Virtual Flow Meter – Sensitivity Analysis

Part One

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Virtual Flow Metering – Sensitivity analysis – Part one

1 Abstract

Virtual flow metering becomes increasingly reliable and accurate enough to be accepted as an option to the physical flow meter. In order to prove the concept and to get an objective measure about the accuracy and the sensitivity, Kongsberg Digital has developed a new method for validating the design and securing a better understanding of the varying relationships for the system. This method indicates which parameters are the most important for a virtual flow meter to give an optimal accuracy.

By using the latest technology within multiphase flow simulation and dynamic process simulators, a digital twin (virtual plant) can be utilized to replicate the behavior for the entire production unit. A virtual flow meter is then connected to this solution, with the same data exchange used for the real plant. Utilizing this method, a controlled environment (i.e. the virtual plant) is obtained while keeping the real plant behavior in abnormal or failure modes. The sensitivity analysis then introduces known and traceable errors / malfunctions in the virtual plant and monitors the Virtual Flow Meter's ability to handle abnormal measurements and signal failures.

The sensitivity analysis will be conducted in two parts however; this paper will only consider part one.

Part one:

The sensitivity of a virtual flow meter solution for each well transmitter will be investigated, for a normal well; pressure temperature and choke positions will be available for the virtual flow meter. Any inaccuracies in these transmitters will be investigated, yielding a baseline for expected accuracy of a virtual flow meter for a standalone well. The investigation will be carried out for both a heavy oil well and a gas condensate well.

Recommendations will also be given, in order to make a virtual flow meter solution more viable by adding additional measurements where the system has the highest sensitivities.

Part two:

For a normal case, the export flows will be available to the virtual flow meter, and will serve as a basis for an advanced reconciliation system in order to back allocate flows from the export lines to the wells. The purpose of this system is to equip the virtual flow meter to self-correct deviations in order to match the export flows. Only reasonable variables will be available for the virtual flow meter to adjust in order to self-correct, such as choke positions, gas-oil ratio from the wells, water cut, reservoir pressures, etc. This will make it possible to track the performance of the virtual flow meter as there will be no uncertainties in the data input in to the virtual flow meter.

A number of sensitivity tests will then be performed on the system:

- The well dynamics will be varied over time, to measure the expected accuracy that a virtual flow meter is able to obtain in a perfect environment.
- Well/flowline modelling will be investigated; how much can the model deviate before giving significant losses in accuracy?
- Temperature and pressure transmitter failures; which transmitter is of significance to the solution?
- Choke Curves/position; how much missing choke information can the system handle before the accuracy suffers?

Kongsberg Digital will present the results from a study where a digital twin was used to identify the vital parameters and transmitters required for virtual flow meters of different level of accuracies.

2 Introduction

Model based allocation systems have been used for two decades. Most of them are based on a steady state approach, but some are also dynamic, meaning that the system will have a solution also in transient conditions. These systems have mostly been pipeline models reaching from well to inlet facilities on a production unit. The technology is identified using many different names, but Virtual Metering is arguably the most common term. The basic principle of such systems is that the pipeline model is fed with real time measurements from the DCS or SCADA into model boundaries, enabling it to simulate process states of the pipeline in real time.

Contents

2.1 Abbreviations

Acronym	Description
ACV	Annulus Choke Valve
BHP	Bottom Hole Pressure
BHT	Bottom Hole Temperature
DCS	Distributed Control System
GOR	Gas Oil Ratio
PCV	Production Choke Valve
VFM	Virtual Flow Meter
WC	Water Cut
WHP	Well Head Pressure
WHT	Well Head Temperature

3 K-Spice Meter

K-Spice® Meter is a complete dynamic Virtual Flow Metering (VFM) system where the oil and gas produced from each well matches the total production measured by a fiscal metering system located downstream. The basis of the VFM system is a high fidelity dynamic multiphase and process simulation model, representing the complete field from the wells, through flowlines to onshore or topsides, including the processing plant to export. The model is built in K-Spice® and LedaFlow®.

In brief, the VFM system performs data validation on data received from DCS, compares the data with the model, reconciles the data and back allocates flow to the different wells, calibrates the model to the reconciled data, and estimates the model performance of parts of the system and the complete system by use of statistical methods. The VFM system is a modular system, built from a set of production reconciliation modules.

3.1 K-Spice

K-Spice® is a dynamic process simulation tool for chemical processes in general, and upstream oil and gas processes in particular. A dynamic simulator solves the mass and energy balances in a process system to obtain a rigorous description of the system's time-varying behavior.

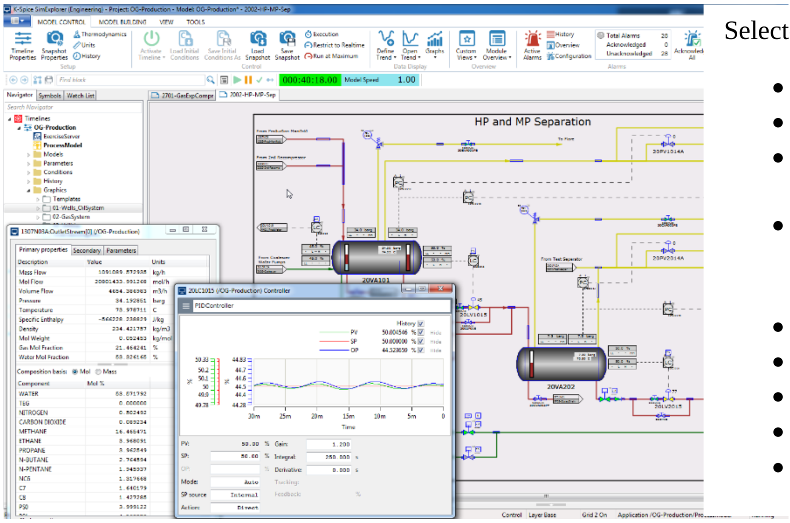

Figure 1 – K-Spice® user interface

Selected features:

- High fidelity models
- Rigorous thermodynamic package
- Produced with a sound basis in first-principles physics, chemistry and engineering
- Usually a one-to-one correspondence between an entry on an equipment data sheet and an item in the model
- Multiphase flow models (LedaFlow®)
- Control modules
- Shutdown systems (C&E)
- Sequences
- Compressor control algorithms

KONGSBERG engineers have been developing K-Spice® since 1989. It has been developed to meet the evolving demands for sophisticated and advanced simulation and decision-support systems in the petroleum and chemical industries.

Highly skilled engineers, with many decades of experience in dynamic simulation and process engineering, have refined our simulator solution. With such experience and skill, coupled with modern software development techniques, the resulting K-Spice® simulation system is:

- **Powerful**. Accurate, large-scale models can be easily constructed and tested. Multiple parallel models, each emphasizing certain data items (variables, parameters, etc.) can be run to optimize production and evaluate operational alternatives quickly.
- **Lifecycle-oriented**. The simulator can be used in all phases of a project life cycle, from engineering studies, through operator training, to on-line systems. A single model and a single software tool can be used for all these applications.
- **Widely applicable**. K-Spice® has been successfully used to simulate processes in diverse sectors such as oil and gas production, refining, pulp and paper, petrochemicals, bulk chemicals, fine chemicals and primary pharmaceutical manufacture. However the primary focus of K-Spice® is upstream petroleum applications.
- **Rigorous**. Models in K-Spice® use rigorous, first principle models of the processing equipment, control equipment and fluid properties. Where necessary, K-Spice®, also allows you to build and use simplified models.
- **Flexible**. K-Spice® is designed to be tailored to a users' specific work practices and application designs.
- **Open**. K-Spice® supports open data exchange standards and integrates easily with engineering database systems and enterprise management systems.

K-Spice® is in continuous use by KONGSBERG engineers and is therefore in a continuous state of evolution and refinement.

