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Field performance evaluation of a non-radioactive MPFM in challenging conditions in the Middle East

Hugo Harstad (CTO)[1]
Hamza Fahd Matallah (Senior Field Engineer)[1]
Audun Aspelund (Expert Back Office)[1]
Ahcene Nasri (Senior Field Engineer)[1]
Emad Safar (Senior Engineer)[2]
Ahmed Aburghiba (Specialist WS)[2]
Fatma Al Hazeem (WS Engineer)[2]
Mouzah Al Khatrash (WS Engineer)[2]
Bohlool Asgar Ali (MPFM Global Manager)[3]
Fateh Samai (Country Manager)[3]
Antranik Khokazian (Field Manager)[3]

[1]ABBON AS, Norway
[2]Kuwait Oil Company (KOC), Kuwait
[3]SGS Gulf Ltd., Kuwait

Abstract

Production testing using mobile test separators and multiphase flow meters (MPFM) are widely used in KOC, Kuwait. The utilization of multiphase flow meter technology for monitoring well streams can be a supplement to, or in some cases replacement for traditional testing methods, such as test separators. MPFM allows for increase of the measurement frequency or even continuous monitoring, compared to traditional testing methods. The ABBON 3PM non-radioactive multiphase meter provides additional benefits compared to other multiphase meters, as it does not use any radioactive sensors, making it ideal for well surveillance, mobile- and fixed production well testing (see ref. 1).

As part of KOC's strategy to introduce and evaluate new oil and gas production measurement technologies, the ABBON 3PM meter was tested to evaluate its suitability.

This paper describes the field trial test of the ABBON 3PM under different GOR/GVF conditions of dry and wet wells. In addition, the tested wells contained different amounts of H_2S and water salinity was on the higher side. The meter performance was compared to a mobile test separator designed to accommodate relevant gas and liquid flow rates, and water cut. This paper summarizes the results, field experiences and conclusions of the test.

1. Introduction

Multiphase flow testing, or the ability to measure multiphase flow accurately without requiring separation, has been the goal of a number of metering companies and operators for several years (see refs. 2, 3 & 4). KOC has experience with a number of multiphase flow meter technologies on both permanent and mobile applications, however previous KOC experiences with multiphase flow meters include issues with frequent re-calibration, mechanical breakdown, and "black box" flow models.

Given the recent improvements in MPFM technology and the potential gains with the use of the Abbon 3PM non-radioactive meter in terms of safety and operation, KOC has conducted a field trial test on Abbon 3PM multiphase flow meter to assess the performance and suitability.

The trial was originally planned for 3 well tests with a conventional mobile test separator for reference measurement. The test campaign started on April 17th by first running 3 wells, finishing on April 19th. The testing resumed on May 10th with 3 new wells, finishing on May 15th. The sequence was as follows (see also Table 2):

- Well 1, April 17th 2017, one single flow period
- Well 2, April 18th 2017, three flow periods with 3 choke settings
- Well 3, April 19th 2017, one single flow period
- Well 4, May 10th 2017, one single flow period
- Well 5, May 11th 2017, four flow periods with 4 choke settings
- Well 6, May 15th 2017, two flow periods with 2 choke settings

The KOC evaluation was done based on the last 3 wells listed above.

The span of flow rates and fractions measured by ABBON 3PM were as follows:

- Liquid flow rate: 2,470 – 4768 STB/D
- Gas Flow rate: 0.21 – 2.335 MMscf/D
- Water cut: 0 – 63%
- Gas Volume Fraction: 44 – 83%

2. Background

The significant needs for production measurements in brownfields and new oil field developments for increased oil recovery, monitoring and production planning were the principle drivers for initiating the KOC field trial. In order to make wise decisions, understanding the various aspects of the Abbon 3PM technology was crucial for KOC. Furthermore, when additional compliance testing is required, there also exists another potential application for the Abbon 3PM technology, namely mobile well testing. It is perhaps in this arena that the Abbon 3PM flow meter will be most quickly and readily applied providing KOC the most immediate benefits. There are certain jobs in KOC which cannot be done without test separator such as cleaning, exploration wells, well test with phase samples collection, heavy oil and low flow rate wells. However, providing alternative test methods to the traditional test separators may mean diversity in flow measurement methods to extend the field testing envelope beyond the limitation of one single method. The need for gas/liquid- and oil/water separation are required for accurate measurements when using a test separator, but are not necessary when using a multiphase flow meter. In addition, a multiphase flow meter can handle high pressures and high flowrates. The Abbon multiphase meter also reduces HSE exposure, compared to other meters, by eliminating the need of radioactive sources.

Figure 1 ABBON 3PM multiphase meter

3. Abbon 3PM Operating Principle

The ABBON 3PM multiphase meter is a patented, non-radioactive, in-line multiphase meter measuring individual volumetric flow rates of oil, water and gas from a well or in a pipeline, e.g. connected to a manifold. The meter uses the patented TWINFLOW™ TECHNOLOGY.

The meter utilizes a combination of momentum flux measurement by measuring the differential pressure (DP) over a physical constraint ("Venturi-effect") and electromagnetic impedance measurements between electrodes placed in connection with the constraint. In addition, cross correlation of the time varying impedance measurements is used to facilitate flow velocity.

The ABBON 3PM multiphase flow meter consists of the following parts:

- Compact metering unit including impedance sensors and DP, P and T measurements
- Ex-ia approved (intrinsically safe) sensor electronics, mounted on the metering section
- ABBON Flow Computer (AFC-3PM) in a 19" rack enclosure for safe area installation with embedded flowrate calculation software.
- Client computer with ABBON Client Software (ACS-3PM) as user interface.

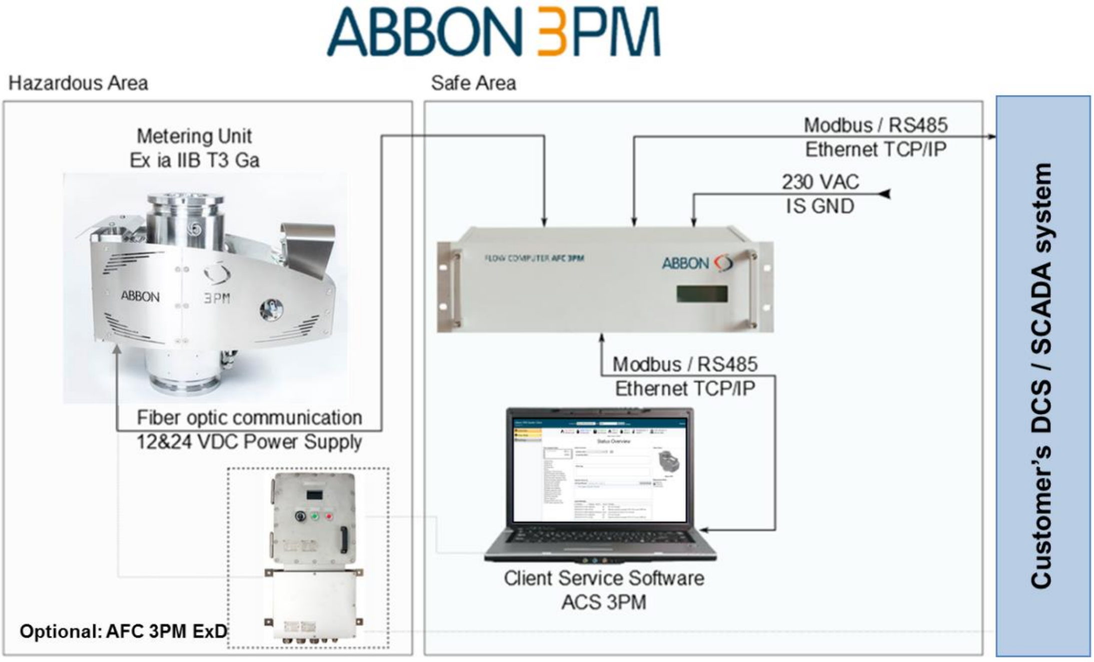

Figure 2 General System Description Diagram for ABBON 3PM.

