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Continuous Well Production Flow Monitoring and Surveillance

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Abstract

In E&P, from asset managers to front end operations staff, there is a common problem – we are data rich, but information poor. In particular, timely well-by-well production surveillance and allocation often remains a problem. Gathering data, even real time data, from wells and facilities hasn't been an issue, but validating the data and relating this data to individual well production rates in a coherent, consistent and timely manner and then taking prompt action, is a challenge. Traditional routine well testing simply provides a series of snap-shots of a well's performance, which may or may not reflect the production during the intervening period. Errors are typically spread across the wells and reservoirs through a reconciliation process comparing estimated well productions and actual metered sales on a weekly or monthly basis.

This paper describes the development and application of a new tool, FieldWare* *PRODUCTION UNIVERSE* * (PU)[1], which estimates real time well production rates from simple field measurements and provides online reconciliation against bulk measurements and export meters. The novel aspect of the technique is that it uses dynamic, data-driven models to describe the production process, together with a new well test methodology for capturing the data to build the initial models. Well tests include a deliberate disturbance to the production to determine the dynamic characteristics of a well. The models do not require underlying physical or process models, predetermined multiphase flow correlations, compositional data or well/piping/equipment details. This has made the models quick to set-up and easy to maintain.

FieldWare *PRODUCTION UNIVERSE* is now fully operational and used for well-by-well production surveillance and monitoring at many of Shell's production facilities worldwide, both onshore and offshore. The application of PU has helped increase production through improved monitoring, resolved hydrocarbon allocation problems through real time reconciliation, allowed an increase in time between well tests and reduced travel to field locations.

The availability of real time production data is a key enabler for future smart optimization and intelligent diagnostics. PU is a foundation element for Shell's Smart Fields initiative.

Introduction

This paper is intended to introduce the Shell's *PRODUCTION UNIVERSE* project at a high level and share some of the experiences and findings of the first phase of the development. In particular, we wish to highlight the PU application as an example of the innovative synthesis of oil and gas operational and technical expertise and state of the art mathematical techniques.

Historically the oil and gas production industry has relied on traditional methods for individual well production flow monitoring and surveillance. This provides periodic well test information using test separators or multiphase meters, sometimes supplemented with real time pressure and temperature data gathered from the well between tests. Since the test separators / multiphase meters are normally shared among a number of wells, the actual performance of a well is only measured periodically or on demand. Typically around 2% of the well monthly production is measured by well testing. Thus the surveillance of individual wells is a periodic discontinuous process. This is not optimal, as many well problems are not detected until a well is re-tested. Well test conditions may be very different from actual operating conditions.

This conventional surveillance and monitoring methodology is premised on the concept that oil and gas production systems were largely steady state and these snap shots in time were adequate to manage the business. However in many fields, well performance and plant-operating conditions can change rapidly and there is value in closer and more regular well production surveillance. Furthermore when a field enters a period of rapid production decline, it requires a higher level of attention and higher frequency of data gathering. The inadequacy of the "snap shot" paradigm then becomes even more pronounced.

[1] FieldWare and Production Universe are trade marks owned and used by companies of the Shell Group

Within the industry, some attempts have been made to use well and process flow physical models to provide real time estimates of well production. However, these have proved to be tedious to set-up /calibrate and difficult and expensive to maintain, particularly in a typical operational environment. Nevertheless, there continue to be a number of such systems in operation, mainly restricted to the more high value or critical wells with relatively stable performance.

In order to move to a continuous real time model for well flow monitoring and surveillance, and to fully utilise the flood of data becoming available, new robust tools suitable for the oil and gas production environment were needed. This was the initial driver for the development of FieldWare *PRODUCTION UNIVERSE* (PU).

The concepts used in PU take well surveillance and optimisation into an exciting new dimension. By moving from a monthly allocation, surveillance and monitoring process to a daily /real time process significant benefits have already been realised in Shell operations worldwide.

The use of increasingly abundant real time data for better management of oil and gas production has been discussed at length in a large number of papers. We cite, for example, the papers listed in the references section. The contribution of the *PRODUCTION UNIVERSE* development is that it provides a concrete, sustainable, operational solution for a fundamental problem in oil and gas production surveillance: What is the real time multiphase performance of each well?

