North Sea
FLOW
Measurement Workshop

On Estimation of Water Cut Changes and PVT Calculation Approaches in Virtual Flow Metering

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1 INTRODUCTION

Virtual flow metering (VFM) is playing a significant role in surveillance independently and in conjunction with multiphase measurement instrumentation. Many production wells do not have physical metering installed and count solely on VFM. Even when wells are complemented with thorough measurement instrumentation, VFM still adds value as a backup when sensors fail.

An accurate approach for calculating thermodynamic and transport properties (for the rest of the article, PVT) is a key element for a successful VFM software. This is due to the fact that multiphase flow equations count on these properties as part of the closure. For example, the friction correlation requires viscosity as input. The fluids in production vary significantly in composition and consequently in properties and behaviour. Usually, a fluid sample is taken to specialized labs to analyze composition and provide experimental measurements for the behaviour of the fluid. However, the experimental data are discrete in nature and local. Therefore, a generic and a more continuous solution is desirable, hence, relying on modeling. There are several approaches to predict PVT. One of them is to use empirically fitted models, but these models always have poor extendibility and generality outside the fitted range and composition. Moreover, they are not thermodynamically consistent over phases. A more appropriate and physically grounded approach is the use of equations of state (EoSs). There are various categories of EoSs. Cubic EoSs like Soave-Redlich-Kwong (SRK) [1], SRK with Huron Vidal mixing rules (SRK-HV) [2] and Peng–Robinson (PR) [3] are amongst the lightest in computations. Consequently, they are the most widely used in industry. Among the heaviest in computation time are the multi-parameters EoSs, which are at least one order of magnitude higher than Cubic EoS in computation time [4]. Span–Wagner [5] for pure CO2 and GERG (Groupe Européen de Recherches Gaziéres) [6] for mixtures are examples of multi-parameters EoSs. The Cubic-Plus-Association (CPA) is one of the state-of-the-art approaches which has been a good compromise between accuracy and computation time. There is also an Extended Corresponding State (ECS) category that can be very expensive if shape factors are evaluated analytically. The accuracy that ECS offers motivated for a simplification by using cubic EoS for shape factors closure [7, 8]. This resulted in a cost smiler to CPA with high accuracy, consistency and generality.

In principle, a generic and accurate approach will be computationally expensive. Often, this expense renders the approach impractical for usage within large simulations. Therefore, it is common in oil and gas industry to employ cubic equations or tables that are produced using these equations. The EoS is fitted to experimental measurements conducted on the fluid sample as part of the fluid characterization procedure. VFM software commonly supports several PVT approaches including; simple models (e.g. stiffened gas), cubic EoSs and flashing over tables. For practical reasons, real time systems usually run on tables, often referred to as tab files. The tables are static and produced at a specific water content and gas oil ratio (GOR). In many occasions the operators keep the fluid file and only send the Tab file to the support team. Often, this happens only once at the time of well configuration. Hence, the EoS and the tab files are not adjusted to the changes in fluid composition and/or operational condition as frequent as should be.

In this study, we evaluate the quality of this approach by comparing the results produced using table to that produced when using EoS directly. The study covers wide ranges of water cut, temperature and pressure observed in production.

Since VFMs are usually accurate in predicting total liquid rates but not always specific on oil and water cut, the latter is often manually estimated in a rough and discreet manner. The estimate also counts on the quality and frequency of the last water cut measurements. The work presented here incorporates a sensitivity study of the effect of water production changes on temperature changes across the choke. While it is a common knowledge that gases tend to cool, and liquids tend to heat across choke (Joule-Thomson effect), production flows are multiphase and vary in water content, GOR, and operational conditions. Thus, the behaviour varies based on composition and the level of pressure and temperature at the upstream and downstream the choke. The results of the study demonstrate these variations over a range of water content, temperature and pressure observed in production. The results shed light on the potential role of the temperature sensor downstream the choke in capturing water cut changes. The knowledge gained can lead to a more accurate and continuous approach for estimating water cut within VFM. If so, much better predictions for the other two phases and the fields behaviour can be achieved.

2 METHODOLOGY

2.1 Numerical tools

In this study two software packages are used, namely, FlowManager® [9] and PVTSim Nova. The FlowManager®, a widely used virtual metering software, is studied to demonstrate the PVT Tab file capabilities and possible challenges using them. PVTSim Nova is used as a reference and for benchmarking.

2.2 Setup

For the scope of the study, flow across choke component was chosen. This choice was made because the choke model depends solely on upstream PVT to calculate the temperature change across the choke for a given downstream pressure. The PVT downstream the choke is calculated assuming an isoenthalpic process. This enables us to validate the Tab file PVT approach downstream the choke at varying pressure drops in comparison with isoenthalpic valve from PVTSim Nova. Thus, we can isolate uncertainty from the hydrodynamic model and numerical scheme.

