Abstract
With a renewed mandate to optimize the production from offshore assets, an oil and gas company is in the process of deploying a field-wide well performance monitoring system based on Well Performance Monitor. The pilot project implemented in one of the field’s facilities validated the fact that Well Performance Monitor will assist engineers in their well surveillance tasks. Well Performance Monitor is Powered by Matrikon, which represents vendor neutrality. This product works with third-party control systems and applications.

Well performance monitoring enabled production engineers to optimize the use of their time by being able to quickly pin-point issues and initiative corresponding actions in less time than previously required.

Based on cleansed real-time measurements and updated well performance curves obtained from well models, Well Performance Monitor gathers the real-time and production data and determines a wells operational mode and estimated real-time well flow rates.

All results are presented in a colour-coded two dimensional map of the entire field that allows the quick identification of production losses or well instability. Users intuitively drill down to access process variable trends and schematic displays that are presented in the context of the well as part of a field-wide hierarchy.

Process signal cleansing and filtering is also an important component of well performance monitoring and its influence on the outcome of the real-time rate calculations can be illustrated. Maintaining production levels in large and mature gas-lifted fields is challenging in the face of typical problems such as artificial lift equipment faults, sub-optimal water injection rates, scale build-up and high water-cut producers. In these circumstances, the real-time visualization capabilities of Well Performance Monitor play a key role in reducing the amount of time that engineers use for data gathering and issue identification.

As a result of the initial successes, Well Performance Monitor implementation is in the process of being expanded to the entire field of over 300 wells.

Introduction
Large and mature onshore and even offshore fields are becoming more and more prevalent. A frequent solution to maintaining production from wells with declining reservoir pressure or increased water-cut, is the deployment of gas lift as a method for artificial lift. However, gas lift is not without issues of its own.

Compression plant constraints and unplanned shutdowns, hydrate formation and gas lift equipment faults all contribute to unexpected production losses that require constant surveillance from field production engineers. In addition, typical field problems such as scaling and water breakthrough can also have a long term impact on well production.

In the face of these problems, production engineers are often challenged to identify, analyze and solve problems at well and field levels in the most efficient manner and in the least amount of time. The oil and gas company identified the need to provide their engineers with the tools necessary to gain visibility into their operational status and as a result, well performance monitoring technology was deployed at one of their offshore facilities.

Well performance monitoring allows engineers and production managers to focus on the problem wells that may be showing signs of performance problems. The technology also provides users with real-time trends and displays required to analyze and diagnose problems in a prioritized and time efficient manner. The hope was that engineers and managers’ valuable time would be optimized in problem solving rather than spending it manually gathering information for the necessary analysis.

It should also be noted that the SCADA system console that was available onshore at the time of the pilot project was neither user-friendly nor re-configurable and therefore a more robust, realtime data monitoring and visualization system was deemed necessary.
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Well Performance Monitoring

The pilot system was deployed for all 42 wells of one of the field’s oil gathering facilities. Real-time data was gathered through an interface with the automation system and stored in a commercially available process data historian. The system was connected to the historian and relevant production databases to gather all the information in the context of pre-configured “well objects”.

Process Data Cleansing

Real-time data is pre-processed with a proprietary algorithm simply known as “data cleansing” in which all non-natural real time signal values are removed. By using data cleansing as opposed to traditional filtering techniques is important in order to preserve the real-time pattern of behavior of the process signals. The process signals reveal the true nature of the underlying process dynamics of the operational asset, in this case the real time behaviour of the producer and injector wells. The importance of these non-traditional data cleansing techniques is illustrated in the sections below.

Real-time cleansed data is written back to the process historian so it can be accessed by all realtime data consumers and data visualization users. Using the cleansed data, certain calculations and behaviour estimations are performed by the system to aid in the detection of changes that could be considered as potential production losses or well problems.