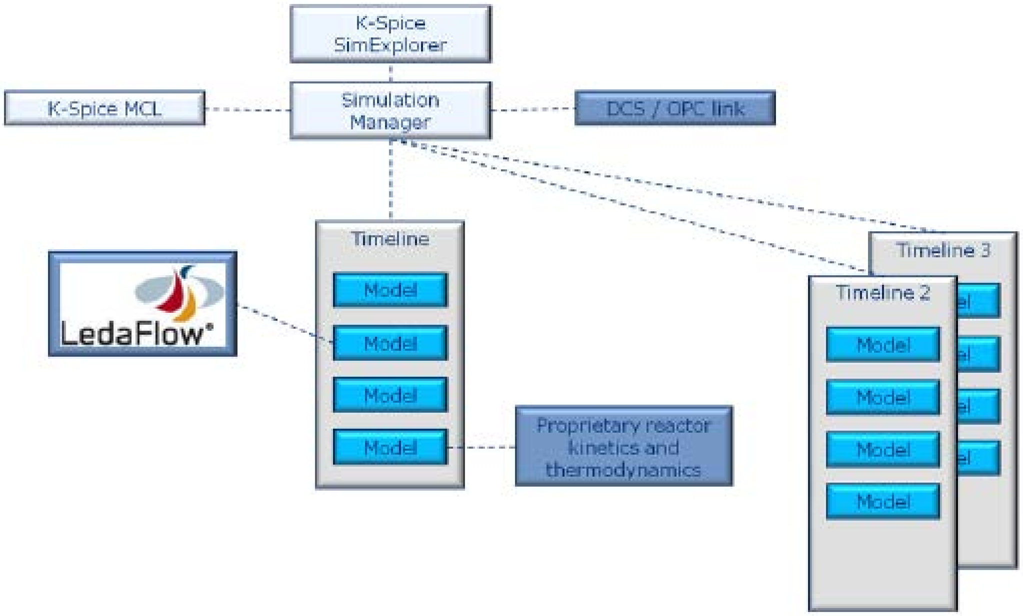

Figure 2 – The K-Spice® architecture

In addition, K-Spice® is a multipurpose dynamic process simulator which is often used throughout the entire life-cycle of a facility, from feasibility study to operation and production optimization.

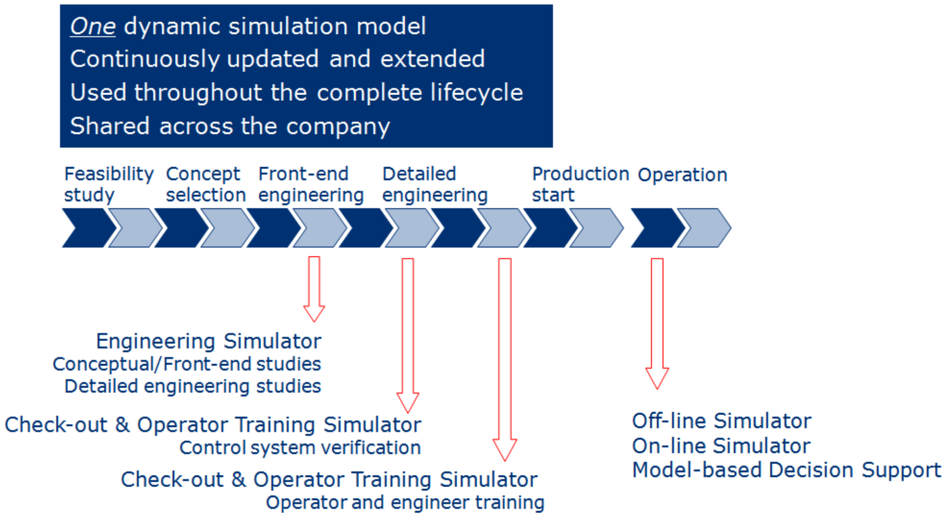

Figure 3 – Simulation life cycle concept

The simulator is typically used to increase knowledge and reduce risk in the following activities:

- Front-end engineering and design studies.
- Flow assurance studies.
- Safety analyses.
- Verification of equipment sizing.
- Verification of control philosophy.
- Verification of operational procedures.
- Safety checks.
- Confirmation of start-up and shut down procedures.
- Control system verification.
- Operator training.
- Pre-commissioning checks.
- Support during plant commissioning.
- Post start-up modification and verification.
- Analysis of operational problems.
- Plant debottlenecking and optimization.
- Production optimization.
- On-line decision support for operations and maintenance.
- Design of modifications and plant retrofits.

These models are developed, tested and verified throughout all the different project phases and consist of a very rich set of detailed design data. By synchronizing these models with online process conditions, it provides the production optimization team with additional information such as:

- Access to thousands of estimated process conditions over the whole operational range, calculated and updated in real-time.
- Access to data that is not measured or possible to measure with traditional transmitters.
- Compare measured data vs. calculated data and alarm the user upon large deviations
- Perform statistical analysis.
- Enable Overall Process Performance.
- Enable extended equipment performance monitoring.

3.2 LedaFlow

LedaFlow® is the product of ten years of innovative development by SINTEF, sponsored, guided and supported by TOTAL and ConocoPhillips, commercialized and developed further by KONGSBERG. LedaFlow® is based on models that are closer to the actual physics of multiphase flow and provides a step change in detail, fidelity, quality, accuracy and flexibility over existing multiphase flow simulation technology.

The resolution of modelling is increased, solving mass, energy, and momentum conservation for each of the three phases of flow (oil, gas and water). This improves the accuracy in simulation of critical transient events and consequently provides a step change in the understanding of the fluid behaviour. In addition, each of the nine fields (continuous and dispersed) has its own mass equation. Figure 4 below outlines these nine fields. The additional mass balances provide the potential to refine the closure rules to match new laboratory data.

The separate energy equations for all three phases are solved giving much more accurate information during stratified flow and during blow down conditions, where the temperature of the slower moving liquids at the bottom of a pipe can differ considerably from the gas flow above. This is particularly important for estimating corrosion rates and pipe-wall temperatures for material selection and to determine hydrate risks.

Composition tracking of individual components along the pipeline allows composition to vary due to differences in velocity between phases, interfacial mass transfer and merging of different fluid compositions throughout the network – based on the GUTS thermodynamic engine or using the integrated Multiflash™ multiphase equilibrium calculation package.

Wells are simulated using inflow performance relationships such as IPR table, PI linear, single or double quadratic, Vogel, back pressure and under-saturated and well inflow zones along the well pipe. Advanced injection options like fracture and viscosity correction are also available.

The LedaFlow® partners have invested significant resources to validate LedaFlow® against experimental and field data using databases with over 12 000 data points. TOTAL and ConocoPhillips have also contributed with validations against field data, as have the partners in the LedaFlow® Improvements to Flow Technology (LIFT) program.

Successful production system design and operation requires a detailed understanding of multiphase flow behaviour. LedaFlow® was developed to bring higher accuracy and resolution to multiphase flow simulations for long tie-backs and production from deep-water reservoirs.

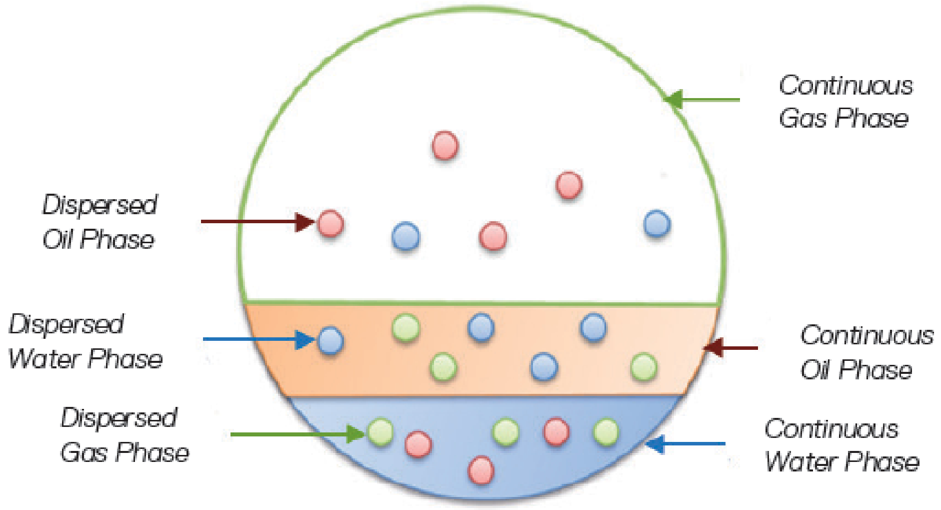

Figure 4: Basis for 1D Model (4)

4 Digital twin

The basis of the sensitivity study will be a model based on the Digital Twin concept. for this study, since a perfect environment is needed to test out the sensitivity of the system, there will be two identical models; one taking the place of the real plant, and one imitating the plant. The only data exchange between these models are typical I/O’s (e.g. transmitter measurements and valve command/position) from the control system. See figure 5 below.