Development of FieldWare *PRODUCTION UNIVERSE.*

In the late 1990's a data driven modelling application was developed to track the performance of a well test in real time, which was later to form the heart of the FieldWare WellTest application. This experience provided the foundation for the more ambitious PU development. The R&D commenced in 2000 with seed ideas originating from recent mathematical and control theory concepts. The project was initially viewed as extremely speculative, but was deemed promising enough to receive R&D seed funding.

A key decision was made to apply selected mathematical and control theory techniques to existing unvalidated and under-utilised real time data gathered directly from the actual production facilities in the field. The techniques used included, among others, non-linear optimization for the modelling and reconciliation process, fuzzy modelling, soft sensing and dynamic black-box model identification using subspace and output error techniques. An example of the underlying mathematical insight is the geometric interpretation of the reconciliation process. Here, the reconciliation process is envisaged and solved as a best approximation in an inner product space to the total production, from a set of "admissible" linear combinations of the estimated separate well productions. This set of 'admissible' well productions in turn is a convex set in the linear span of the estimated well productions

Support was received from several Shell Operating Units that provided testing on actual facilities, hence, the PU development was exposed from an early stage to the "real life" oil and gas production environment. Issues encountered included instrumentation calibration errors, sub-optimal well performance, logistical problems, well testing errors, control loop performance issues, busy operations personnel and concerns over production deferments caused by well testing.

The PU project also received invaluable support from Shell Operations and Central Production Leadership as its development started to obtain results.

A pragmatic approach was taken to the development of *PRODUCTION UNIVERSE.* Prototypes were developed using Matlab and then translated into full product version (RAD – Rapid Application Development approach). The prototypes were in use by end users (Shell production operations staff) for extended periods prior to coding of the product versions. This reduced the time needed to get the early prototype version of PU into use and to provide the users significant opportunity to steer the final product. The initial product version of PU was deployed in late 2003.

The PU development project continues with the objective of establishing the full benefits of the use of real time data and data driven modelling within the oil and gas production environment. There is also continued effort to refine the product to further increase its accuracy and sustainability as experience with real time production management increases. Work is currently in progress on PU Version 3. Version 2 is currently being rolled out globally to the top 60 Shell assets by Shell Global Solutions.

Fundamentals of *PRODUCTION UNIVERSE.*

PU provides dynamic data driven models of the production system from wells to export point. Due to the way it is constructed PU accurately reflects the production flow behaviour of the actual wells and plant. The well models estimate water, oil and gas production flows in real time, primarily from well instrumentation and propagate these flows through the model. Effects such as back out of weaker producers at headers are captured in these models.

The initial well models can be derived from historic well test and production data. These data are typically extracted from a real time data historian such as OSIsoft's PI. Alternatively the initial well models can be generated from multiple runs of a physical model such as Petroleum Expert's, Prosper or AppSmith's Inc.WinGlue™.

For a particular well a number of models can exist, combing discrete sets of measured parameters. There is generally a preferred model which best reflects the well's behaviour. The secondary models can be used as a fallback option, should an instrument contributing to the preferred model fail.

There are no physical models used – no well tubing diameters, no roughness, no fluid properties, no near well bore "skins", and no pre-assumed multiphase flow correlations. Well measured parameters are related to volumetric flow as recorded on a test separator or multiphase meter.

The data driven approach has proven to be robust and usable in the oil and gas production environment for real time operations.

The use of physical models is still extremely valuable, particularly in combination with the data driven models.

A key aspect of PU is the Deliberately Disturbed Well Test (DDWT), which is used to characterise well performance. These tests are conducted with either conventional test facilities or multi phase meters, but go beyond traditional production well testing. The objective is to relate well production (oil, gas, water) to the dynamic behaviour of measured well parameters e.g. flowing tubing head pressure, down hole pressure, delta pressure, choke position, ESP speed, casing head pressure, gaslift injection rate, temperature. The well is exercised over its normal production range. Testing does not rely on achieving a steady production rate for the well. The emphasis is on capturing the response of the well to step changes in controllable parameters. One of these parameters is the test separator pressure. By varying this the flow line and test header influences on well production (back-out effects) are captured. A DDWT can in fact be shorter than a conventional well test. If there is a series of well test data over a longer period of time, then PU modelling also allows well decline effects to be captured. (Fig 1) In the upper screen showing the DDWT data there are five data sets being used to model the well. In the lower screen of Fig. 1 the parameters used in the respective models can be viewed. Models can be selected/deselected in the upper right hand panel to achieve a best model fit.

