 meters (standard deviation of diff for the preceding 6 hours = 0.15 kg/m³) is a peak diff of +30 kg/m³ ,where the DT show lowest density. According to calculations the DT MV indicates a water volume fraction of approx. 13 % in the hour with highest density, based on the assumption that the initial correlating density values are pure oil.

As water, being a heavier component than oil, it is unexpected that the DT should under-read the density caused by increased water volume fraction. The water would rather be expected to cause an over- read of the mixture density by the DT. As there is no water meter available the following assumptions are indicated.

- The SOL over- reads density in mixtures with increased water content

Intrusion of water in oil will change the rheology of the mixture, and possibly affect the Sol reading.

The Sol by-pass sampling system is collecting more water than observed by the DT measuring the process pipe flow average.

- The DT under-reads density in mixtures with water.

The DT calibration curve is based on pure oil. Single point calibration on site is conducted on a low density value (754 kg/m³). There are indications that the slope of the calibration curve should have been steeper, and that its precision is reduced with higher densities. It should be observed that the correlation between the 2 meters is high, also at high densities under stable process conditions. It should also be noted that the variances seen in line density described above may have little influence on fiscal allocation reports, as it will be handled as short term irregularities.

## 5.2 Effect of process temperature and flow-rate

Effects of temperature have only been evaluated to a limited extent. The records indicate that the Sol (by-pass line arrangement) exhibits a different response time to process temperature changes, than the DT.

The SOL meters are showing increased density during low- (SOL3) and high flow-rate conditions (SOL 2 and 3). This is resulting in increased Diff. These results are based on a significant number of hourly averages, and proved to be repeatable. Process variations may, however cover this effect of flow-rate.

## 5.3 Effect of composition

Some unexplained step changes are observed over a given time. Radiometric density meters are affected by media composition, by different mass dampening coefficient (μ) of different chemical elements. With respect to crude oil μ may to a small extent be altered by the composition of the oil, but in particular by varying water fraction and salt content. Deviation of this nature has not been focused upon in the current test. They may be compensated by laboratory analysis or online water content and salt meters.

## 5.4 Differences between SOL lines

Alteration between the 2 Sol- Lines indicates that the SOL calibration implies an uncertainty. The 2 flow-lines shows different results when changed. Line 2 to 3 change results are repeatable, whereas line 3 to 2 results varies. It should be noted that the number of changes is limited. It should also be noted that the density Diff. recorded in this test is the density of the SOL meter in operation at any time, against the DT.

# 6. Conclusions

The test has not provided a verification of density precision, as it has not been possible to carry out a calibration of the DT in situ. In this respect the Sol(s) have been used as reference meters.

The results are documenting that the DT has a high correlation to the Sol under regular process conditions. It is more reliable under process shut downs and start-ups.  During, and after process disturbances the Sol and the DT show different results, probably caused by the differences in metering principle, i.e. process pipe measurement against by-pass loop. In general the DT is less affected by process disturbances, and is showing faster recovery than the SOL.

The Test has demonstrated that the DT represents an efficient measure of density changes, with respect to precision, sensitivity and repeatability. It has not been calibrated during the test period. The DT provides an excellent method for validation and verification of the existing Sol and possibly other by-pass installed meters

<u>The benefit of using the DT in export oil process application is :</u>

It is a low cost installation, clamped to the pipe with no by-pass loop requirements.
It measures at the prevailing temperature and pressure.
It measures over a large segment of the process fluid.
It is a highly reliable instrument without requirement of frequent attention and recalibration

<u>The challenge of using the DT in fiscal density metering is:</u>

Development of a traceable density calibration process and procedure in situ.

Alternative solutions may be
- Establishing a reliable sampling and laboratory test procedure
- Establishing means of filling the DT pipe segment with known density oil(s).

## 6.1 Further evaluation

It would be of interest to continue this evaluation with focus on documentation of correlation with oils with differences in chemical composition, water ingress and salt content. It may also be of interest to expand the study on SOL line precision at different temperatures and flow-rates.

Stavanger 24.09.2017

Erik Sveinsvoll. AkerBP
Per V. Wærnes Sensor Technology

# 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.