We can see that the values available for sharing from the real plant model will be the bottom hole pressure and temperature transmitter (BHP and BHT), well head pressure and temperature (WHP and WHT), annulus head pressure and temperature (AHP and AHT) and the choke positions of the annulus choke valve (ACV) and production choke valve (PCV).

The virtual flow meter logic considers all values made available to it and predicts an estimate for reservoir pressure, temperature and, GOR or WC. The logic continuously validates and weighs the results in the connected virtual plant model.

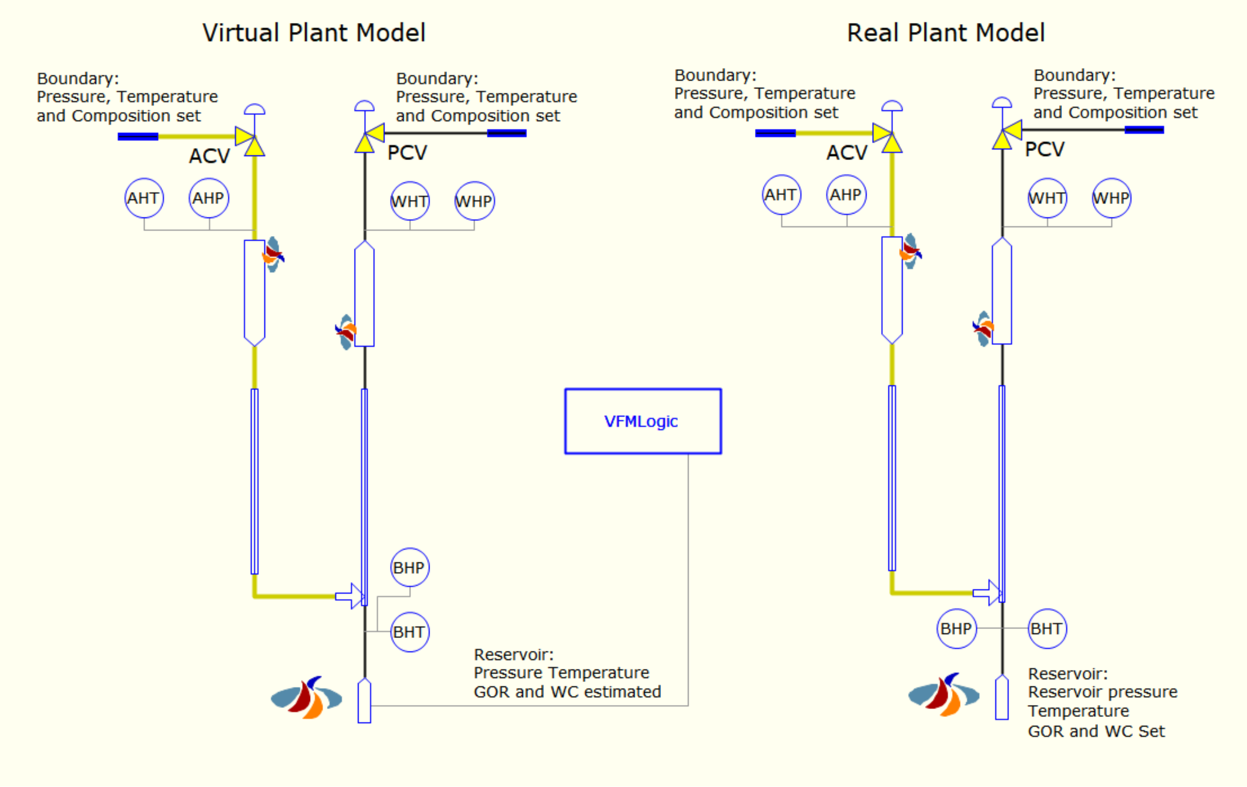

Figure 5 – Conceptual drawing of the digital twin connected to the virtual plant model with the available transmitter values showing.

The LedaFlow® models are based on a typical well geometry with a depth of approximately 2000 meters, as shown in figure 6.

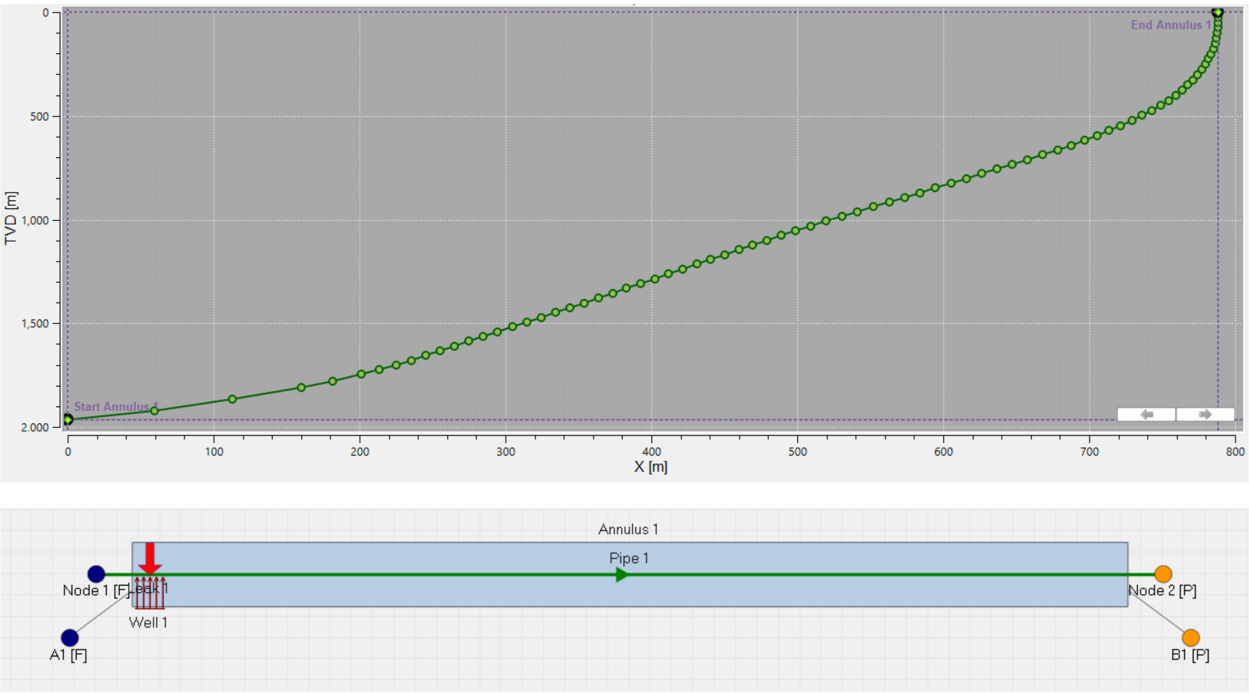

Figure 6 - Overview of the LedaFlow® well model used for the real and virtual plant model.

This model is then used for both the virtual plant model and the real plant model as seen in figure 5. The boundaries for these well models are then defined upstream of the annulus choke valve and downstream of the production choke valve. For the real plant model the reservoir is set to have a defined GOR, WC, reservoir pressure and production index. The virtual plant is continuously estimating reservoir pressure and, GOR or WC, with either GOR or WC set as a constant. Since the reservoir pressure is a variable, the virtual flow model does not need a production index, as this will act as a pressure boundary at the location of the bottom hole transmitters.

The two known major uncertainties for a well can be considered to be either the production choke valve or the reservoir conditions (Pressure, Productivity index, GOR and WC). These two cannot easily be estimated at the same time, and one of these will have to be predefined. For this paper, the reservoir conditions are assumed to have the biggest uncertainties and thus we trust the production choke valve parameters.

5 Results and discussion of the sensitivity study

Looking at the well models, the sensitivity will be investigated for three different gas oil ratios and different pressure drops over the choke. The water cut is kept at a moderate level. The cases will be trialed in two versions, one with GOR fixed, and one with the water cut fixed. The system will estimate the other along with the reservoir pressure/production index. Note, gas lift was not considered for these cases.