3.1 ABBON 3PM Key features

- Compact design
- No radioactive sources
- No upstream or downstream flow conditioning is required
- Continuous measurement of the flow rates and high time resolution signals
- All calibrations are carried out at the factory prior to shipment to simplify field operations
- Field specific fluid parameters are entered into the flow computer before measurement

The meter has been extensively tested and qualified with blind testing and performance testing (Ref 1).

3.2 Overview of the Principle of Operation

The meter contains two parallel flow channels where the differential pressure- and electrical impedance measurements take place. The flow is split into two identical parts by a symmetrically shaped divider on the inlet of the meter, in order to ensure equal flow in the two channels. There is one electromagnetic impedance measurement system in each channel, and the differential pressure is measured between a location at the inlet and a location inside one of the flow channels. The electromagnetic impedance is measured between electrode-pairs integrated and flush mounted in the pipe wall inside the channels. There are two of these electrode pairs, separated in the axial direction, in each channel. The design provides two time-varying impedance signals, similar in shape, but one displaced in time relative to the other. By cross-correlating these two signals the time delay is found, and hence the velocity of the disturbance creating the signals is determined. The flow rates of oil, water and gas are calculated based on the impedance measurements obtained by the electrodes in combination with the measurement of the differential pressure across the body.

The overall schematic illustration of the calculation model is shown in **Figure 3** below.

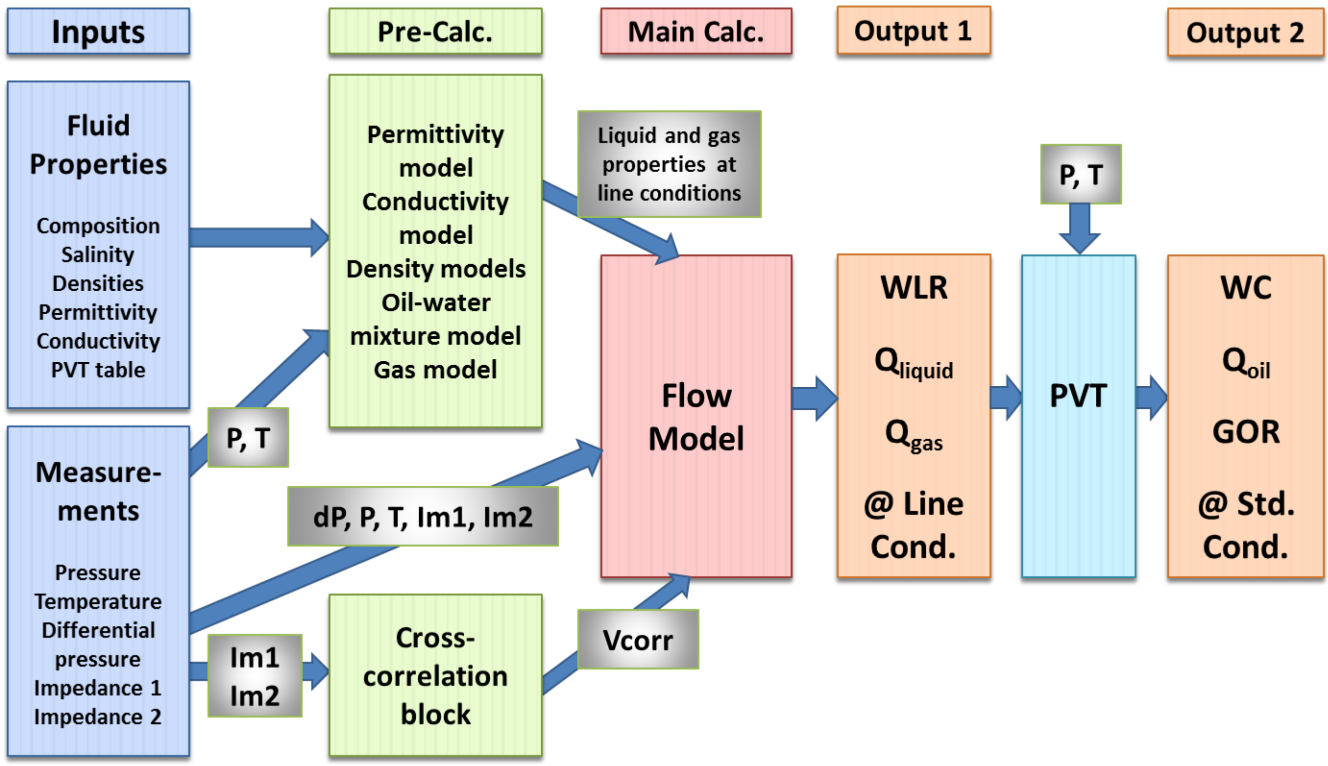

Figure 3 Schematic block diagram of the ABBON 3PM flow model. The impedance inputs are capacitance in case of oil-continuous flow and conductance in case of water-continuous flow.

The ABBON 3PM measures the mixture density indirectly through the momentum flux equation, without using a gamma densitometer. The DP and the flow velocity are used as inputs to this calculation. The pressure and temperature are assisting measurements used for correcting the fluid parameters at the sensor location.

The water conductivity, the dielectric constant of the oil (relative permittivity) and the densities of oil, water and gas are input parameters to the flow rate model. These are entered into the flow computer by the operator or service personnel and they are routinely set during commissioning.

3.3 Functional description of the sensors

A functional description of the individual parts of the ABBON 3PM is given in this section.

Capacitive Impedance

In the oil-continuous state of the liquid mixture, the capacitive impedance is measured between two electrodes covering the cross section of the measurement channel. The design of the ABBON 3PM measurement channel ensures a maximum sensitivity and accuracy, minimizing stray capacitances and effects of non-homogeneous flow regimes. The electrode material is in compliance with the client's requirement for wetted parts. The capacitance is converted to relative permittivity (dielectric constant) of the fluid mixture, which is a function of the physical properties of the content of the measurement channel. In the next step the permittivity is one of the input parameters to the flow rate algorithm. The relation between measured capacitance and the dielectric constants of reference fluids is established during static calibration at the factory, prior to FAT and shipment of the meter.