Figure 1 shows a schematic for the setup. The temperature upstream choke (TUC), pressure upstream the choke (PUC), volumetric flow rates $Q^{\bullet}$, pressure downstream the choke (PDC) are set. A temperature and pressure (TP) flash is performed upstream choke and enthalpy hUC is estimated. To describe the choke, we assume isoenthalpic pressure drop, hence, the enthalpy downstream the choke hDC is set equal to hUC. A pressure-enthalpy (Ph) flash is performed to predict temperature downstream the choke (TDC).

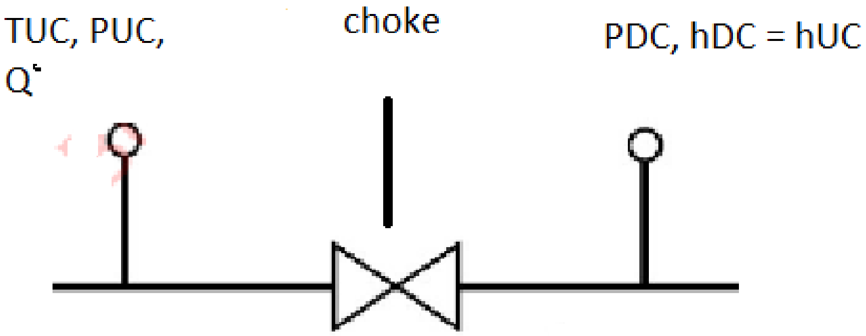


Fig. 1 - Experimental setup schematic

The setup uses a static table for a typical reservoir fluid with GOR=194, produced at 1% water (weight based). The results of the table flash at the inlet and outlet of the choke are compared to the results from the EoS using PVTSim Nova. Without changing the table, we vary water content at the inlet of the choke and vary pressure downstream by manipulating the choke characteristics. When we change water, we keep the GOR and total mass constant. We compare the results to PVTSim Nova that is using a fluid reflecting the water content modification. The study covers wide ranges of temperature and pressure observed in production.

To show that refinement and frequent adjustment of the Tab file can be of favorable impact, the study included a comparison to refined tab files and tab files that are adjusted to the water saturation for the given new operational conditions.

3 RESULTS AND DISCUSSION

3.1 TDC sensitivity to water content - Simulation

Figures 2-6 show the predicted change of the temperature downstream the choke as we increase water content using PVTSim Nova. The confidence that PVTSim Nova results reflect the behaviour of the given fluid is because the EoS was characterized for that particular fluid.

Figure 2 illustrates TDC trend for upstream temperature (TUC) and pressure (PUC) of 30 C°, and 180 bar, respectively. The figure shows that at 140 bar the fluids were behaving more as compressed fluids and the choking resulted in heating up the fluid and thus an increase in the TDC even at zero water in the system. As the PDC drops, the cooling effect become more prominent at no water content. The trend for the three pressures downstream the choke (PDCs) is monotonic increase of TDC as water is added to the system.

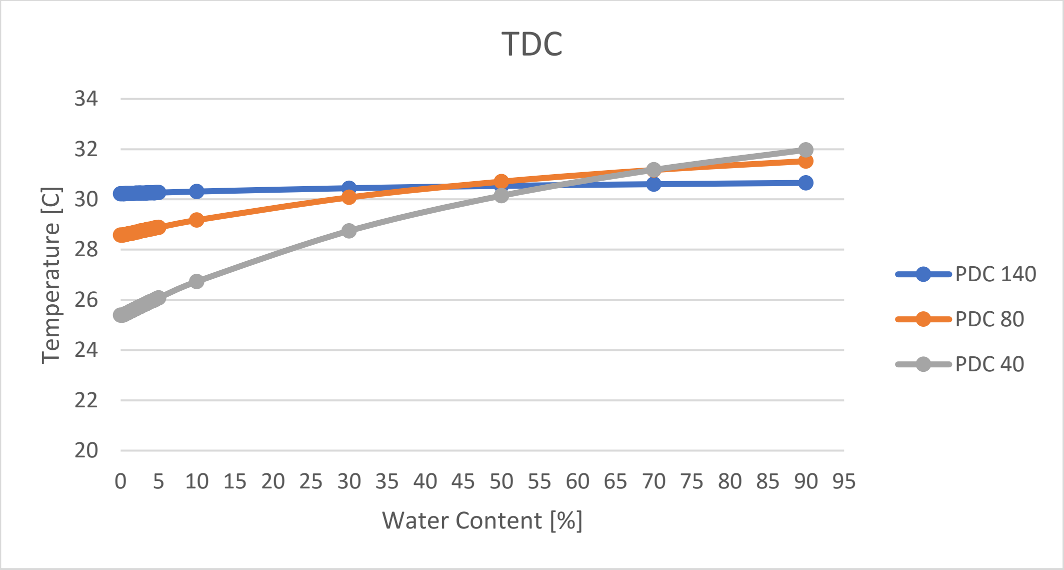


Fig. 2 – Temperature downstream the choke as function of water content using PVTSim Nova. Upstream temperature and pressure 30 C°, and 180 bar.