The estimated variable is tagged in the plot. For example, in the BHP-GOR-LowDP, case, the deviation is introduced in bottom hole pressure, gas oil ratio is estimated, and there is a low differential pressure over the production choke. Full test matrix, including details on the reference flow is shown in Appendix 1.

5.1 Case 1 – Oil Well

The oil well, as specified in Tables 1 through 3 in Appendix 1, is defined to have a base GOR of 125 Sm3/Sm3 and a water cut of 20%. The cases are simulated for 3 different pressure drops over the production choke: low pressure, half way to critical flow, and with critical flow over the choke. Deviations due to inaccuracies in each transmitter is investigated.

5.1.1 Case 1 - Bottom Hole pressure

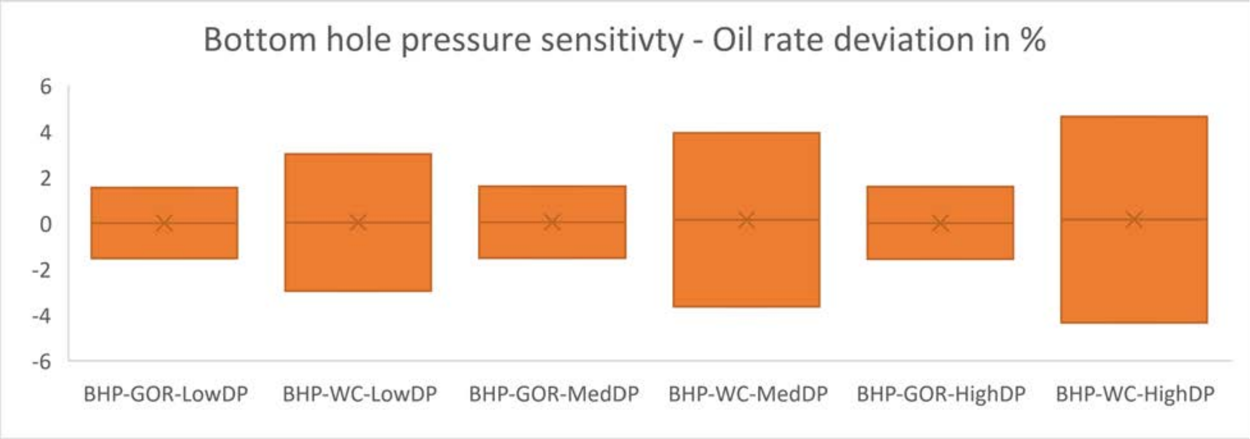

Figure 7 – Oil rate deviation in % towards the reference flow with respect to a +-2 bar deviation introduced in bottom hole pressure, with either GOR or WC estimated.

A deviation of +-2 bar is introduced to the transfer between the virtual plant and the real plant in bottom hole pressure. The deviation in oil rate, as a result, is constant along the different delta pressures over the choke, where the water cut is fixed and gas oil ratio is estimated. The deviations are increasing slightly for the opposite case, when the gas oil ratio is set and the water cut is estimated.

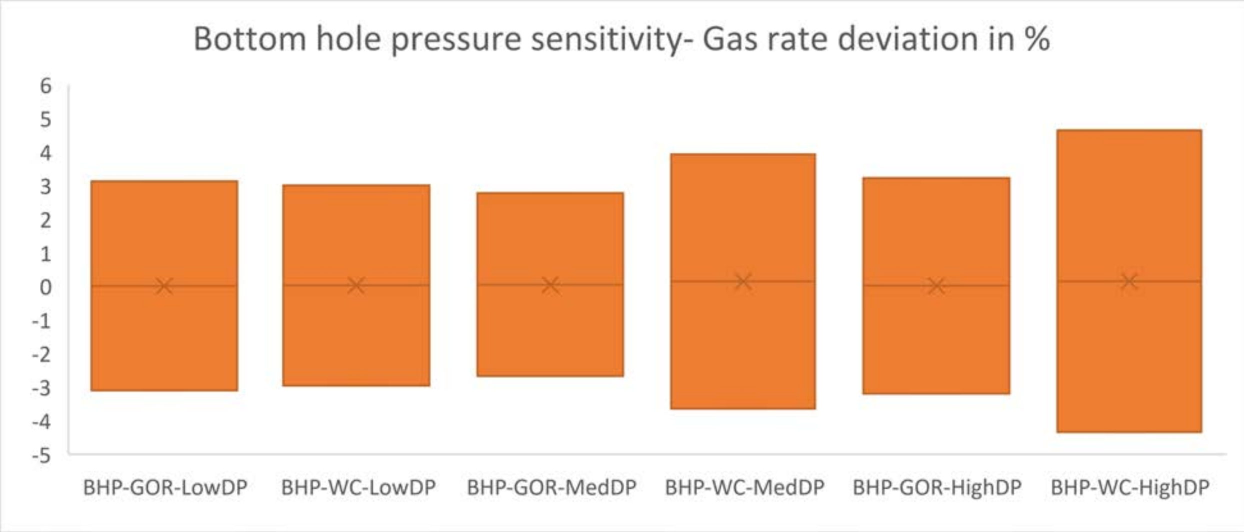

Figure 8 – Gas rate deviation in % towards the reference flow with respect to a +-2 bar deviation introduced in bottom hole pressure, with either GOR or WC estimated.

For the gas rates, the deviation is more or less constant, as the deviation introduced directly influences the density/pressure drop across the well bore.

5.1.2 Case 1 – Well Head Pressure

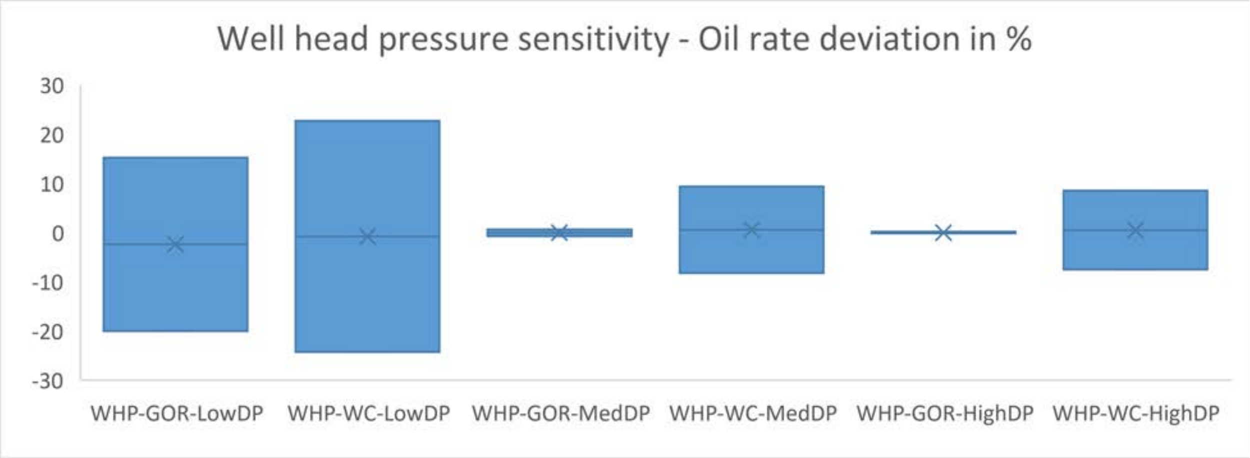

Figure 9 – Oil rate deviation in % towards the reference flow with respect to a +-2 bar deviation introduced in well head pressure, with either GOR or WC estimated.

A deviation of +-2 bar is introduced to the transfer between the virtual plant and the real plant in well head pressure. From the figure, one can see that this is a very sensitive measurement for low pressure over the choke and the sensitivity is reduced significantly as the choke pressure difference increase. One can also see that the system is much less sensitive to these deviations when estimating gas oil ratio rather than water cut.