The permittivity measured by the ABBON 3PM will vary with varying percentages of oil, water and gas. Increasing water fraction at a constant GOR will increase the dielectric constant, while increasing the gas fraction at a constant WLR will decrease the effective fluid mixture dielectric constant. The ABBON field engineer measures the dielectric constant of a pure oil sample from the relevant well under test.

Resistive Impedance

In the water-continuous state of the liquid phase, the conductance of the mixture is measured by a system of electrodes. Electric current is injected into the conductive flow and is split in two equal parts, axially in the flow channel. The current passes two ring electrodes that measure the voltage drop along the path. Since the current entering the fluid is also measured, the conductance is given by Ohm's law. The conductance is converted to conductivity and, similarly to the effective fluid mixture dielectric constant mentioned above, the conductivity is also an input parameter to the flow rate algorithm.

The fluid mixture conductivity will decrease with increasing amounts of oil and gas. The sensor does not distinguish between oil and gas, but in combination with the density calculation, the phase fractions are determined. The ABBON field engineer measures the conductivity of a pure water sample from the relevant well under test.

Momentum Flux

The differential pressure is measured between a position upstream of the TWINFLOW^{TM} measurement section and a position inside the section. The inlet and outlet angles of the measurement section and the cross section area of the channel are designed to resemble the features of a classical Venturi meter. The same equation therefore applies, namely that the product of the mass- and volume flow rate is proportional to the measured differential pressure.

In a simplified manner one can say that the DP meter is used for determining the mass density of the fluid mixture, based on dP and velocity inputs.

Cross-Correlation

The capacitance and conductance impedance measurements are recorded with a high frequency compared to the time variations of the fluid flow. Cross-correlation between an upstream and a downstream signal is applied to determine the time shift and hence the velocity of the flow. The upstream and downstream impedance sensors are located inside the measurement channel. The impedance sensors are sensitive to disturbances in the flow, such as gas bubbles and water droplets, and as long as such disturbances detected by the upstream sensor are repeated on the downstream senor, the time shift and velocity can be determined.

3.4 Meter inputs

The Abbon 3PM needs a set of fluid input parameters in order to work optimally. These are:

- Oil density
- Water density
- Gas density
- Oil permittivity
- Water conductivity (related to water salinity)

For conversion from line condition to standard condition there are two options:

- By using oil, water and gas densities to generate a black oil model
- By using available PVT data

In case oil- and gas compositions are available, the oil- and gas densities will be calculated by a PVT software package.

4. Field Test Setup

Three wells were initially considered as candidates for the qualification test; however during the campaign three additional wells were tested. A normal test day would require one hour for rigging up and configuration, 6 hours of well testing and data logging, and 30 minutes for rigging down.

All testing was done flowing from the wellhead; through a choke, and the ABBON 3PM in series with the test separator, allowing for direct, real time comparison.

The multiphase flow meter was installed immediately upstream of the SGS test separator; exposing the meter to an undisturbed flow stream benchmarked with the SGS mobile test unit. The test separator utilizes turbine and coriolis meters for liquid flow rate determination and orifice plate meter for gas flow rate measurement. After a well was switched onto the test line, it flowed through to the multiphase meter and then through the test separator that acted as the reference instrument in the trial.

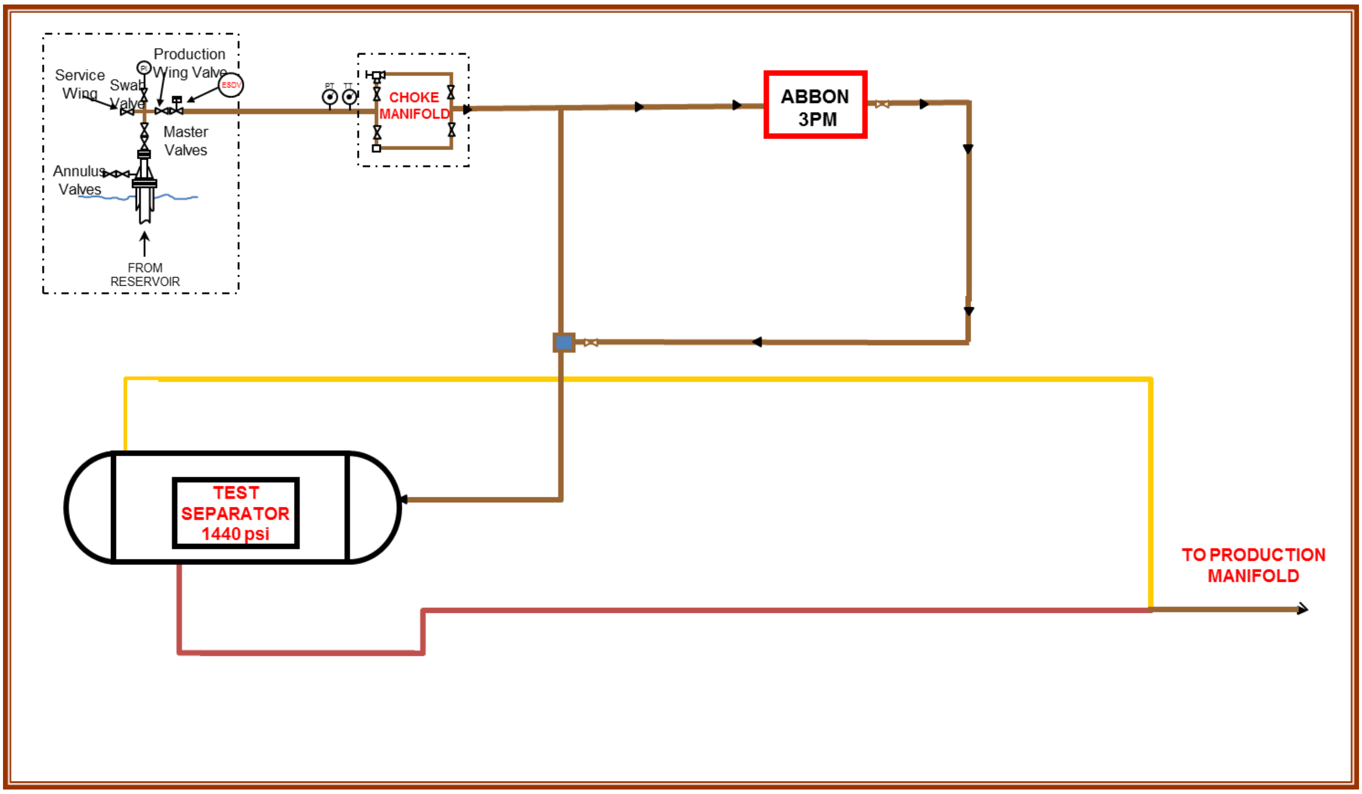

Figure 4 Multiphase meter and well test layout

4.1 Meter Installation

The ABBON 3PM multiphase meter was installed in a skid and used as a mobile metering unit (Figure 5). It can easily be transported and be installed in a pipeline, on a test header or on a manifold. The metering skid can be installed either by using a conventional crane or a fork lift. The skid has ANSI 4", 2500 RTJ flange end connections, located 1300 mm apart from each other, aligned 180º and in a 435 mm height from the ground. End flanges should be connected in accordance with ASME PCC-1.