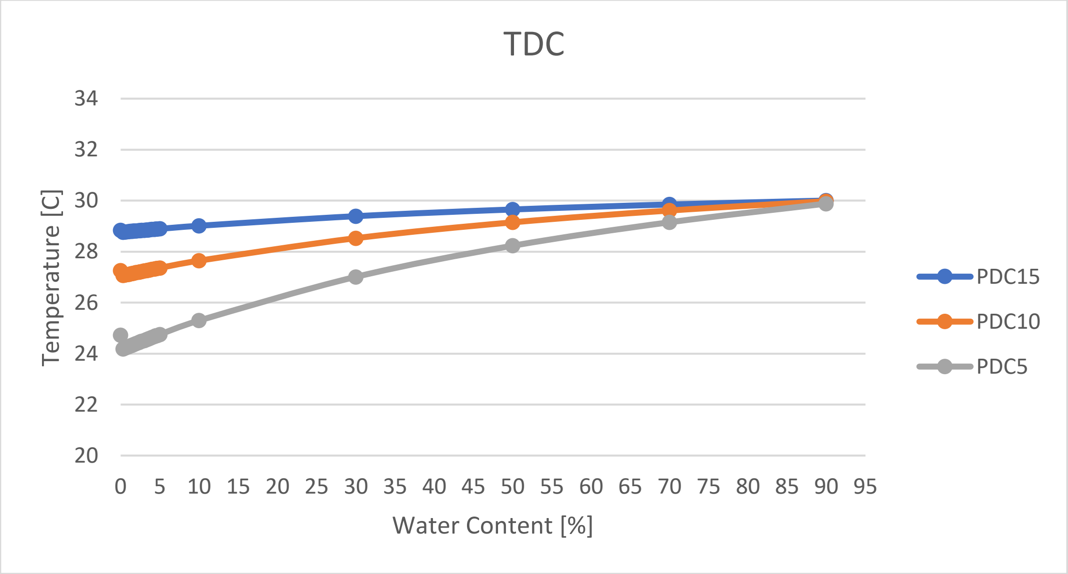


Fig. 3 – Temperature downstream the choke as function of water content using PVTSim Nova. Upstream temperature and pressure 30 C°, and 20 bar.

Figure 3 illustrates the TDC trend for TUC and PUC of 30 C°, and 20 bar, respectively. The figure shows that as the PDC drops, the cooling effect becomes more prominent at no water content. For PDCs of 15, and 10 bar, the TDC exhibited a monotonic increase as more water is added to fluid. However, at PDC 5 bar we see a boost for the cooling as we added water before the trend shift and TDC starts to increase monotonically with more water. The explanation is that between 10 and 5 bars an amount of water has dissolved in the gas phase which further boosted the cooling effect.

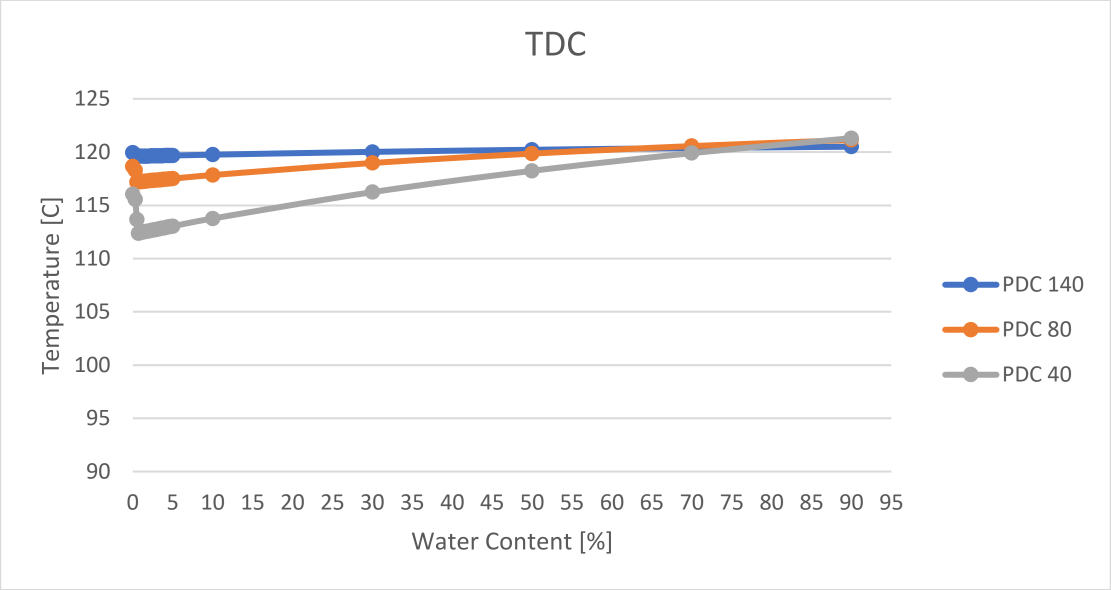


Fig. 4 – Temperature downstream the choke as function of water content using PVTSim Nova. Upstream temperature and pressure 120 C°, and 180 bar.