Well Mode Calculation

Using a cleansed pressure signal, the wells “Mode” is calculated based on the amount of variation of the pressure during a defined time period. If the production wing valve is open, the well can be considered to be in “Stable” or “Unstable” well production mode. “Stable” if a certain variability threshold based on the same well’s typical behaviour is not exceeded and alternatively “Unstable” if it is exceeded. If the well choke is closed, the well is marked as “Shut-In”. This basic configuration can be enhanced based on particular field’s behaviour and real time signal availability.

Real-Time Well-Rate Estimation

Using the cleansed data, the wells oil, gas and water rates are estimated based on the wells performance curves. These performance curves have been extracted using a third-party well modeling (nodal analysis) application in the form of a flat text file, known as well performance curves or sensitivity curves, containing the performance of each well for each well head pressure and gas lift rate setting. The well performance curves are generated by the field’s optimization engineers using calibrated well models.

Figure 1 illustrates a typical performance curve set with each curve representing the production rate corresponding to one well head pressure and the Xaxis representing gas lift rate in MMscf/day.

Well Performance Monitor performs a bi-linear interpolation into these curves with each pair of valid (cleansed) well head pressure and gas lift rate point sampled from the field to produce an oil, gas or water rate estimation.

A set of curves can be derived for oil, gas and water rates. The end result is a trend of the real time calculated rates according to the real time signals and the well’s performance curves. Examples from two wells are shown in Figure 2 with the oil, gas and water rates represented in red, black and blue respectively. Note the discontinuity in the rate estimations in the middle of the trend corresponding to the point in time where the well model performance curves were updated by the field engineer. The system continued calculating the rates in real-time using the new performance curve files.

Figure 1 - Real Time Well Rate Calculation

Figure 2 - Calculated Well Rate Trends
This calculation method is not complex, performance curves and interpolation techniques are common concepts in engineering calculations. This is important because the calculations performed by the system can be easily understood and interpreted by production engineers who do not need to regard the system as a “black box” type device, which makes implementation and deployment of these types of technologies more difficult to adopt.

This rate calculation technique is also computationally efficient, several times faster than the simulation tools used to generate sensitivity files, making the scale-up of the system to a large number of wells feasible without compromising the frequency of execution of the calculations.

Well models are validated and if necessary calibrated at regular frequencies using latest production well tests. The output from a well model is the set of well performance curves and from this, text-based performance curves can be extracted. The rate calculations will be accurate so long as the well model remains valid and the real-time signals are accurate.

Of course, a sudden change in water cut or GOR will completely invalidate the well model assumptions and the resulting rates; however, changing conditions in the well behavior or composition will definitively make the well’s process variables and the well rate calculation trend change with a specific pattern that can be recognized by engineers. These patterns are also subject to characterization and Well Performance Monitor’s rule-based engine could be configured to alert in such cases. An example of this is the signal characterization in wells “watering out”, presented as a case for the use of intelligent agents by Randi-Helene Halmøy et al in the 2008 SPE Intelligent Energy Conference.

**Well Capacity and Well KPIs**

Well Performance Monitor also has the capability to connect to relational databases in order to map time-indexed relational database data as process data tags. This feature was used to tap into the production database and obtain the well capacity (or potential) and the trend of well test results for every well. This data can now be displayed and trended within the system as any other real-time process variable.

Well capacities are revised for each well on a weekly basis and any changes made to the database are automatically captured by the system for the purposes of well surveillance. Capacities represent an average production rate for the well and are adjusted based on performance changes observed from production well tests.

Having obtained access to the well capacity, the following KPI (Key Performance Indicator) can be a measure of the well’s performance with respect to its estimated oil production capacity: calculated in real-time. The KPI provides a measure of the well’s performance with respect to its estimated oil production capacity

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\text{Well Performance KPI} = \frac{\text{Estimated Oil Rate}}{\text{Well Capacity}}
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If this index is less than, say 0.75, the well should be investigated for a possible production loss. If, on the contrary, the index is 1.20 or higher, this might signal an invalid well model, significantly different production conditions than expected or an unexpected change in water cut. In any case, the index serves as a surveillance index for all wells.