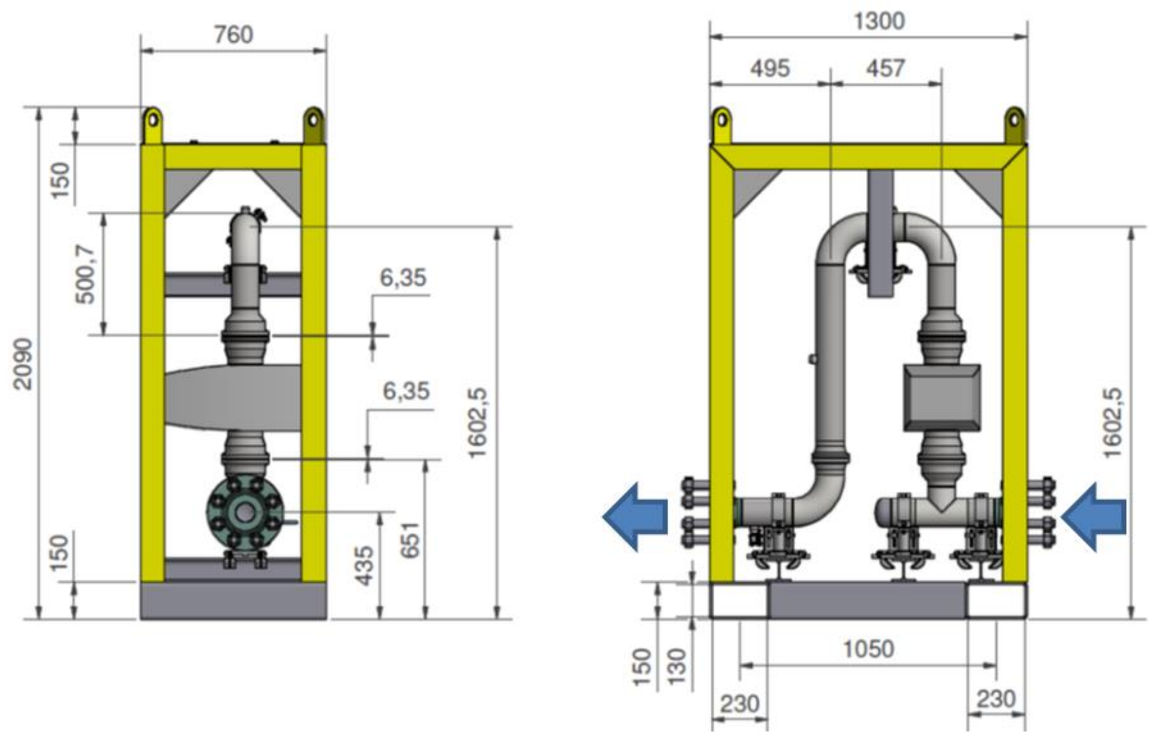

Figure 5 Illustration of the ABBON 3PM in the metering skid.

The meter can be installed upstream or downstream of the choke, considering the flowing conditions and the pressure drop across the choke. The meter shall be installed for vertical upward flow, downstream of a blinded T-bend. Figure 5 and Figure 6 show how the ABBON 3PM is installed vertically upward, with a blinded T-bend.

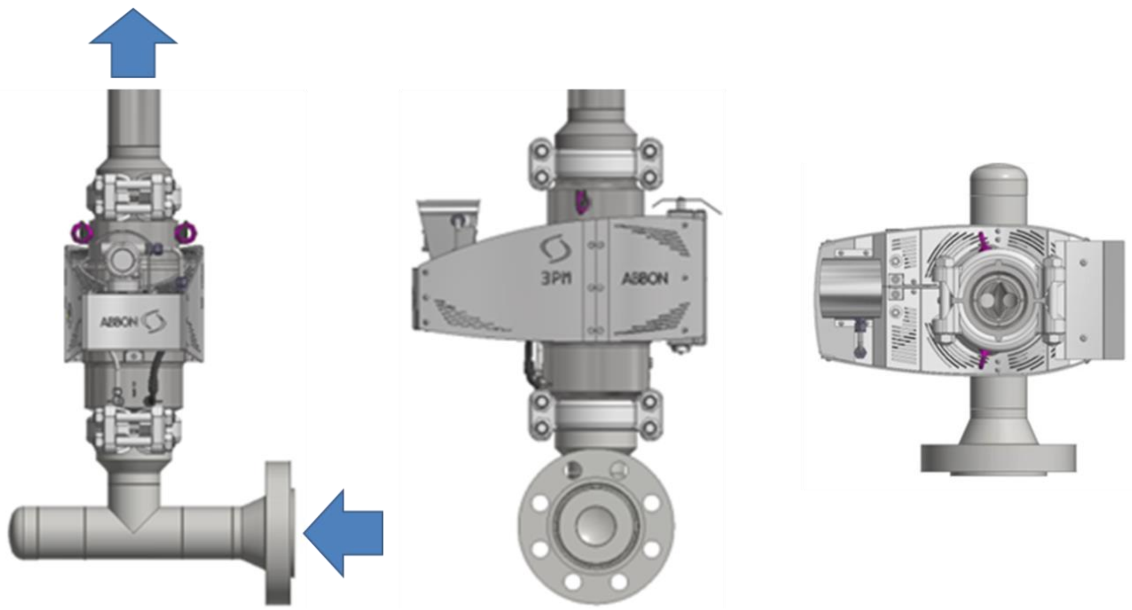

Figure 6 ABBON 3PM in vertical upward installation

Figure 7 Abbon skid in mobile field application. Left: Connected to a wellhead and a mobile test separator, Right: Compact skid with Abbon's field supervisor

4.2 Reference system (SGS test separator)

The SGS test separator is a horizontal vessel utilizing automatic Fisher Level Controller, turbine- and coriolis meters for liquid flow rates, orifice plate for gas measurement and EESiFLO EASZ-1 meter (combined with manual shakeouts) for water cut determination, see Figure 8 below.

Figure 8 SGS mobile test separator used as a reference measurement system.

4.3 Meter sizing analysis

Figure 9 below shows the six wells' flow rates, including different choke settings, based on the test results achieved, plotted vs. the ABBON 3PM operating envelope for a 3 inch meter. It should be noted that in some of the cases the DP is very close to the lower DP limit for the meter. The flow rates are in actual (line) conditions.