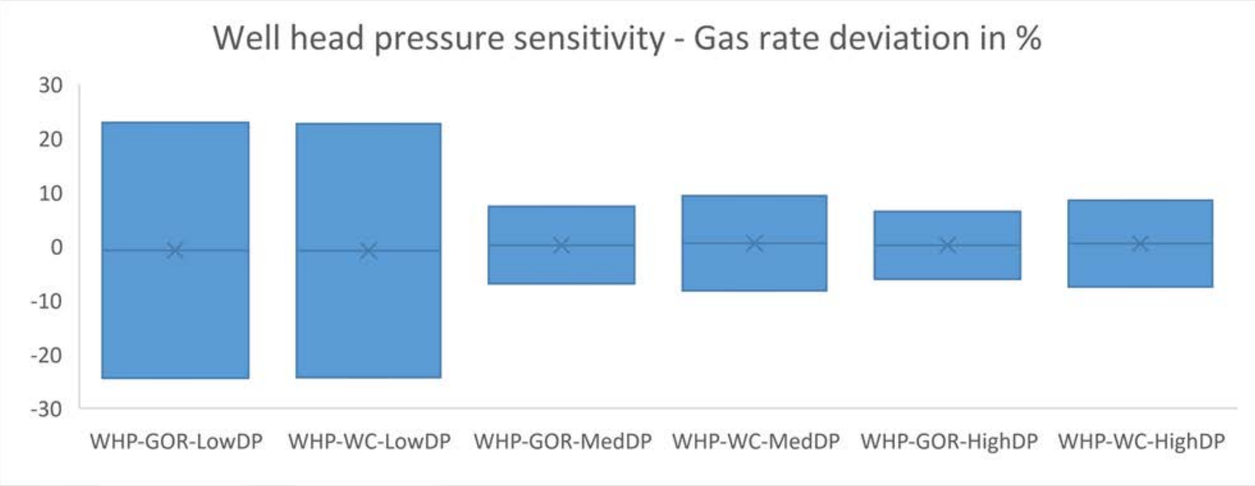

Figure 10 – Gas rate deviation in % towards the reference flow with respect to a +-2 bar deviation introduced in well head pressure, with either GOR or WC estimated.

Looking at the gas rates from Figure 10, these flows are only influenced indirectly due to the different flows with a higher or lower well head pressure. The estimated gas oil ratio or water cut remains, more or less, constant through this test.

5.1.3 Case 1 – Choke and incorrect GOR or Water Cut sensitivity

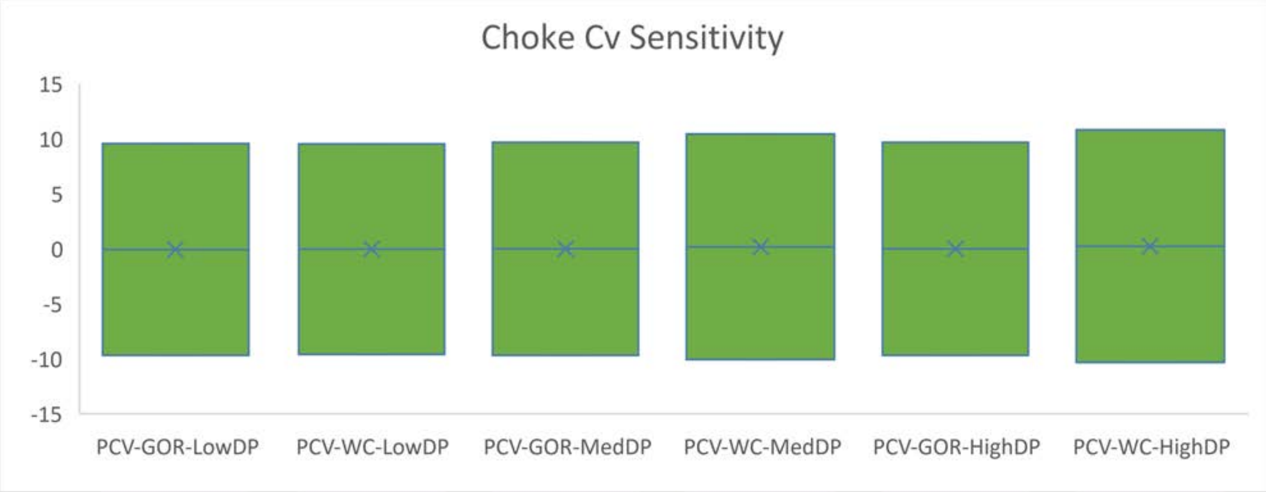

Figure 11 – Oil rate deviation in % towards a 10% difference in production valve choke Cv.

Introducing a mismatch in choke Cv at 10% in the absolute Cv value will introduce a 10% flow deviation. Since this is a gravitationally dominated well, amongst the basic well transmitters and equipment, the pressure drop over the well choke is the only reliable measurement to estimate the flow. Thus the virtual flow meter will only increase the reservoir pressure to account for this.

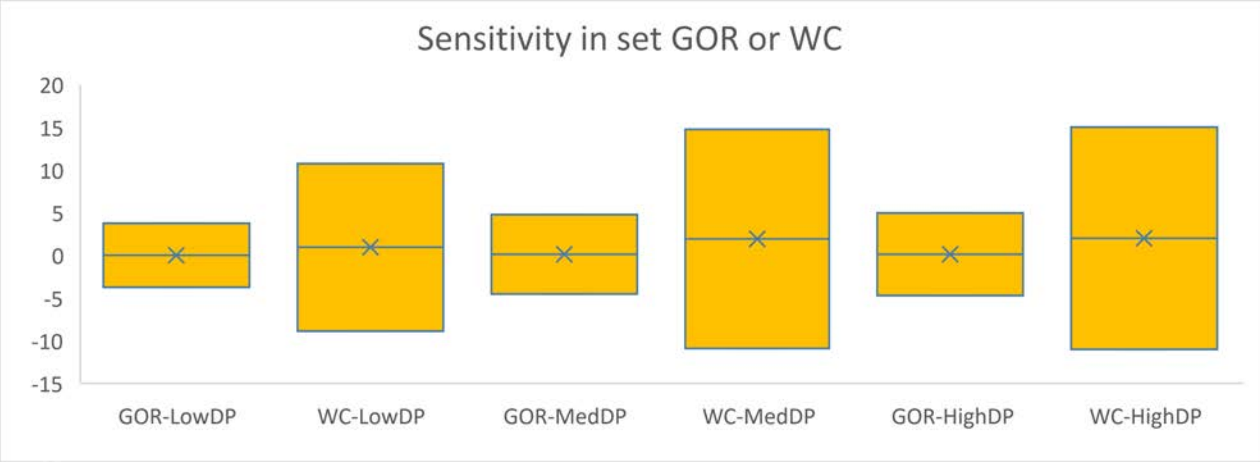

Figure 12 – Oil rate deviation in % towards the reference flow with a +-10% difference in gas oil ratio for cases estimating water cut and a +-25% difference in water cut for the cases estimating gas oil ratio.

In figure 12, deviations have been introduced to the fixed gas oil ratio or the water cut to see how much an incorrect setting will affect the well rates. From figure 12 it can be seen that for an oil well the system is more accurate when estimating the gas oil ratio than the water cut.

5.2 Case 2 – Gas well

The gas well, as specified in Tables 4 through 6 in Appendix 1, is defined to have a base GOR of 15000 Sm3/Sm3 and a water cut of 20%. The cases are simulated for 3 different pressure drops over the production choke: low pressure, half way to critical flow, and with critical flow over the choke. Deviations due to inaccuracies in each transmitter is investigated.

5.2.1 Case 2 – Bottom hole pressure

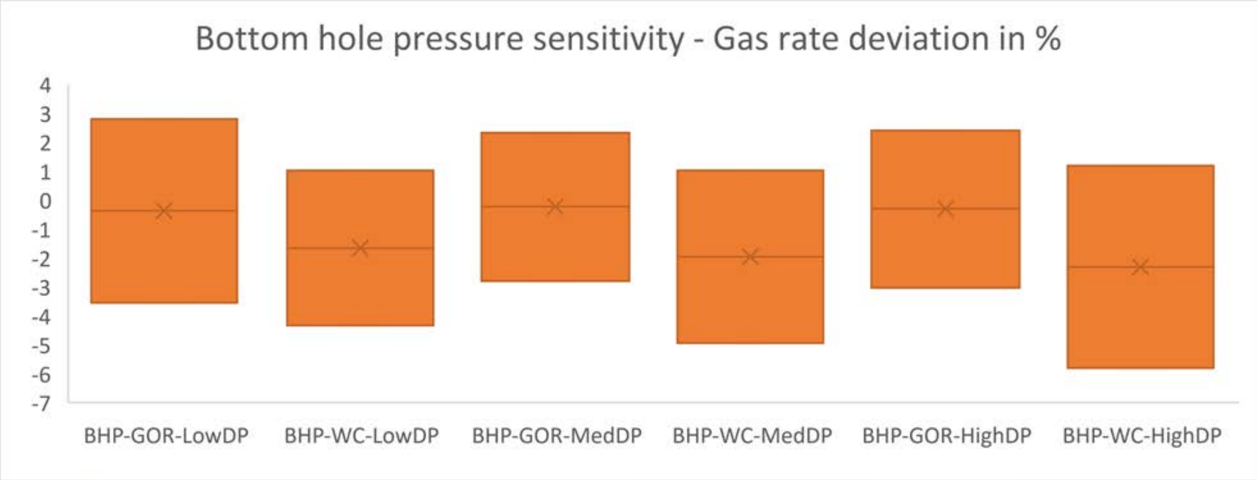

Figure 13 – Gas rate deviation in % towards the reference flow with respect to a +-2 bar deviation introduced in bottom hole pressure, with either GOR or WC estimated.