**Visualization**

All the information gathered by Well Performance Monitor is summarized in a two-dimensional map showing all the wells in each facility, area or field. Each well is represented by a block whose size and colour can be mapped to different well-based variables or indexes. The default map of the system displays the size as proportional to the well’s oil capacity and the colour as the Well Performance KPI explained above. The bigger blocks (automatically grouped in the top-left corner) are the most important wells and the ones tending towards the red are the ones producing considerably below capacity as shown in Figure 3.

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Clicking on each well block allows the user to drill down to well-specific schematics displays and trends that can be used to perform more in-depth analyses on the behaviour of each well, as illustrated in Figures 4 and 5.
Process Signal Cleansing

It is common knowledge that real-time process data can lead to several potential problems with the quality of the data, either because of faults developing in the different system and system interfaces from the signal transmitters (fully digital with modern technology) up to the process historians, or due to noise introduced by measurement methods and the nature of the process.

Examples of these are faults developing in signal transmitters, but more frequently in the interfaces between SCADA/DCS systems and the historian will show as flat-lines or missing data, with the signal quality indicator remaining in its last state: i.e. “good”. Flow measurements will be inherently very noisy. Swivel type contacts in offshore turrets and dirty connections in general will also generate signal drop-outs and noise. The movement of offshore platform structures will introduce noise into otherwise stable level measurements.

The conventional approach to noise reduction has been traditional filtering techniques, but it is well known that these introduce delays and distortions in the behaviour of the process signal masking one of the most important features of real-time data: the pattern of behaviour of the real-time trend. The simplest traditional filtering technique is averaging which works based on the assumption that an average calculation will cancel any disturbances or unwanted noise (which will be effectively true while dealing with zero-mean noise); however, the evident side-effect of averaging process data is the masking of features that can be quite important: the process dynamic characteristics.

In this context, the ideal process data cleansing “filter” would remove any non-natural process signal values, without affecting the normal pattern and dynamics of any legitimate process data variation. This process will be referred to as “Process Data Cleansing”, as opposed to traditional filtering techniques.

Process Data Cleansing is not so critical for human process data visualization; i.e. presenting the data in trends to human users, because the human mind can automatically ignore noise and focus on average values to perform the required analysis.

However, when real-time process signals are used for on-line calculations, it is quite important to “cleanse” the data in order to achieve trustable real-time calculations that can be used for display and trustworthy intelligent alarming.

The importance of process data cleansing is not readily evident; so to illustrate this point and investigate the effects of noise in the real-time calculations performed in this project: i.e. well rate estimation using well performance curves, a simple experiment was performed as depicted in Figure 6.

Synthetic wellhead pressure and gas lift rate signals within the range of a real well model were generated. Normally distributed zero-mean noise and spikes were added to the signals keeping the noise levels low and the signal to noise ratio relatively high. The noisy signals were used to estimate the well rates first filtering the data using three methods:

- raw signals, with no data cleansing or filtering (Red trend)
- simple 30 minutes average (Yellow trend)
- well Performance Monitor data cleansing technique (Black trend)

The results are shown in Figure 7. The rate calculated with raw signals (Red) exhibits a very noisy behaviour which actually masks the true dynamic low frequency behaviour of the process variable. In fact at some points the rate estimation fails because the operational point of the noisy signal is not within the input range of the well performance curves (grey dots). On the other hand, the rate calculated with non-standard data cleansing techniques (Black) exhibits a smooth behaviour, in accordance with the process dynamics. Finally, the rate calculated with the averaged values (Yellow) does not follow the dynamics of the process and is frequently out of sync with the black (cleansed data generated) trend. The same exact rate calculation technique was used in each case.
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Figure 6 – Data Cleansing Experiment Set-Up

Figure 7 – Data Cleansing Experiment Results
Comparing the results of the totalized volume in 12 hours with the total volume of the rate calculated with the signals before the noise was added (reference rate) results in the following errors:

- rate from raw signals: 15%
- rate from averaged signals: 0.3%
- rate from Cleansed signals: 0.03%

Although the use of average signals does significantly reduce the error due to noise in the presence of the zero-mean noise introduced, it fails to represent the true well process dynamics.