Figure 4 demonstrates the TDC trend for TUC and PUC of 120 C°, and 180 bar, respectively. The figure shows that as we choke the flow to a lower PDC the cooling effect magnifies at no water content. The figure also shows that at such high temperature we see a boost for the cooling as we added water before the trend shift and TDC starts to increase monotonically with more water. The explanation here is that at such high temperature, even though PDCs are relatively high, an amount of water has dissolved in the gas phase which further boosted the cooling effect.

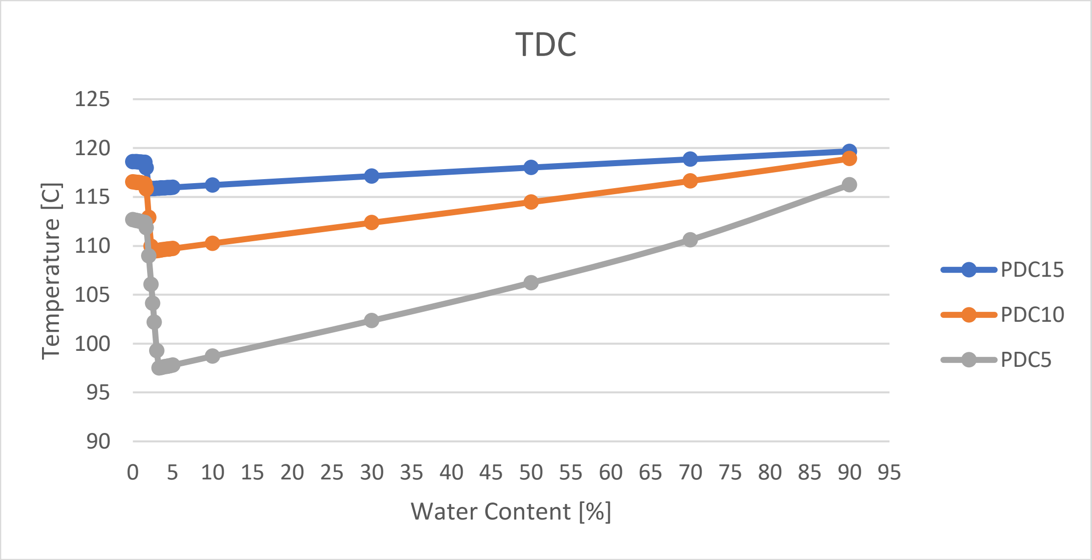


Fig. 5 – Prediction of temperature downstream the choke as function of water content using PVTSim Nova. Upstream temperature and pressure 120 C°, and 20 bar.

Figure 5 illustrates the TDC trend for TUC and PUC of 120 C°, and 20 bar, respectively. The figure shows that when TUC is high and PDCs is much lower than the ones in figure 4, the circumstances cause more water to solve into the gas phase. Consequently, a greater boost for cooling and less steep line before the trend shifts direction.

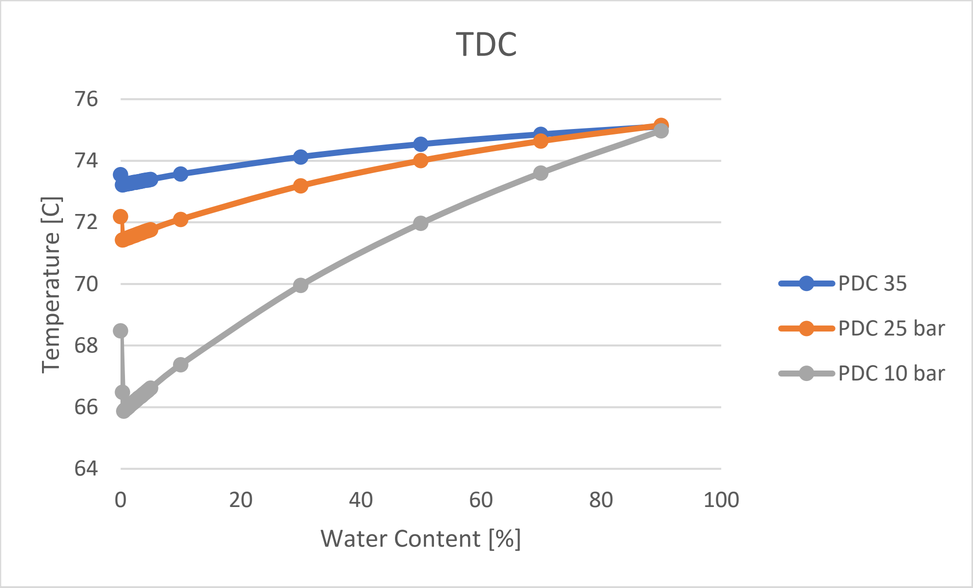


Fig. 6 – Prediction of temperature downstream the choke as function of water content using PVTSim Nova. Upstream temperature and pressure 75C°, and 50 bar.