From Figure 13, it can be seen that the gas flow is not very sensitive to deviation, even with significant deviation in the bottom hole transmitter. To compensate for this deviation in bottom hole pressure, the system estimates the gas oil ratio or water cut significantly different from the actual value, as shown in figure 14. The estimated gas oil ratio ranges from 10000-40000 Sm3/Sm3 through this test, thus over or under estimating the oil flow severely.

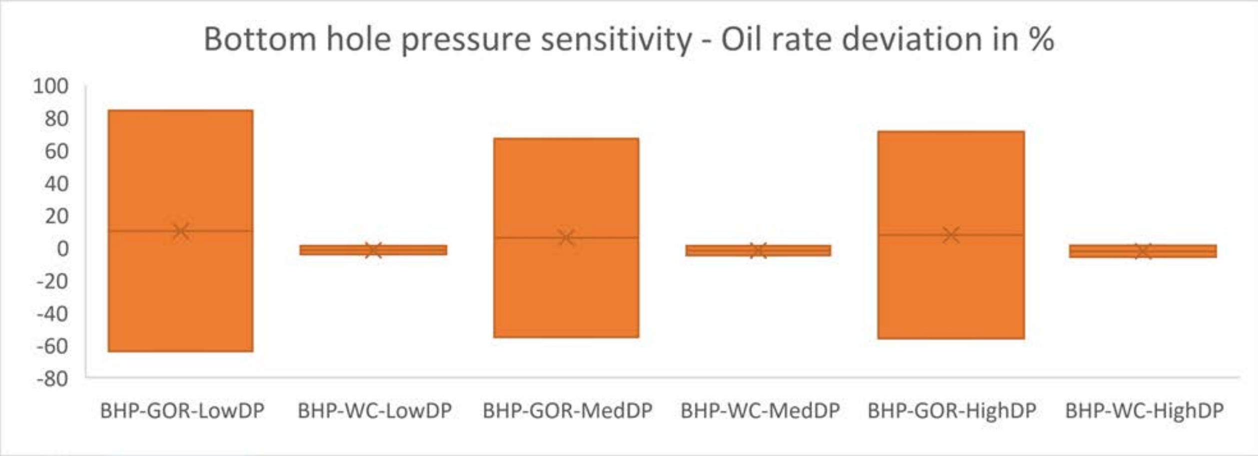

Figure 14 – Oil rate deviation in % towards the reference flow with respect to a +-2 bar deviation introduced in bottom hole pressure, with either GOR or WC estimated.

It can be seen that a gas condensate field is very sensitive to the hydraulic pressure drop over the well bore and it requires a significant change in gas oil ratio to account for the different pressure drop. However, estimating the water-cut will ensure both an accurate oil and gas rate estimation, but the system will then report water rates incorrectly, as this phase will account for the model mismatch.

5.2.2 Case 2 – Well Head Pressure

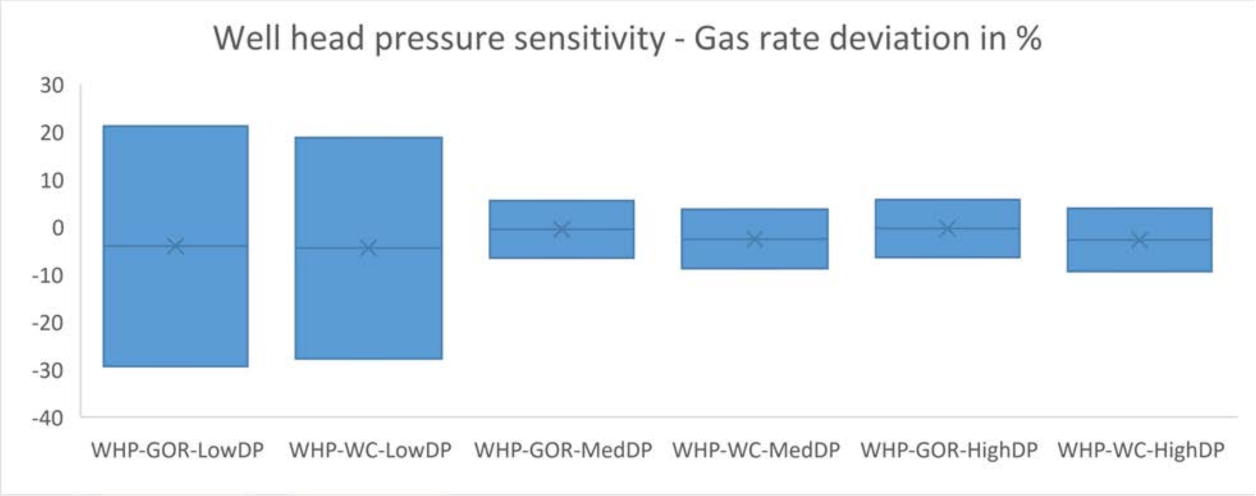

Figure 15 – Gas rate deviation in % towards the reference flow with respect to a +-2 bar deviation introduced in well head pressure, with either GOR or WC estimated.

The gas rate is more sensitive to deviations in the well head pressure than the bottom hole pressure. The deviation is highest at low pressure differences over the production choke and it still remains quite high, +-7% even at moderate to high delta pressures over the choke.

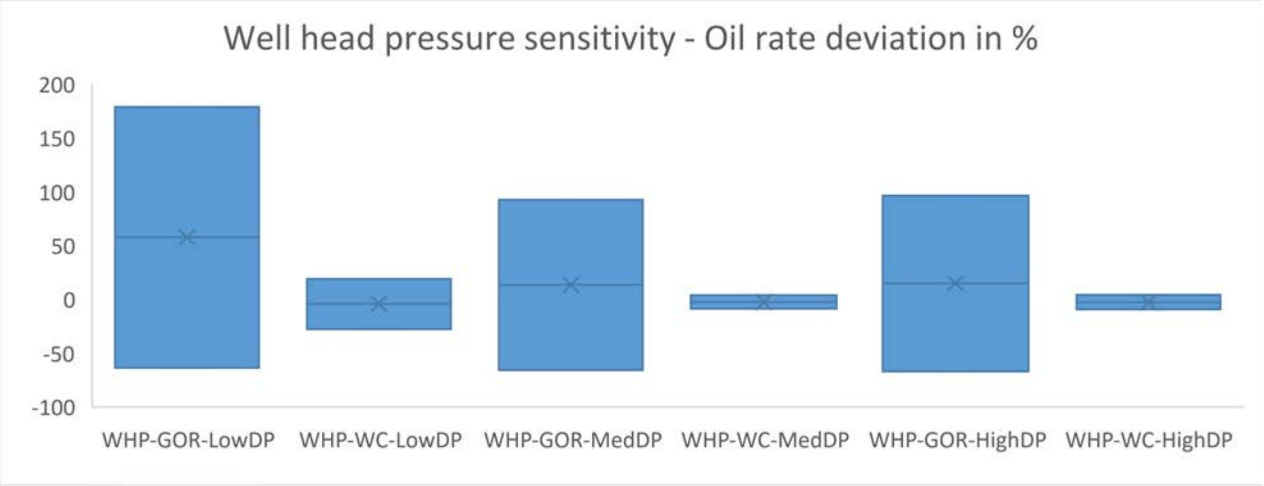

Figure 16 – Gas rate deviation in % towards the reference flow with respect to a +-2 bar deviation introduced in well head pressure, with either GOR or WC estimated.