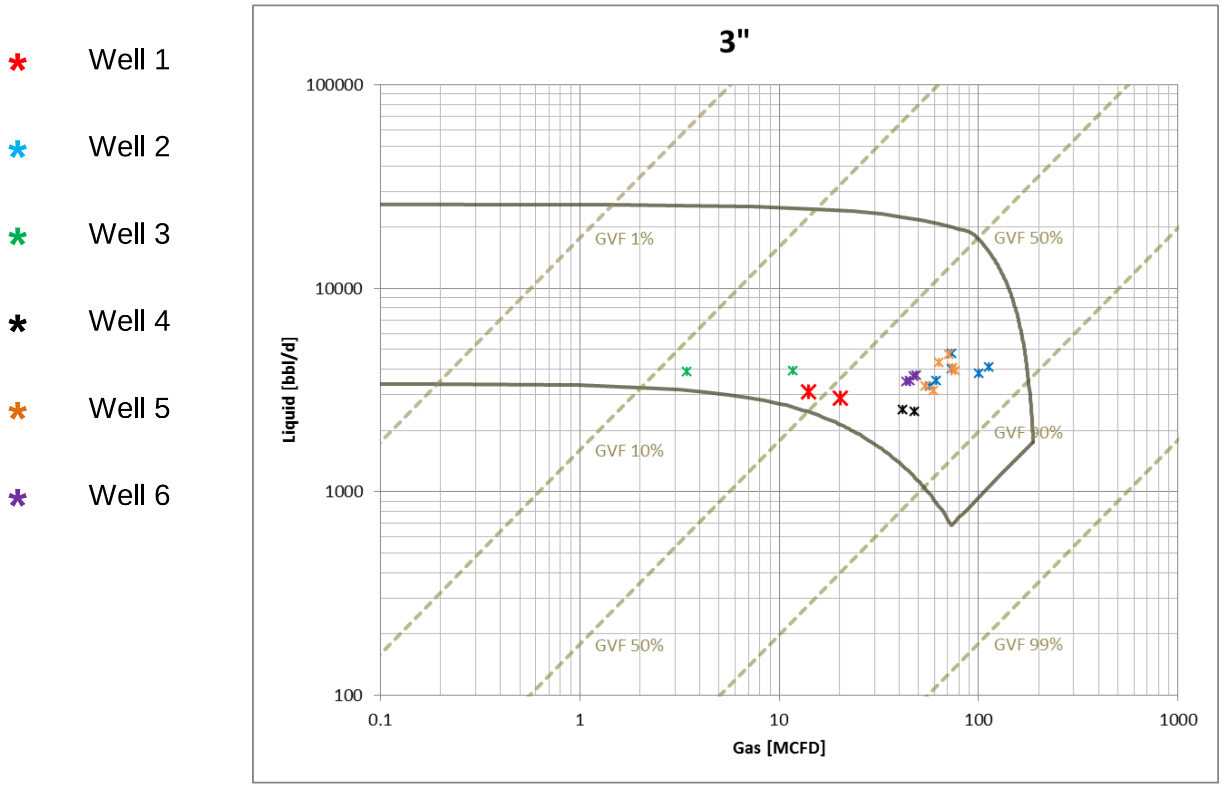

Figure 9 Meter working envelope versus the six KOC wells

5. Meter configuration and set-up

The Abbon multiphase flow meter was set up under the supervision of a KOC representative. Atmospheric liquid samples were taken by Abbon field engineer from each well to be tested for fluid properties during the operation. Oil density, oil permittivity, water density and water conductivity were measured by the Abbon field engineer to set the configuration parameters of the Abbon 3PM. Abbon brought a field kit for measuring the necessary input quantities, see Figure 10 below.

Figure 10 ABBON field kit for measuring fluid parameters (on the ground).

5.1 Description of the preparation and set-up process

Liquid sampling

In order to perform the measurement for the required input parameters and meter set-up, the liquid sample was taken from the ABBON skid sampling point in a standard oil field ASTM D91/D96 tubes and centrifuged for oil and water separation.

Figure 11 Left: L-K Industries Melton Oil Centrifuge for field applications, right: a centrifuged oil-water sample from KOC well in a ASTM D91/D96 tube.

Water cleaning

The water extracted from the ASTM D91/D96 tubes following centrifugation had to be cleaned prior to conductivity measurements. For cleaning the water samples from the flow line, Abbon utilizes a two-stage filtration procedure, where the filtration is conducted under low vacuum created by the laboratory pump, as illustrated in Figure 12 below.

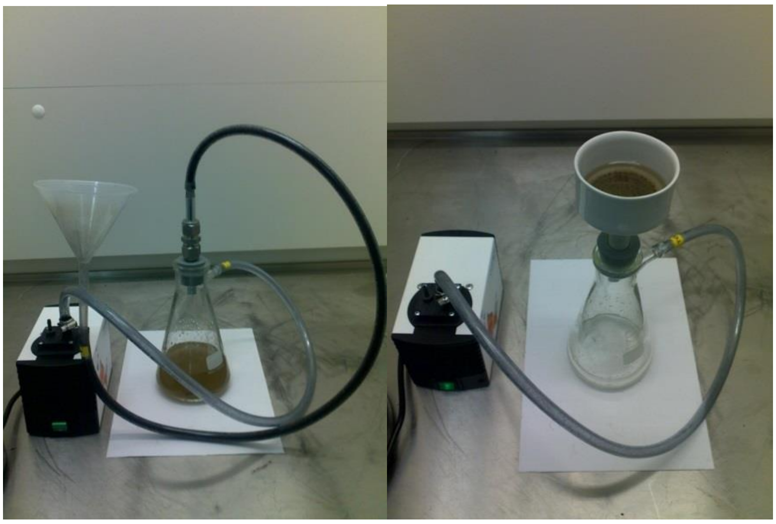

Figure 12 Left: water filtrate after the first filtration with activated charcoal. Right: water filtrate after the second filtration stage to remove remaining activated charcoal particles.

Water conductivity measurement

The water conductivity is measured using a Cond 3310, which is a professional conductivity meter for mobile applications, including data logger and USB-interface.

Figure 13 Water conductivity instrument “Cond 3310”

Oil permittivity measurement

The oil permittivity is measured using an Alpha DCM-470, which is a professional Dielectric Constant meter for mobile applications, requiring only 10 ml of oil to perform the measurement. This oil sample was taken from the ASTM D91/D96 tube after centrifugation.

Figure 14 Oil permittivity instrument “Alpha DCM-470”

Oil & water mass density measurements

Mass density measurement of oil and water is performed using a standard oil field instrument, the Anton Paar DMA 35 Handheld densitometer.

Figure 15 Illustration of the density measurement by Anton Paar DMA 35 Handheld densitometer

Additional fluid properties

The gas phase contained low to medium amounts of CO_2 and H_2S. The water salinity was on the high side, giving relatively high mixture conductivity at Well 3 which was water continuous and had a moderate GVF (~75%).

Table 1 Additional water and gas properties provided by the operator

KOC Trial Wells	CO2 (%)	H2S (ppm)	Water Salinity (ppm)
Well 1	4	10000	245000
Well 2	1.4	3	240000
Well 3	1.4	0	230000
Well 4	4	30000	245000
Well 5	1.4	3	240000
Well 6	7	30000	n/a

6. Well Test Results

The well test results are shown in Table 2 below. The results are sorted by the order the well was tested and the date of the test.