Figure 6 illustrates similar behaviour for conditions around the average temperature and pressure of the wells we provide service for.

The results in Figures 2-6 give an example of how trending of TDC can give an insight about water content in the system by running several sensitivities and trending for the fluid at hand. They show clearly that TDC sensors have more information to offer for VFM systems than currently utilized. Therefore, advancing TDC sensors and research work for finding a proper bias and uncertainty compensation mechanism, is of very high importance.

The trending also motivated for a walk-through wells data to see if similar patterns can be captured. The next subsection discusses this in more details.

3.2 TDC sensitivity to water content – Well life

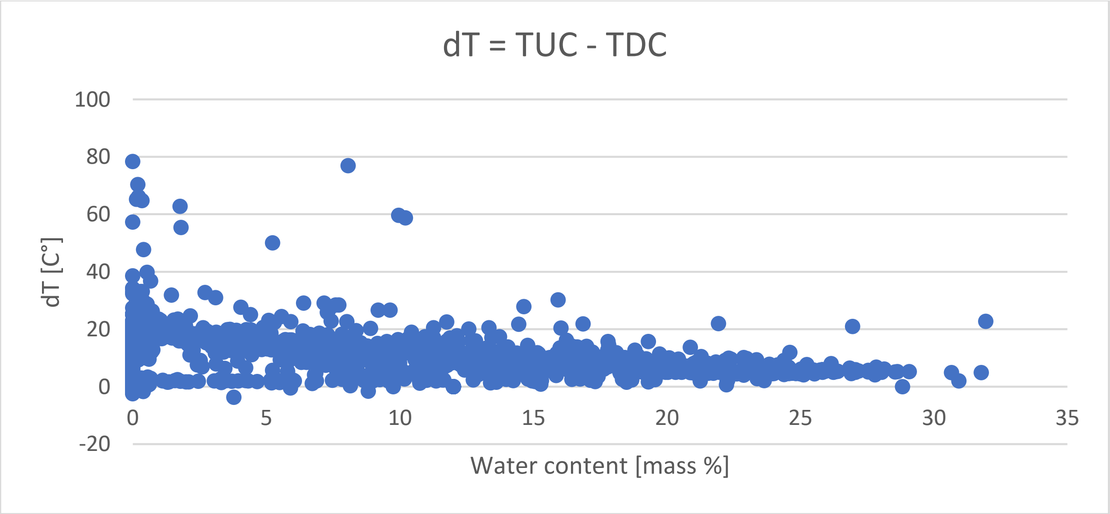


Fig. 7 – Temperature change across the choke as function of water content.

The results shown earlier motivated for looking at temperature change across the choke over a well life as water cut increases. Figure 7 shows the temperature difference between TUC and TDC for a generic well where data was masked. The masking of the data does not influence the trend. The figure demonstrates that regardless of the changes in all the other parameters of influence (e.g. choke opening, PUC, PDC, etc.), the trend observed using PVTSim Nova was reflected in the data. Figure 7 shows that TDC with respect to TUC in terms of dT is getting smaller as the well gets older and water cut rises.

As stated earlier water cut is usually manually set in VFMs. Utilizing the sensitivity study presented here has the potential of defining a more accurate and continuous approach for estimating water cut within VFM. Consequently, better predictions for the other two phases and the fields behaviour can be achieved.

3.3 Tab file approach

This section of the article explains the attempt to study the possible inaccuracies and erroneous situations of using Tab file approach and/or not updating it as the field operational conditions change. Data and figures that are redundant in behaviour were not included here. All the previous operational conditions in section 3.1 were simulated using Tab file approach. The original Tab file provided by the operator was 50 by 50 grid points and saturated with 1 percent water. The approach did very well for the operational conditions near the conditions at which the Tab file was water saturated, as shown in Figures 8 and 9. The error compares to PVTSim Nova were less than 4% in terms of maximum absolute deviation (AD).