A deviation in well head pressure tells the same story as for a deviation in bottom hole pressure for a high gas oil ratio well. With an extreme sensitivity to gas oil ratio estimation. The water cut can, however, be estimated with only a small impact to the oil rate for medium and high differential pressure over the choke. For a low pressure drop over the choke, the oil rate will still have a sensitivity of +-30%.

5.2.3 Case 2 – Choke and incorrect GOR or Water Cut sensitivity

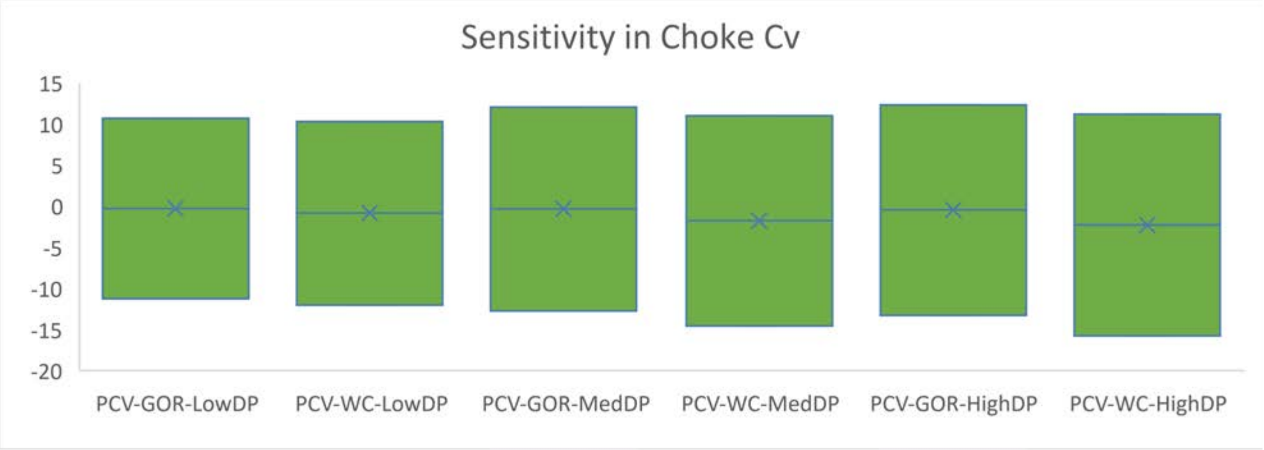

Figure 17 – Oil rate deviation in % towards a 10% difference in production valve choke Cv.

Introducing a mismatch in choke Cv at 10% in the absolute Cv value, will introduce a 10%-12% flow deviation. This deviation increases slightly for the cases with medium and high differential pressure over the production choke due to a slightly higher flow, creating frictional pressure drop in the well bore. This is compensated with an increase or decrease in water cut or gas oil ratio. For cases with significant pressure drop over the well bore, the choke pressure drop along with the well bore pressure drop can be utilized for a higher accuracy in flow estimation.

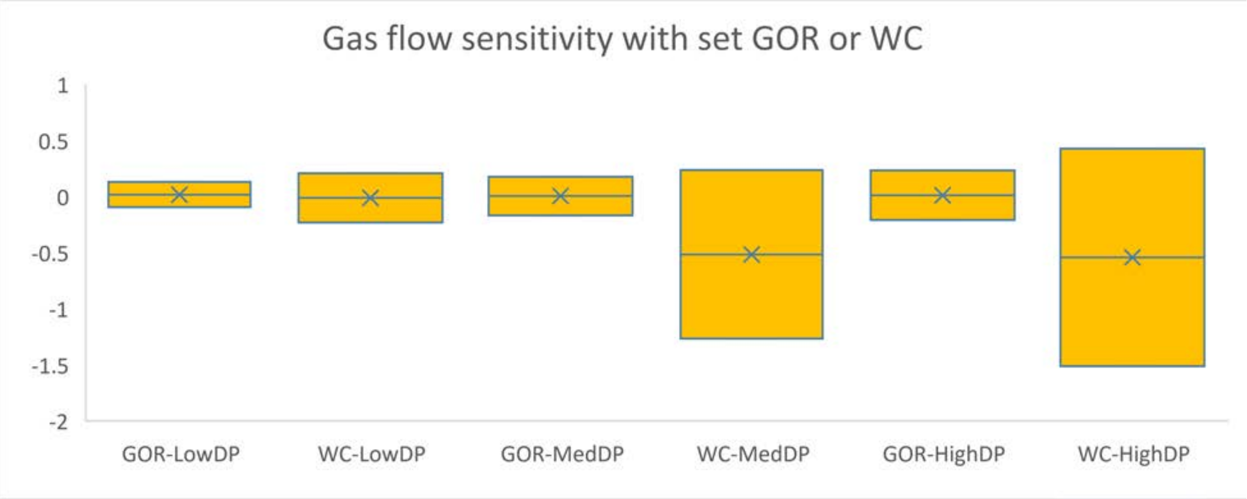

Figure 18 – Gas rate deviation in % towards the reference flow with a +-20% difference in gas oil ratio for cases estimating water cut and a +-25% difference in water cut for the cases estimating gas oil ratio.

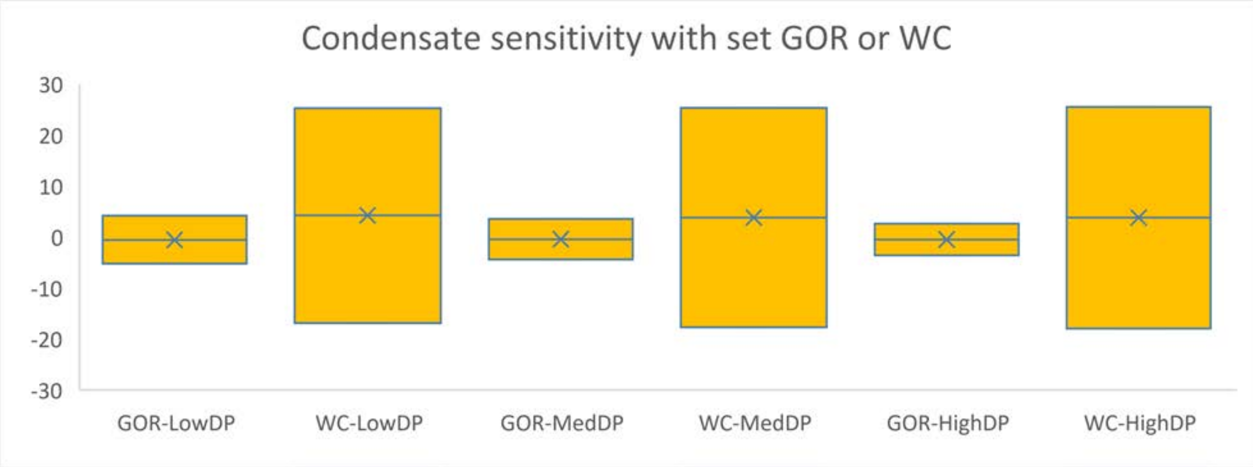

Figure 19 – Oil rate deviation in % towards the reference flow with a +-20% difference in gas oil ratio for cases estimating water cut and a +-25% difference in water cut for the cases estimating gas oil ratio.

Due to the small amounts of liquids produced in a high gas oil ratio well, the gas rate is not sensitive to big deviations in gas oil ratio or water cut input as seen in figure 18. The same holds true for the oil deviation, only introducing a difference in +-5% in oil rate with a 25% difference in water cut for the well. The oil rate production is, however, sensitive to a deviation in the set gas oil ratio.

6 Conclusions

In general, for a virtual flow meter system, the more accurate transmitters available the better the expected solution can be. However, this does depend on the type of well, and where the well is in its lifecycle. The need for accurate transmitters is not as important when the well produces at high pressures. But as the well moves toward low pressure production it becomes increasingly important. This can be planned for by having multiple transmitters at each location, thus increasing the likelihood of having accurate measurements available.

For an oil well (at low gas oil ratios) it is recommended, based on the findings in this paper, to have water cut as an input to the system. This increases the accuracy of a virtual flow meter significantly. Furthermore, the total flow estimate is highly dependent on a correct choke model, and as such, it is very important to validate the choke curve to ensure correct behavior across the operation range of the choke. In addition, at very low pressure drops over the choke, the solution will be very sensitive to even small deviations in the surrounding pressure transmitters.