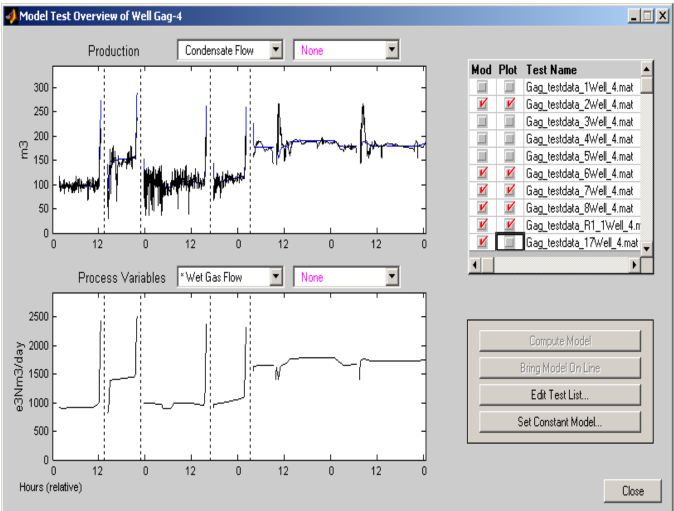


Fig 1. Multiple DDWT Data Sets

Once created the individual well models are used to compute the well production per stream. PU accumulates daily flow per well, which reflects the actual producing conditions, including trips and restarts and plant operating mode changes. These daily volumes are written back to the Data Historian for future reference. The daily volumes can also be validated for input into the Hydrocarbon Allocation database.

Figure 2 shows a typical well. The upper portion of the screen plots the well stream flow and the lower the associated well parameters. The upper right section of the stream displays the current daily cumulative flow and flow outages. The models are allowed limited extrapolation. Where extrapolation takes place the flow is recorded with a broken line. Diagnostics and Communications information relevant to the well are also shown.

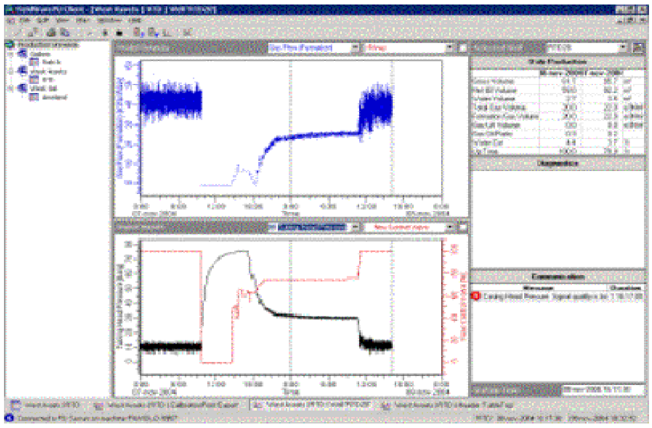


Fig 2. Individual Well GUI

A simplified abstract topography (Fig 3) is constructed relating wells to a calibration point. The calibration point can be a non-fiscal or fiscal measurement. Typically the calibration point is a bulk separator, preferably providing oil, water and gas measurement on a continuous basis. Note that traditionally data from the calibration point are only used for trending and computation of daily production (cumulative flows).