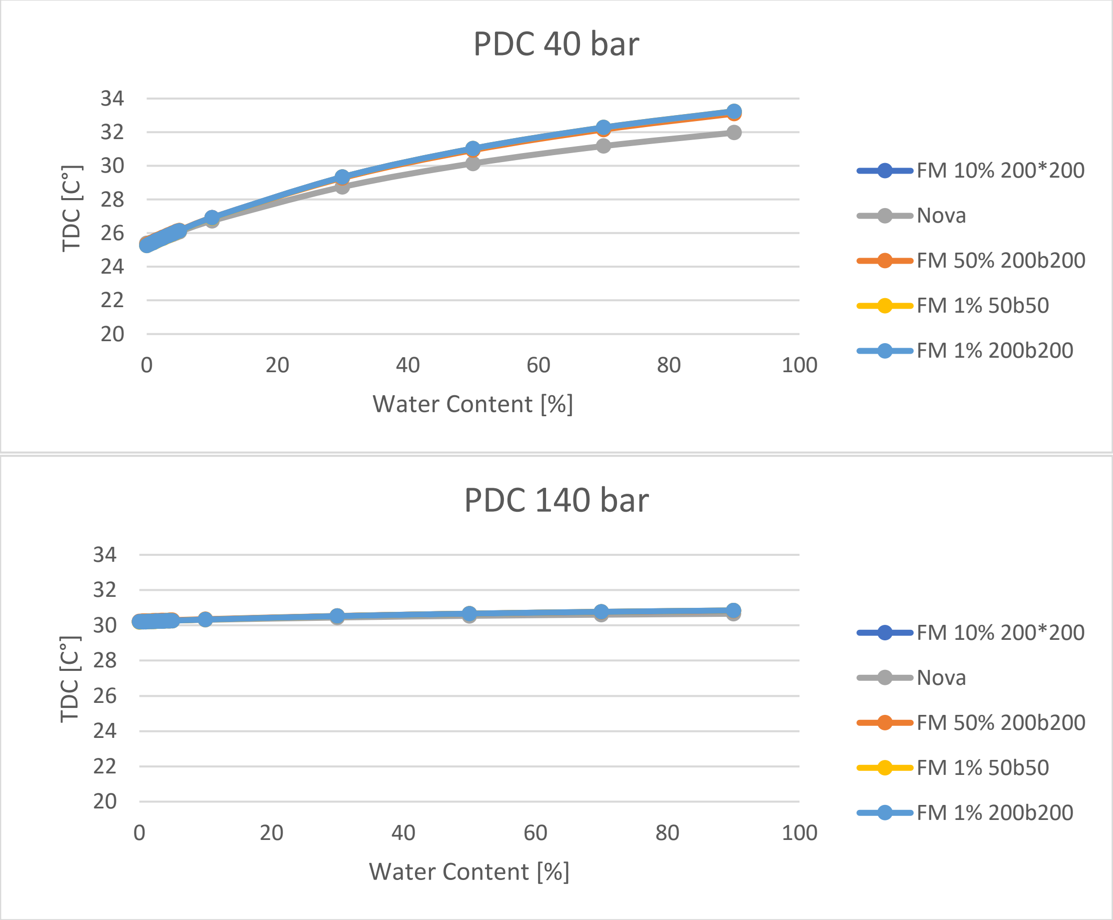
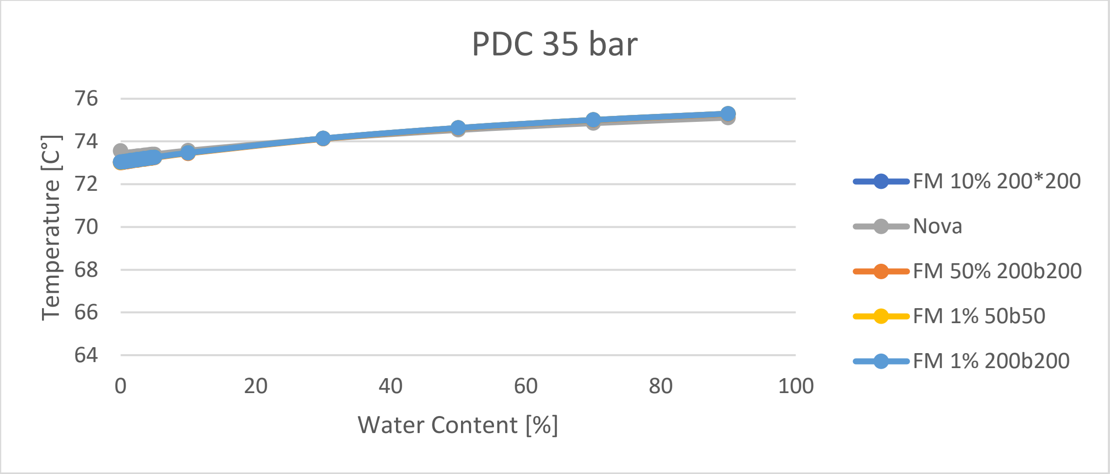


Fig. 8 – Comparison of TDC prediction using PVTSim Nova vs. tab files with different resolution and water content. TUC 30 C°, PUC 180 bar. Two PDCs of 40 and 140 bar.