**Initial Results**

The field operator engineers were thrilled to have the real-time data of process measurements for each well available at their desk in a web-enabled tool. Previous initiatives to make this data available consisted of a control system console in one of the offices. The console, being for the purpose of process monitoring and control and being in a remote location from the operations had a slow response time and did not have displays suitable to the needs of the engineers.

Access to the data on the new system on a well by well basis was easy and intuitive and the surveillance of field well conditions was performed in a fraction of the time.

The well rate calculation for a good number of wells was intermittently failing because the well’s operational point was not lying within the input domain of the well performance curves. This can be for one of two reasons: the well performance curves were generated with a too narrow operational range or the well models are altogether outdated and need to be updated with the current well operational state and conditions. This unexpected result provided focus to those engineers charged with validating and calibrating the well models.

Another important group of wells was seen performing according to capacity and as such appeared as “green” blocks in the well performance visualization map. It was observed by one of the users that the system effectively combined information from three systems: the real-time database, the relational databases and the well model files, to produce a single vision of the field where discrepancies can be analyzed. In the case of the “green” wells, no major discrepancies were found: effectively the real-time estimated oil rate using the well models and the real-time measurements were in agreement with the wells officially estimated capacity stored in the production database.

The engineering team is only starting to realize the full potential of the system and have mainly focused on the use and trending of real-time measured variables. But the use of higher degree calculations for the well rates and mode and the automatically calculated well performance KPI will come with time, as they seek new ways of interacting with the system to characterize changes in well behaviour that represent typical failure modes. The fact that these calculations are easily understood will help in the process of adopting their use.

In spite of the short time using the new system, the field operator’s management team is convinced of the key advantages of the new system and has already commissioned the extension of the system to all the field wells.

**Key System Advantages: Simplicity and Configurability**

For successful use of optimization tools for the upstream oil and gas industry, it has been observed that upstream asset optimization tools need to be as simple as possible, robust and easy to learn and use. This is true for the implementation of any upstream real-time information system. The use of technology in upstream operations has been challenging if compared with the extensive deployment of higher-level control and optimization techniques used in downstream process operations. Based on field experience, black-box type approaches are being discontinued because the users will not understand how calculations and results are being achieved and they will tend to distrust such results.

The system deployed in this field is simple and easy to use based on the fact that:

- it can be accessed from a common web-browser
- it is intuitive to use and places all related information in the context of the production asset being analyzed; in this case, the well
- performs simple, easy to understand calculations such as the Mode, Real-Time Rates and the Well Performance KPI

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At the same time, the system is also highly configurable, and can grow with the growing demands for higher level analyses and calculations expected from the more mature and demanding users. When users have been accustomed to using the basic features, the system could be developed further to include:

- intelligent alarms to warn of failure modes characterized as changes in the real-time operational conditions.
- real-time performance maps; where the operational point is seen moving in historically and in real-time in the well performance curve plane.
- extensions into Production Operations workflows such as executing and analyzing well tests and requesting well work-overs.

Recommendations

Based on this experience and similar projects, the recommended roadmap for new technology deployment projects as applied to upstream operations is as follows:

**Stage 1:** Deploy a productized solution in a limited, but representative area of the field. The solution must contain all standard features applicable to the field with little or no requirements gathering from field personnel. This stage will also highlight data communication infrastructure issues or other technical constraints that may exist in the current systems.

**Stage 2:** Allow users to experience and use the new technology and propose enhancements and features that will increase the benefits of the new technology in their daily operations. Users will acquire hands-on knowledge of the possibilities of the new technology. The data cleansing algorithms can also be validated and fine-tuned at this stage using dynamic modeling if necessary.

**Stage 3:** Incorporate a rationalized new set of features into the solution before extending its use in the rest of the field.

**Stage 4:** Continue to incorporate more elaborate features and workflows in parallel with the growth in the use of the solution. Complex solution features are not deemed feasible if users are not prepared to take advantage of them or will actually deter new users from adopting the use of the new technology.