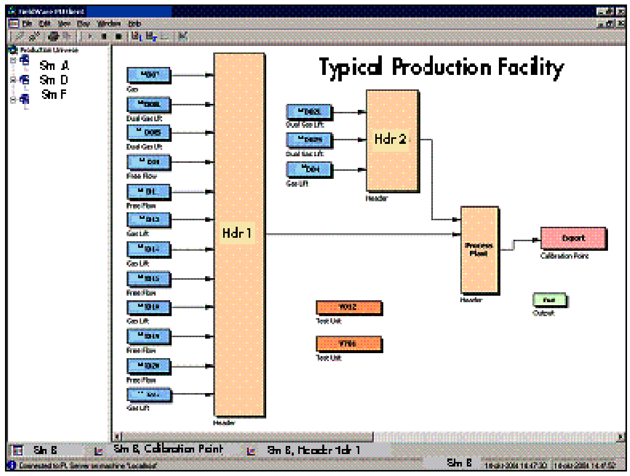


Fig 3- Simplified Abstract Topography

PU production data per well are compared and reconciled automatically against the installation's overall export meter. (Fig 4). This provides a reconciliation factor for each produced/injected stream on a continuous basis for the current day and the last 24 hours. Also reflected in this Graphical User Interface top-level is a diagnostics panel, which alerts the user to events in the production systems. Event detection can be single point measurements or a complex logical mask to detect a specific event e.g. contamination of the water disposal stream with oil, identified by concurrent deviation in water and oil reconciliation factors. There is also an information panel on communication status, which alerts the users to defective instruments and communications infrastructure, for example RTU failure.

With this single screen an asset managers can gauge the current health of their production systems. If all the reconciliation factors are within acceptable bounds he knows his production system is under control – well models accurate, instruments working, communications highway functioning. If this is not the case it is possible to drill down to process, header and well level to locate a problem.

PU retains only 2 days of live data as all raw data resides in the Data Historian. PU can also be configured to write back calculated data to the Data Historian. This can include daily well cumulative volumes, rates, and reconciliation factors.
PU can be re-run from historic data stored in the Data Historian.

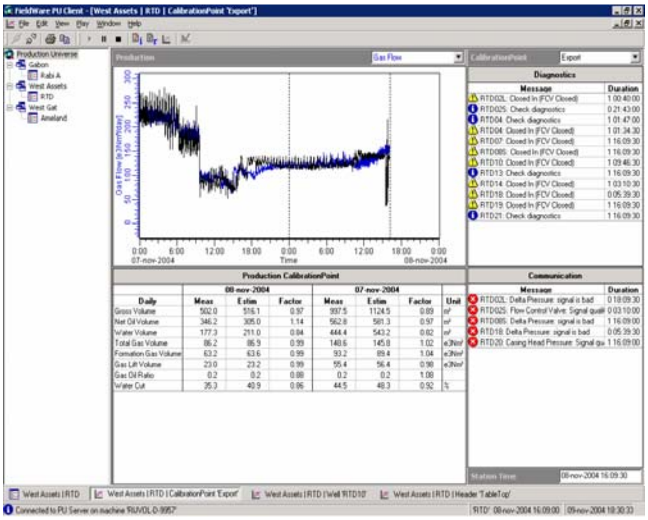


Fig 4 – Top Level GUI

The output from the measurements on the bulk separator (calibration point) in fact provide a 24 x 7 data stream at 1 minute or more frequent intervals. PU uses the dynamic variation seen at the calibration point to further tune its well models. Plant trips and restarts are very visible and generate a lot of useful data especially when the field is brought back on line. The dynamic well models are updated every 24 hours to reflect the total information available in the preceding period. Thus decline in well rate; increase in GOR and water cut can usually be tracked. (Fig 5)