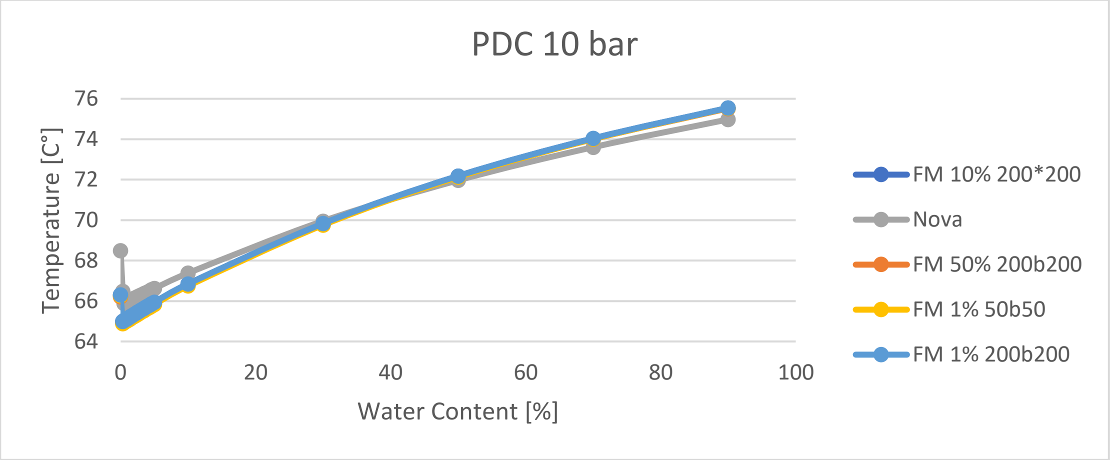


Fig. 9 – Comparison of TDC prediction using PVTSim Nova vs. tab files with different resolution and water content. TUC 75 C°, PUC 50 bar. Two PDCs of 10 and 35 bar.

Nevertheless, there were circumstances where the accuracy using the original Tab file was significantly deviating from these produced by the EoS as shown in Figure 10. To investigate the contributing factors further, the analysis was repeated using tab files that are more refined (200 by 200) grid points. This was to investigate whether the loss of inaccuracy was due to interpolation. Figure 10 shows that refinement was just enough to improve accuracy significantly and confirm the doubts that grid spacing plays a role.

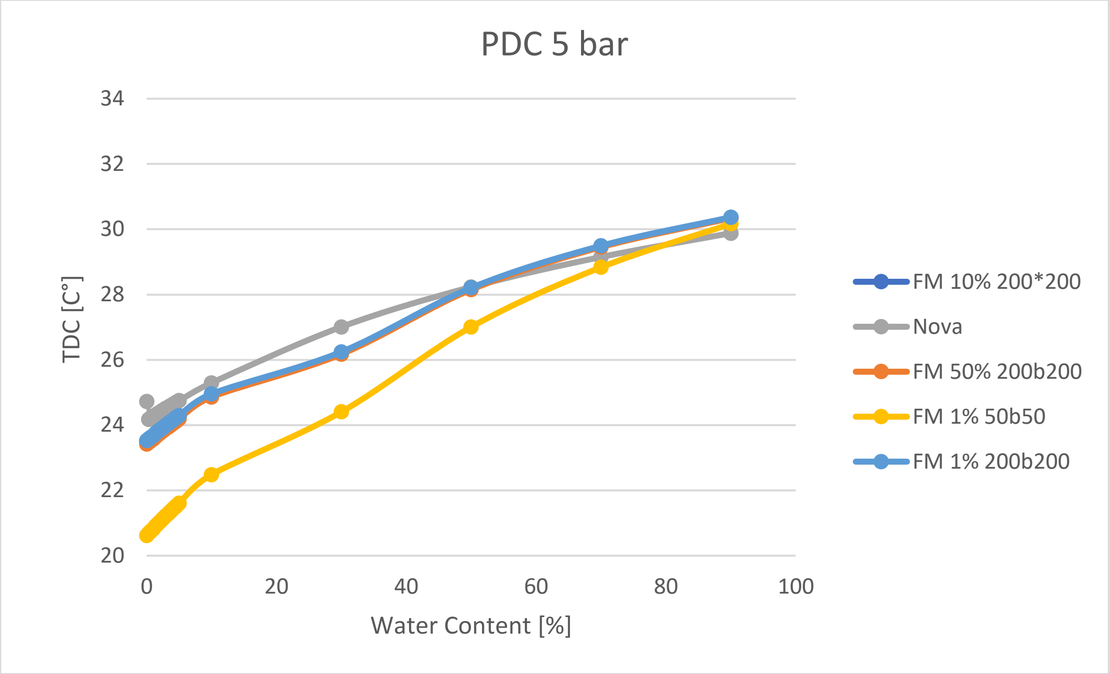


Fig. 10 – Comparison of TDC prediction using PVTSim Nova vs. tab files with different resolution and water content. TUC 30 C°, PUC 20 bar. PDCs was 5 bar.

Moreover, in some situations the error was large, and Tab file refinement was not sufficient to improve the accuracy. An example is illustrated in Figure 11. To investigate the source of this problem, a Tab file was produced for each water content that was simulated. The comparison plotted in Figure 11 shows that from certain threshold the simulation using Tab file has improved compared to PVTSim Nova. This threshold was the amount of water that was enough to saturate the other two phases for the given new conditions. For the scenario plotted in Figure 11, the threshold was 10%. As seen from the Figure 11, 10% has improved the results significantly compared to the Tab file that was using 1%. The 10% Tab file was as good as 50% since they overlap.