Table 2 Test results from testing 6 KOC wells

KOC Trial Wells	Date	Choke size	Meter Temp [°F]	Meter Pressure [psi]	Oil Q [STB/D]	Water Q [STB/D]	Total Liq [STB/D]	Gas Q [MMscf/D]	GOR 1 [scf/STB]	GOR 2 [scf/STB]	Tot GOR [scf/STB]	WC [%]	API Gravity Oil	Type of Flow
Abbon														
Well 1	17.04.2017	48	148	175	1627	1256	2883	0.21	129	63	192	43.6 %	20	ESP
Well2	18.04.2017	48	142	451	3428	563	3992	1.977	577	158	734	14.1 %	32	Natural Flow
	18.04.2017	64	148	535	4166	602	4768	2.335	560	175	735	12.6 %	32	Natural Flow
	18.04.2017	42	145	476	2810	495	3304	1.625	578	162	740	15.0 %	32	Natural Flow
Well 3	19.04.2017	48	138	228	909	1560	2469	0.655	721	100	821	63.2 %	28	Natural flow
Well 4	10.05.2017	64	161	394	1952	1982	3934	0.425	83	135	217	50.4 %	24	ESP
Well 5	11.05.2017	48	144	439	3353	573	3926	2.012	600	153	753	14.6 %	30	Natural Flow
	11.05.2017	64	148	551	4105	600	4705	2.313	564	178	742	12.8 %	30	Natural Flow
	11.05.2017	56	148	584	3781	499	4280	2.186	578	165	743	11.7 %	30	Natural Flow
	11.05.2017	42	146	434	2645	499	3144	1.539	582	187	769	15.9 %	30	Natural Flow
Well 6	15.05.2017	64+128	149	347	3701	0	3701	0.97	262	138	400	0.00 %	31	Natural flow
	15.05.2017	128	150	352	3460	0	3460	0.9	260	139	399	0.00 %	31	Natural flow

6.1 Definition of errors

In this paper the, errors in oil, water, total liquid and gas flow rates are expressed as relative errors defined as:

Relative error = (MPFM reading – Reference reading) / Reference reading

While for the water cut the errors are expressed as absolute error defined as:

Absolute error = MPFM reading – Reference reading

6.2 PVT Impact on Multiphase Meter Accuracy

The Abbon 3PM measurements are taken at the pressure and temperature of the fluid passing through the meter, i.e. actual conditions, at which the meter itself measures its temperature and pressure. The measurement at actual conditions is the principle behind the MPFM flow measurement technology. The conversions to standard conditions are performed on the basis of:

- Rates measured and calculated at actual conditions for water, oil and gas
- Measured temperature and pressure of the fluid passing through the meter
- Values describing the fluids behavior when pressure and temperature are brought to standard conditions

Accuracy in PVT correlations contributes significantly to the overall accuracy when reporting results at standard conditions. For this reason it was decided to perform several comparisons in the evaluation of the multiphase meter. The comparisons started with the standard conditions reported by the test separator which was compared to the standard conditions reported by the Abbon 3PM. In addition, the actual conditions reported by the test separator were compared to the actual conditions reported by the Abbon MPFM, in order to eliminate errors due to limited PVT data. Finally, the actual conditions for both the test separator and MPFM were converted to standard conditions using the same correlations. Thus, the error generated from the PVT correlation will be the same for both the test separator and MPFM.

6.3 Performance plots

The following figures summarize the comparison between ABBON 3PM and test separator at standard conditions.

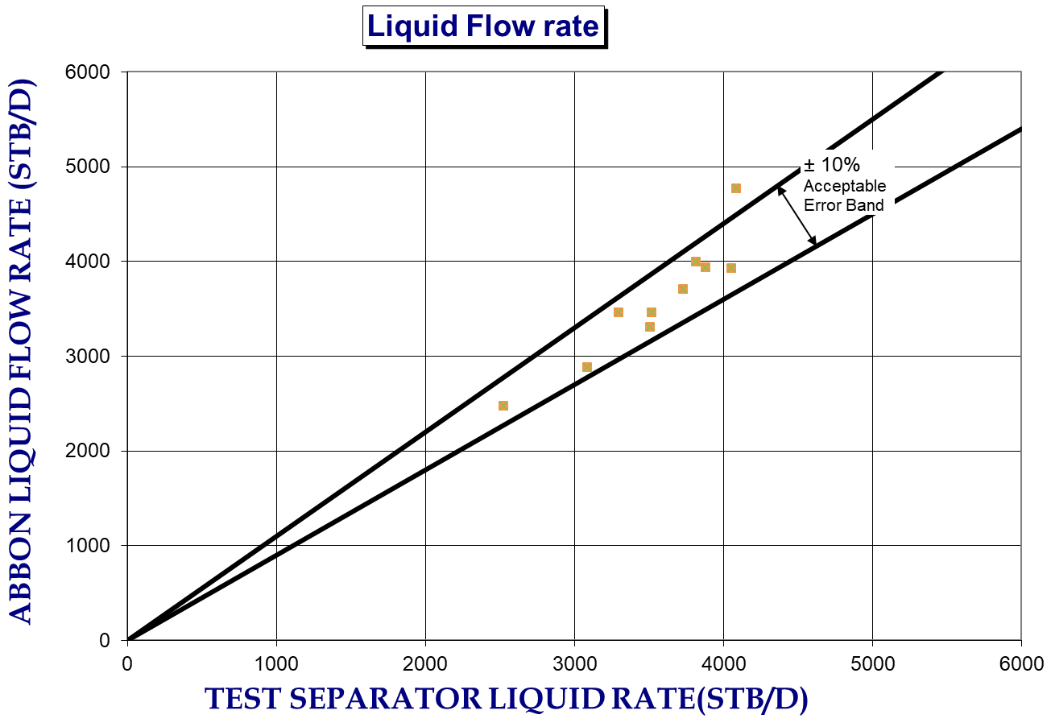

Figure 16 ABBON 3PM liquid flow rate vs. test separator liquid flow rate.