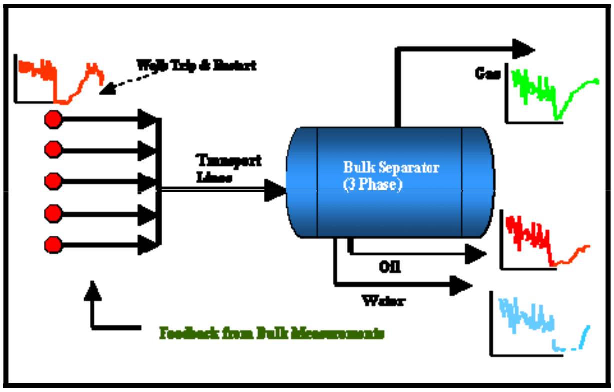


Fig 5 – Reconciliation Concept – Process Dynamics

PU thrives on dynamics (e.g. well bean up / bean down) to continuously update individual well models. Normal E&P operations provide a dynamic environment with well interventions, process trips etc. If assets exhibit stable production with minimal dynamics then dynamics can be introduced. With the wells in the normal production status (i.e. to bulk separation) wells can be beaned up/down for short periods to cause transients to ripple through the process. Single or multiple disturbances can be introduced simultaneously. These pseudo tests are known as Deliberately Disturbed Production Tests (DDPT's). If these tests are insufficient to re-align the models then PU initiates a full DDWT.

PU uses not only measured parameters from wells, but also header, transport lines and facilities data. It is not uncommon to use vessel levels, change in level, level control valve (LCV) position, dP across an LCV, pump speed and valve positions (open/closed) within a total model.

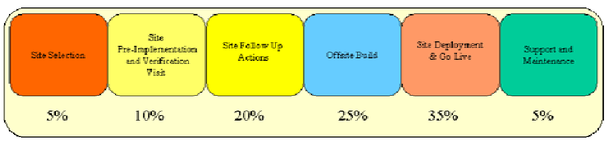
The modeling approach used in PU provides a surveillance tool which is able to track the instabilities seen in most producing fields, as well as being relatively tolerant to errors in absolute measured values and long term instrumentation drift. It's therefore ideally suited to handle the challenges of a real time production environment and can operate robustly with limited intervention.

While the basic concepts of production surveillance are easily understood, it is emphasized that internally PU uses sophisticated mathematical tools and techniques which have been extensively fine tuned to be suitable to the oil and gas production environment.

Implementation Process

Implementing PU is through a proven methodology developed from field experience. This process is rigidly adhered to so that the full value of the application is sustainably realised. PU is only implemented in assets that have passed a readiness check to confirm the instrumentation, metering and communication infrastructure is adequate to support the application and deliver concrete benefits. There are a number of implementation stages:

- Site Selection – ranked on relative gain and ease of implementation.
- Site Pre-Implementation and Verification Visit – field visit to confirm condition of instruments and meters and communications infrastructure.
- Site Follow Up Actions – repair defective instrument and meters.
- Off Site Build – execute DDWT's, configure PU, model wells
- Site Deployment and Go Live
- Support & Maintenance – IT application support, support for users (NetMeeting)



Indicative % effort per phase

Fig. 6 Implementation Sequence

There is a dedicated implementation team for PU operated from Houston (US), Leuven (Belgium) and Rijswijk (Netherlands).

Emphasis is now on improving implementation efficiency and tools to accelerate implementation

It is observed that:

- Implementing PU is as much about people and work practices as it is about the introduction of a new IT application. In particular, PU allows much closer day-to-day well surveillance. Personnel should be well positioned to take advantage of this capability.
- A degree of commitment and effort is needed to get instrumentation, metering and the IT infrastructure in good working order as a prerequisite for the deployment of PU.
- It is only when a tool in place such as PU that various anomalies and data errors in the operational data acquisition systems become apparent.
- The application of PU allows key personnel to keep track of the wells. Hence, well problems and instrumentation are quickly detected.
- Once in place PU provides diagnostics and status information on the validity of the measured data. This allows personnel to identify data problems immediately.
- Asset Managers are suddenly presented with real time information on the state of their asset.

Results

PU implementation has yielded a wide-ranging list of "bottom-line" benefits from Shell operations.

The major areas of benefit seen to date are:

Reduction in Production Decline Rate.

In moving to real time operation and optimisation of a number of fields a significant reduction in well production decline rate has been noted. In one field the annual decline rate was reduced from 20 to 7% and continues to be sustained at this lower level. The reduction is in part attributed to a more stable operation of the field, constant attention to well performance and the early response to well events e.g. early detection of coning well, water break through and manual optimisation.

Optimisation Improvements

By having a good understanding of well performance and the effect of changing separation pressures, and well routing, changes in performance are immediately visible. Where changes have a negative impact they can be reversed immediately. Historically the cycle time for optimisation was days if not weeks. With the current version of PU optimisation of a field is possible on a daily/hourly basis from the office desktop.