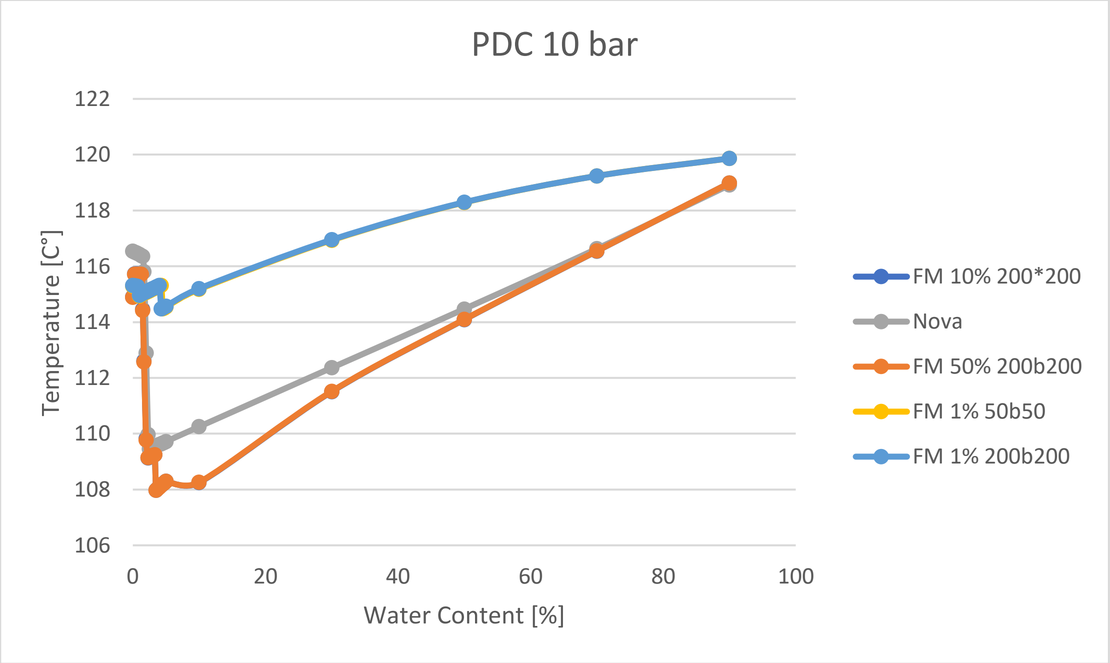


Fig. 11 – Comparison of TDC prediction using PVTSim Nova vs. tab files with different resolution and water content. TUC 120 C°, PUC 20 bar. PDC of 10 bar.

From the findings of this preliminary study, a frequent Tab file independence study is recommended as a practice. We believe that it is an important complement to the tuning process of the VFM. An independence study means finding the Tab file refinement and water content at which the results within the operational envelop would not change with significance as we refine the tab and vary the water content.

4 SUMMERY AND OUTLOOK

A sensitivity study of TDC vs water content was conducted. There was a clear trend and significant sensitivities found as the PDC drops and water cut increases above certain thresholds. Similar trend within a well data set was confirmed for one example with real data. The water cut-TDC signature for more wells is to be investigated. The potential of utilizing this signature for implementation of a continuous approach for estimating water cut should be investigated further. The impact on accuracy of coupling such an approach to VFM is to be assessed.

Furthermore, the quality of Tab file PVT approach was evaluated. The Tab file performs well in many circumstances. However, when the Tab file was stretched to cover conditions far from its static basis, predictions were not accurate. There were also circumstances where there was a loss of accuracy from Tab file due to interpolation. For these cases, grid refinement was a successful remedy. From the findings of this preliminary study, a frequent Tab file independence study is recommended as a practice when tab files are used.

The work has covered utilization of Tab file approach for a wide range of TUC, PUC, and TDC. Nevertheless, more work is required to study higher GOR fluids and study sensitivities when varying GOR while keeping gas liquid ratio constant. Moreover, comparing cubic EoSs to various more advanced EoSs for achieving a better characterization of the fluids should be assessed. Finally, a recommended practice for PVT in VFM should be addressed.

5 ACKNOWLEDGMENT

The authors would like to thank Lundin Norway AS for funding this work through the Subsea Fiscal Metering research and development project. Moreover, we would like to thank Ole Marius Moen for configuring the FlowManager® setup and providing inertia during early phase. Furthermore, we would like to express a deep gratitude to Jaldeepsinh Chauhan and Hashem Nekouie for running the FlowManager® simulations, harvesting the data and aligning them for comparisons. Finally, we would like to thank all our colleagues at TechnipFMC-Field Performance who have contributed through specialized discussions or proofreading, including but not exclusively Ricardo Paggiaro.

6 NOTATIONS

VFM	Virtual Flow Metering
EoS	Equation of State
TUC	Temperature upstream the choke
TDC	Temperature downstream the choke
PUC	Pressure upstream the choke
PDC	Pressure Downstream the choke
hUC	enthalpy upstream the choke
hDC	enthalpy Downstream the choke
$Q^{\bullet}$	Volumetric flow rates.
GOR	Gas to oil ratio at standard condition

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