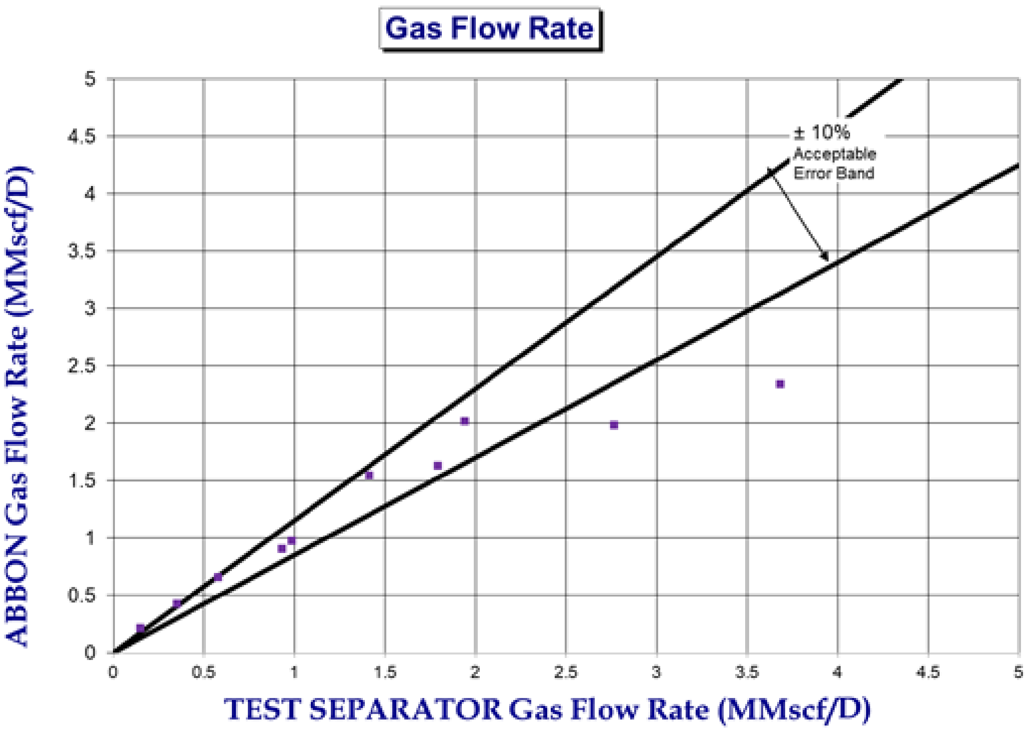

Figure 17 ABBON 3PM gas flow rate vs. test separator gas flow rate.

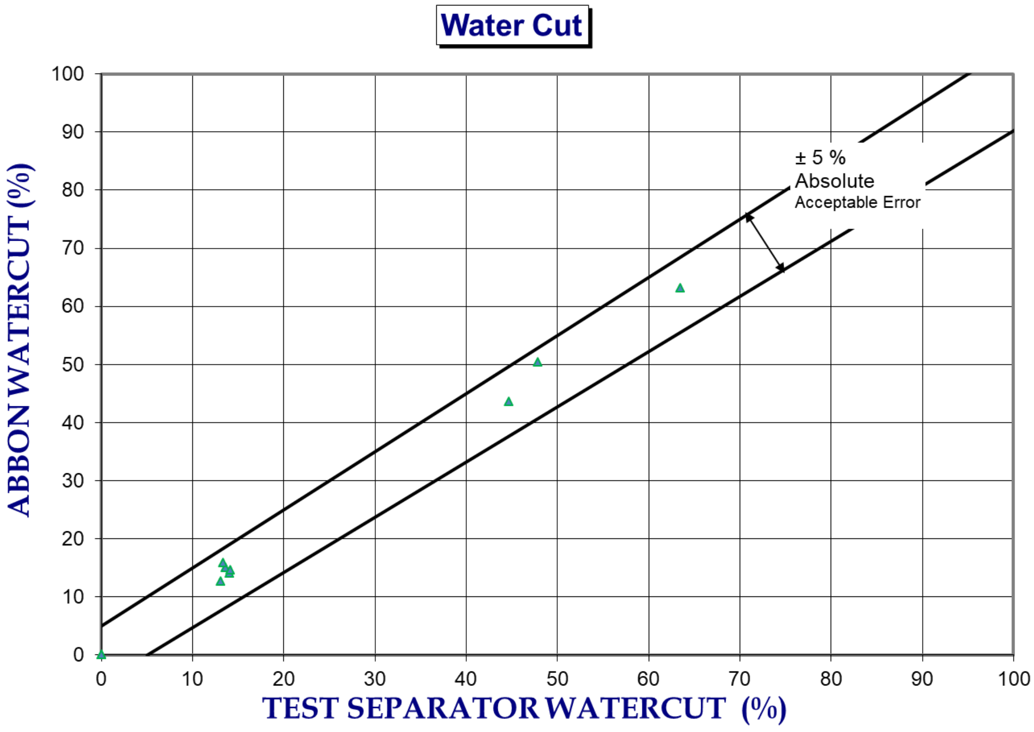

Figure 18 ABBON 3PM water cut vs. test separator water cut.

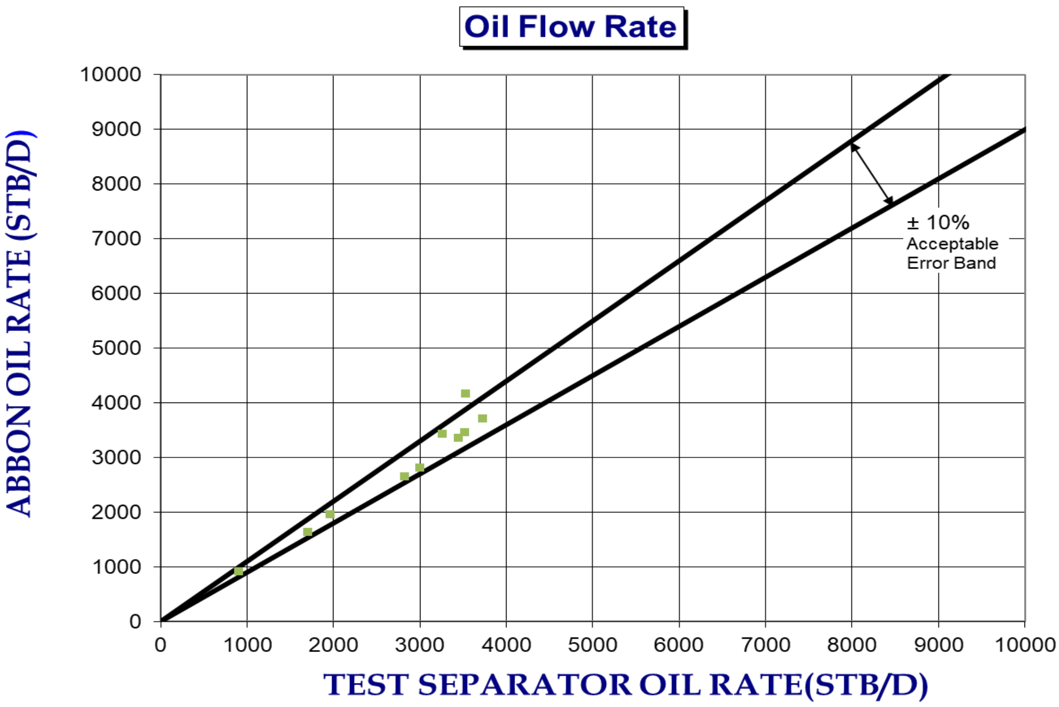

Figure 19 ABBON 3PM oil flow rate vs. test separator oil flow rate.

7. Summary of Test Results

The readings from the Abbon 3PM multiphase meter compared well with the test separator. On liquid flow rates, see Figure 16, the reading from the separator and the multiphase meter showed good agreement. The accuracy was better on the wells with stable flow, and the readings were within 10% relative compared to the test separator.