Reduction in Deferred Production

With PU data available in real time, wells under performing can be detected quickly and compensated by adjusting other wells or opening up closed in wells. The net result is that for fields where PU has been implemented a reduction in deferred production in typically the range 2 to 5% has been achieved.

Focused Use of Resources.

Implementation of PU has reduced the time spent by production technologists and operations engineers on gathering, validating well data and making decisions. Each engineer can therefore manage many more wells. This has allowed the redeployment of scarce staff to other tasks.

Production Forecasting Improvements

Better well performance data provides a basis for a more accurate short and medium term forecasts. This has been very evident in one particular field where actual production is running consistently 5% above forecast. Previously the gap between forecast and actual was consistently on the negative side. The improved allocation of production to wells will profoundly influence the accuracy of the long term forecast delivered by reservoir simulators. More importantly: it helps us better understand reservoir behaviour and thus improve our business planning.

Stabilisation of Production Rates

On a number of fields there has been a marked reduction in the variance in daily production. The peaks and troughs have levelled off. This again is thought to be a result of the attention paid to individual wells, daily field review and optimisation, and a reduction in plant trips.

Reduction in Well Testing

In one Shell operation no routine well test were conducted for a period of 15 months due to technical problems. PU continued to run and track well performance and adjust the well models accordingly. Reduction in well testing duration and frequency has been achieved in other fields. With PU in place a larger number of wells can be allocated to a test facility. This can have an impact on cost if requirements for additional well test equipment can be avoided. In some cases the test separator can be released to operate as a bulk vessel or for long term well service activities.

PU lets the operator know when a well needs to be re-tested.

Reduced HSE Exposure & Logistics Cost

In another Shell operation the introduction of PU has allowed the release of one service/transport vessel with significant cost savings. The need to have operators regularly visit remote offshore location was removed. The reduction in associated HSE risk is a significant benefit.

Increased Production from Sub Sea Systems

Where a single production flow line services a number of wells periodic well testing can inflict a large deferral of production. With PU and the optimum bulk separator instrumentation it is possible to conduct DDPT's to limit deferment.

PU is currently being deployed on a sub sea production system where down hole instrumentation has partially failed. Implementation of PU may defer large capital expenditure for the replacement of down hole instruments or the installation of sub sea multiphase meters

Production Surveillance Instrumentation and Measurement Data Improvements

PU has become a catalyst or enabler focusing attention on the quality and availability of production surveillance instrumentation and measurement data. As PU is visible and used actively from the "coal face" to asset manager level, it becomes very apparent when instrumentation or measurements drop-out of service, manifested by well model predications deviating significantly from export flows.

Quotation from Shell Users

There are a lot of enthusiastic users of PU in Shell from management to a working level. Some quotes are listed:

"PU is a technology boost and a time saver – it adds capability in our business to allow quick and effective understanding of our well performance, so that we can make decisions more quickly around modifications to well parameters in order to maximise production".

"Implementations in our operation demonstrate the value of FieldWare PU's real time well surveillance capability. The beauty of this technique is that it uses mathematics to estimate well production rates using minimal instrumentation and thus less cost, less maintenance and increased reliability."

"There are great gains to be made from PU – we estimate that our production gain will be between 5 and 10% depending on which field we look at. We also see the technology as being a big contributor to our delivery of our vision for improved reliability and reduced operations costs"

Conclusions.

The development of FieldWare *PRODUCTION UNIVERSE* by Shell has delivered a cost-effective tool for real time well multiphase production flow estimation, which is robust and sustainable in a typical oil and gas production environments. Its implementation has already added significant value and provides a sound foundation for future Smart Fields projects. Implementing tools such as PU requires a fully integrated process, from site selection right through to follow-up support and maintenance. Addressing the people and work practices issues can prove to be more important than the technology itself. Just as Personal Computers are the norm today, real time surveillance from reservoir to point of sale will become the norm of tomorrow across the oil and gas industry. The introduction of FieldWare *PRODUCTION UNIVERSE* takes us a significant step towards this ideal.

Acknowledgements.

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