For gas wells, the recommendation is to have gas oil ratio as an input to the system, in order to obtain the highest accuracy possible from a virtual flow meter. As for the oil well, the total flow is also very dependent on a correct choke model. Having an additional measurement for total flow (Venturi) is recommended once the well moves towards low pressure production.

With this in mind, a field cannot rely solely on a Virtual Flow meter solution to estimate all flows, if there are just basic transmitters (pressure and temperatures) available to the system with reasonable accuracy. Occasional well tests, or additional meters are needed. This could be either water cut meters and total flow (Venturi) meters or multiphase flow meters for each cluster of wells that can be used for well tests.

There is also planned a part two of this paper, that will investigate the benefits and sensitivity of utilizing an advanced production reconciliation system in combination with the virtual flow meter that uses the export rates and back allocates flow to the wells.

On a side note, an attempt was made to estimate all reservoir parameters (Pressure/productivity index, GOR and WC), but this was found to be too sensitive with just basic transmitters. Additional transmitters will be required for such an approximation, a water cut estimator, conductivity meter or a similar device that can indicate the liquid split.

7 Appendix 1 – Test matrices:

7.1 Test matrices for Case 1, Oil well with a GOR of 125 Sm3/Sm3

Table 1 - Test matrix for an oil well with low pressure over the production choke (LowDP)

	BHP(barg)	BHT(degC)	WHP(barg)	WHT(degC)	PCV(Cv)	GOR(Sm3/Sm3)	WC (%)
Reference	206.1956	85.31781	95.18326	71.07031	30	125	20
Deviation	**2 bar**	0	0	0	0	125	20
Deviation	**-2 bar**	0	0	0	0	125	20
Deviation	0	0	**2 bar**	0	0	125	20
Deviation	0	0	**-2 bar**	0	0	125	20
Deviation	0	0	0	0	**10%**	125	20
Deviation	0	0	0	0	**-10%**	125	20
Deviation	0	0	0	0	0	**137.5**	20
Deviation	0	0	0	0	0	**112.5**	20
Deviation	0	0	0	0	0	125	**22.5**
Deviation	0	0	0	0	0	125	**17.5**
Reference	Oil Flow (Sm3/h)	Gas Flow (Sm3/h)	Water Flow (Sm3/h)	WHP DSC (barg)	DP PCV (barg)		
Reference	34.9	4360	8.7	90	5.18		

Table 2 - Test matrix for an oil well with low pressure over the production choke (MedDP)

	BHP(barg)	BHT(degC)	WHP(barg)	WHT(degC)	PCV(Cv)	GOR(Sm3/Sm3)	WC (%)
Reference	182.3613	85.34987	78.17648	72.53699	20	125	20
Deviation	**2 bar**	0	0	0	0	125	20
Deviation	**-2 bar**	0	0	0	0	125	20
Deviation	0	0	**2 bar**	0	0	125	20
Deviation	0	0	**-2 bar**	0	0	125	20
Deviation	0	0	0	0	**10%**	125	20
Deviation	0	0	0	0	**-10%**	125	20
Deviation	0	0	0	0	0	**137.5**	20
Deviation	0	0	0	0	0	**112.5**	20
Deviation	0	0	0	0	0	125	**22.5**
Deviation	0	0	0	0	0	125	**17.5**
Reference	Oil Flow (Sm3/h)	Gas Flow (Sm3/h)	Water Flow (Sm3/h)	WHP DSC (barg)	DP PCV (barg)		
Reference	44.58	5570	11.1	50	28.18		

Table 3 - Test matrix for an oil well with low pressure over the production choke (HighDP)

	BHP(barg)	BHT(degC)	WHP(barg)	WHT(degC)	PCV(Cv)	GOR(Sm3/Sm3)	WC (%)
Reference	216.1172	85.44045	102.3653	73.67682	16	125	20
Deviation	**2 bar**	0	0	0	0	125	20
Deviation	**-2 bar**	0	0	0	0	125	20
Deviation	0	0	**2 bar**	0	0	125	20
Deviation	0	0	**-2 bar**	0	0	125	20
Deviation	0	0	0	0	**10%**	125	20
Deviation	0	0	0	0	**-10%**	125	20
Deviation	0	0	0	0	0	**137.5**	20
Deviation	0	0	0	0	0	**112.5**	20
Deviation	0	0	0	0	0	125	**22.5**
Deviation	0	0	0	0	0	125	**17–.5**
Reference	Oil Flow (Sm3/h)	Gas Flow (Sm3/h)	Water Flow (Sm3/h)	WHP DSC (barg)	DP PCV (barg)		
Reference	47.7	5970	11.9	50	52.4		

7.2 Test matrices for Case 2, Gas/condensate well with GOR 15000 Sm3/Sm3

Table 4 - Test matrix for a gas well with low pressure over the production choke (LowDP)

	BHP(barg)	BHT(degC)	WHP(barg)	WHT(degC)	PCV(Cv)	GOR(Sm3/Sm3)	WC (%)
Reference	133.8751	81.97215	105.2826	64.4901	80	15000	20
Deviation	**2 bar**	0	0	0	0	15000	20
Deviation	**-2 bar**	0	0	0	0	15000	20
Deviation	0	0	**2 bar**	0	0	15000	20
Deviation	0	0	**-2 bar**	0	0	15000	20
Deviation	0	0	0	0	**10%**	15000	20
Deviation	0	0	0	0	**-10%**	15000	20
Deviation	0	0	0	0	0	**18000**	20
Deviation	0	0	0	0	0	**12000**	20
Deviation	0	0	0	0	0	15000	**25**
Deviation	0	0	0	0	0	15000	**15**
Reference	Oil Flow (Sm3/h)	Gas Flow (Sm3/h)	Water Flow (Sm3/h)	WHP DSC (barg)	DP PCV (barg)		
Reference	3.4	50630	0.8	100	5.28		

Table 5 - Test matrix for a gas well with low pressure over the production choke (MedDP)

	BHP(barg)	BHT(degC)	WHP(barg)	WHT(degC)	PCV(Cv)	GOR(Sm3/Sm3)	WC (%)
Reference	158.4951	81.63621	122.2173	64.99349	40	15000	20
Deviation	**2 bar**	0	0	0	0	15000	20
Deviation	**-2 bar**	0	0	0	0	15000	20
Deviation	0	0	**2 bar**	0	0	15000	20
Deviation	0	0	**-2 bar**	0	0	15000	20
Deviation	0	0	0	0	**10%**	15000	20
Deviation	0	0	0	0	**-10%**	15000	20
Deviation	0	0	0	0	0	**18000**	20
Deviation	0	0	0	0	0	**12000**	20
Deviation	0	0	0	0	0	15000	**25**
Deviation	0	0	0	0	0	15000	**15**
Reference	Oil Flow (Sm3/h)	Gas Flow (Sm3/h)	Water Flow (Sm3/h)	WHP DSC (barg)	DP PCV (barg)		
Reference	4.5	67520	1.1	80	42.2		

Table 6 - Test matrix for a gas well with low pressure over the production choke (HighDP)

	BHP(barg)	BHT(degC)	WHP(barg)	WHT(degC)	PCV(Cv)	GOR(Sm3/Sm3)	WC (%)
Reference	139.4343	81.30914	105.445	64.06869	40	15000	20
Deviation	**2 bar**	0	0	0	0	15000	20
Deviation	**-2 bar**	0	0	0	0	15000	20
Deviation	0	0	**2 bar**	0	0	15000	20
Deviation	0	0	**-2 bar**	0	0	15000	20
Deviation	0	0	0	0	**10%**	15000	20
Deviation	0	0	0	0	**-10%**	15000	20
Deviation	0	0	0	0	0	**18000**	20
Deviation	0	0	0	0	0	**12000**	20
Deviation	0	0	0	0	0	15000	**25**
Deviation	0	0	0	0	0	15000	**15**
Reference	Oil Flow (Sm3/h)	Gas Flow (Sm3/h)	Water Flow (Sm3/h)	WHP DSC (barg)	DP PCV (barg)		
Reference	4.3	64570	1.1	50	52.37		

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.