On gas comparison, see Figure 17, most of the wells were within 10% deviation between the multiphase meter and the test separator; however, there are some tests that deviate up to 40%. This deviation is likely caused by separator capacity limitation, and that there is no consideration of oil carry over or gas carry under in the calculation of the oil, water and gas flow rates. This issue was confirmed for one of the wells, where the gas reported by the ABBON 3PM meter was compared to both the test separator and a multiphase meter from a different vendor. Then, the Abbon 3PM and the second multiphase meter showed a discrepancy of maximum 9%.

On the water cut, see Figure 18, the readings from the multiphase meter and the samples did also match up, although sometimes several samples had to be taken to get a representative water cut reference.

The comparison of the ABBON 3PM and the test separator as a function of GVF can be seen in the deviation plot (Figure 20) below.

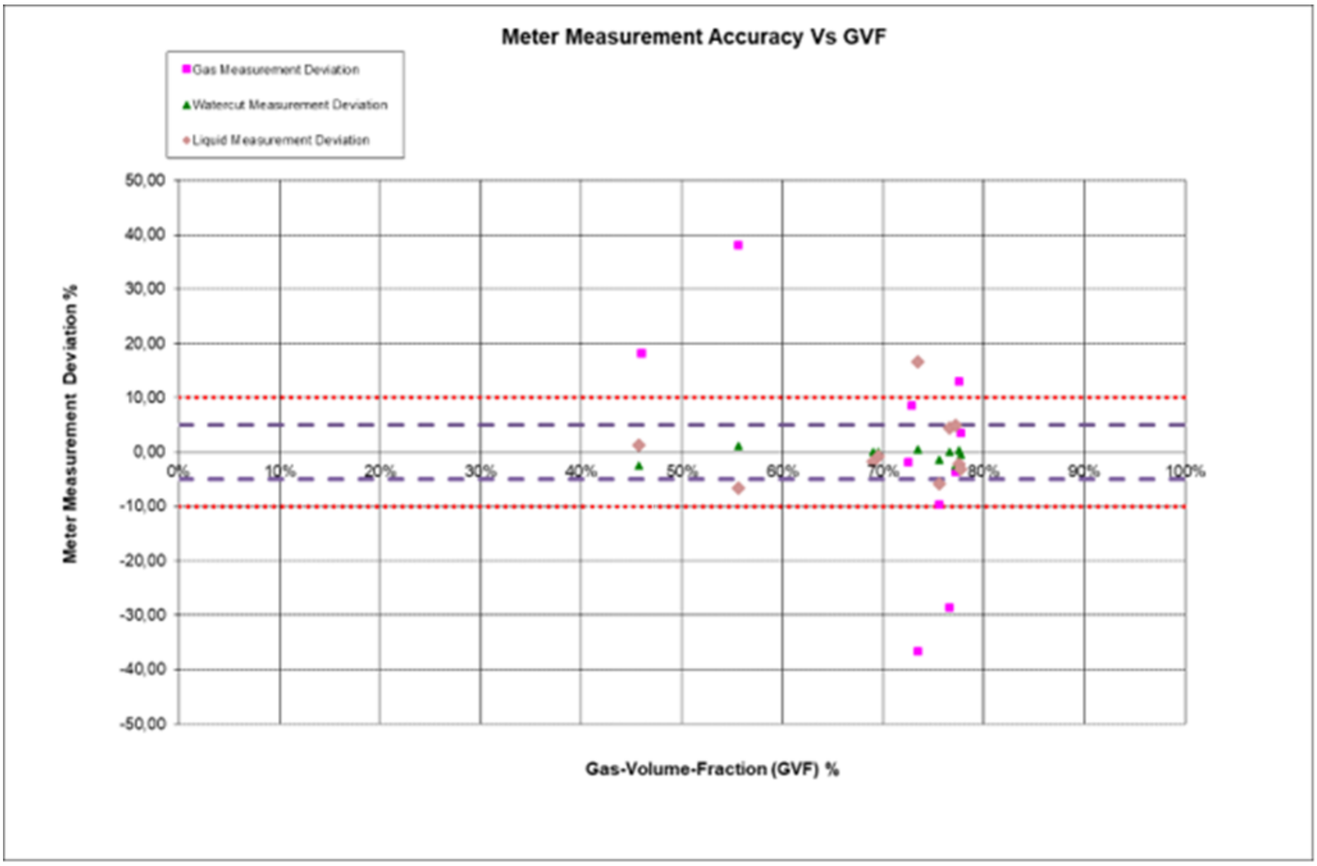

Figure 20 Deviation plot between ABBON 3PM and SGS test separator vs. GVF. Inherent test separator uncertainties have not been considered in the calculation of the deviations.

The flow rates produced by the 6 wells, corresponded well with the ABBON 3PM operating envelope, ref. Figure 9.

For the three qualification wells the water cut deviation was less than 3%, liquid flowrate deviation less than 5% and gas flowrate deviation less than 9%. For gas flowrate, one of the qualification wells had ~20% deviation and the well was retested with a second MPFM resulting in 9% deviation, without considering the combined uncertainties in the two multiphase meters.

8. Conclusions

1. For mobile well testing, rig-up time is of the essence and acquiring correct fluid parameters for each well during rig-up is fundamental for measuring the flow rates accurately. With the right tools, preparation and training, the ABBON field engineer managed to provide the necessary fluid measurements for an efficient commissioning, data logging and reporting.
2. The test separator gas measurement were not reliable for all wells due to separator capacity limitations, causing oil carry over or gas carry under. This observation was supported by the agreement in gas flow measurement between the ABBON 3PM and a second multiphase meter.
3. The data reported by the ABBON 3PM is within the operating envelope of the meter, and the results for the 3 qualification wells were accepted by KOC.

9. Acknowledgement

The authors would like to extend their appreciation to KOC and SGS for their contributions to this paper and their permission to publish the results.

10. Abbreviations

DP	Differential Pressure
GOR	Gas Oil Ratio
GVF	Gas Void Fraction
MPFM	Multiphase Flow Meter
WLR	Water Liquid Ratio
WC	Water Cut
scf	Standard Cubic Feet
MMscf/D	Million Standard Cubic Foot per Day
STB/D	Stock Tank Barrels per Day
FAT	Factory Acceptance Test

11. References

1. Hugo Harstad, Audun Aspelund and Hamza Fahd Matallah, Abbon AS, Bertus Bergsma, DNV GL “Multiphase Flowmeter Performance Evaluation” South East Asia Flow Measurement Conference 15.-16- March 2017, Kuala Lumpur
2. Bertrand C. Theuveny, Jean Francois Pithon, Olivier Loicq, Gérard Ségéral, Schlumberger Oilfield Services; “Worldwide Field Experience of Mobile Well Testing Services with MultiPhase Flowmeters”, ASME Engineering technology conference on Energy, February 4-5, 2002, Houston, TX
3. P.B. Warren, K. H. Al Dusari, M. Zabihi, J. M. Al-Abduljabbar, Saudi Aramco “ Field-Testing A Compact Multiphase Flow Meter – Offshore Saudi Arabia”, SPE 81560, 2003.
4. Florian Hollaender, Schlumberger “Field Testing Multiphase Flow Meter: Lessons Learned and Best Practices” ADIPEC 2013 Technical Conference