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Exception-Based Surveillance - Integrating Well Models, Real Time Production Estimates and Hydrocarbon Accounting Tool in Well Operating Envelopes to Ensure Optimal Well Production within Safe Limits

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Abstract

On a daily basis, the Well, Reservoir and Facility Management (WRFM) team screens all producer and injector wells to identify those wells that are under-performing or outside safe operating limits. A 'Well Operating Envelope' tool has been developed, focused on establishing the boundary conditions of various safety-critical parameters and optimized well performance. Current well operating conditions, derived from real-time gauges and flow estimates from Production Universe (PU), are monitored vis-à-vis these parameters via this tool to identify the "problematic" wells.

Various diagnostic tools (i.e. Surface P-Q curves, VLP-IPR Nodal Analysis, Tulsa Flowline erosion model, Gas-Lift response curve, Inflow performance, SC-SSSV pressure plot and Hall plot derivatives) have been used and visualized for better understanding of the well flowing conditions for both production and injection systems. This tool fetches data from multiple databases like Data Historian, Energy Components and Production Universe (PU); it is also capable of interfacing with Prosper and WinGlue to fetch well performance data automatically.

Following improvements have been observed with implementation of this tool:

- Traffic light and graphical representation enables quick well surveillance in identifying problematic wells and taking corrective measures.
- Monitoring of the daily PU estimated production vis-à-vis well tests, allocated production volumes and the physical well models will increase hydrocarbon accounting efficiency.
- Monitoring real-time parameters like FTHP, FBHP, and flowrates allows the Petroleum Engineers and Operations to operate safely within defined boundaries.
- Monitoring of parameters like GOR, drawdown will enable adherence to reservoir management guidelines and reduce potential reserve losses.

Visualization of information from multiple data sources into this real-time tool provides an effective

and efficient monitoring to ensure optimal well production within safe limits on a day-to-day basis for well, reservoir and facility management.

Introduction

This paper presents the critical components required to define the well operating envelopes and the creation of a visualization tool to enable Exception Based Surveillance in order to actively monitor large number of wells for safe and optimal production. The first step involved re-calculating and tabulating the critical well operating parameters like maximum Flowing Tubing Head Pressure (FTHP), maximum flow rate, maximum Closed-in Tubing Head Pressure (CITHP), erosional limits of completion equipment and surface flowline etc. for each well. Realizing that it is difficult to monitor wells vis-à-vis the limits in tabular form, a Well OE visualization tool was developed. This visualization tool is an MS Excel® based tool which extracts real time inputs from Data Historian and production estimates from Production Universe® and maps against the graphical representation of well operating limits. The tool, which was initially designed to monitor the wells with regards to the safety limits, has been taken a step further to aid in optimization. This has been done by introduction of an 'operating window' – a sub-window within the operating envelope window.

Use of the visualization tool facilitates easy monitoring and Exception Based Surveillance (EBS). Production Technologists are responsible for inputting limits into the tool, which is then used by production programmers for their monitoring before the morning daily production review meetings. Apart from ensuring safe operations, use of the tool is estimated to bring down well surveillance time - saving of 1000 man-hours per year by production programmers.

Brunei Shell Petroleum (BSP) has over 500 producing wells of different vintage, located onshore and offshore, spread over a large area with approximately 90% unmanned facilities. About 80% of existing wells have active sand control installed. Gas-lift is the dominant artificial lift method being used. There are water injection wells to maintain the reservoir pressure and help to maximize the ultimate recovery from the reservoirs. Due to the large number of the wells, Exception Based Surveillance is needed to identify the safety critical wells and take corrective actions if necessary.

Well Operating Envelope Description

The operating envelope of an equipment or process is the extent of the approved limits of key operating parameters for such equipment or process. Ideally it is a graphical representation of the operating limits (maximum and minimum) for a selected piece of equipment or system at various operating conditions. The operating envelope can be used to monitor and ensure that the operating conditions are within safe limits, and to determine the bottlenecks of the equipment or process for optimization purposes.

Operating Envelope Definition

As per WRFM best practices, a well OE has been defined for each well in order to ensure conformance to reservoir and well management principles. The well OE is aimed towards establishing the boundary conditions of various safety-critical and production critical operating parameters of the well and monitoring the conditions vis-à-vis these parameters. As the operating conditions of the well change over time, the OEs need to be reviewed and updated accordingly. In addition, an operating window is defined for each well to identify the "sweet spot" where the well is expected to be operating. A well operating within the operating envelope, but outside the operating window, would indicate we might be within safe limits, but this would indicate a scope of optimization with respect to current well condition.

Operating envelopes and Operating windows are critical elements in the WRFM program. They are vital for performing efficient Daily Production Reviews: data showing that the well is outside the defined operating envelopes or windows needs to be discussed and action plan agreed during this review in order to move the well back into the operating window.

Table 1—Recommended performance curves to be used in the Operating Envelope definition

Well Type	Available Instrumentation	Performance Curve			
		Surface P-Q Curve	Inflow Performance Curve	Lift Response Curve	Hall Plot
Natural Flowing wells	FTHP	Yes			
	FTHP+PDHG	Yes	Yes		
Gas lifted wells	FTHP	Yes			
	FTHP + Q_{INJ} meter	Yes	Yes	Yes	
	FTHP + Q_{INJ} meter+ PDHG	Yes	Yes	Yes	
Injectors	FTHP + Flow meters	Yes			Yes
	FTHP + Flow meters+ PDHG	Yes	Yes		Yes

All the parameters are measured frequently (routine surveillance tasks, permanent gauges) or estimated using physical (Prosper) or data-driven models (PU).

For the majority of the wells, the FTHP is monitored real time using data historian. Some of the other parameters are either connected to transmitters, or expected to be manually collected during surveillance activities. In wells where Flow Control Valves (FCV) are installed and connected to a transmitter, the gas lift rate and pressure may be monitored in real time. Flowing Bottom Hole Pressures (FBHP) can be monitored in real-time for wells completed with Permanent Downhole Gauges (PDHGs).

The real-time production flowrates are typically estimated using data driven modeling software (PU) which has been in practice in BSP since 2004. The development, background and early operational experience of PU within the Shell group are described by Poulisse et al. [4]. Over the years, PU as a tool has found many uses in the Shell group. More details can be found in [5] – [6].

Recommended components of the operating envelopes for wells can be classified based on the well instrumentation available in the downhole completion and surface. The recommended performance curves to be used for defining the well operating envelope based on the completion types are summarized in Table 1.

Once the parameters to be monitored are defined, the Operating Envelope for the well can be constructed and plotted on top of the most appropriate Performance Curve (e.g. P-Q curve) used to monitor compliance to all the limits.

Integration of different Datasources in Operating Envelope tool

The Operating Envelope visualization tool is developed in MS Excel. This tool fetches data from multiple databases like Data Historian, Energy Components and PU; it is also capable of interfacing with Prosper and WinGlue to fetch well performance data automatically. The dataflow is captured schematically in Figure 1.

Current Flow estimates calculated by PU are fetched into the Operating Envelope tool using Excel Visual Basic for Application code (VBA). Well test data is maintained in Energy Components. A Visual Basic script is created, and scheduled to run on a server, to refresh the well test data in OE tool automatically every day.

Prosper Open server utility allows user to generate and import data from prosper to excel sheet without operating on the Prosper file. P-Q Curve is generated in the prosper file of the well, and imported into the OE sheet by the open server utility of Prosper. Similarly the IPR plot is generated and imported into the OE sheet. Lift response plot is also generated in Prosper and imported into the OE sheet in similar manner.

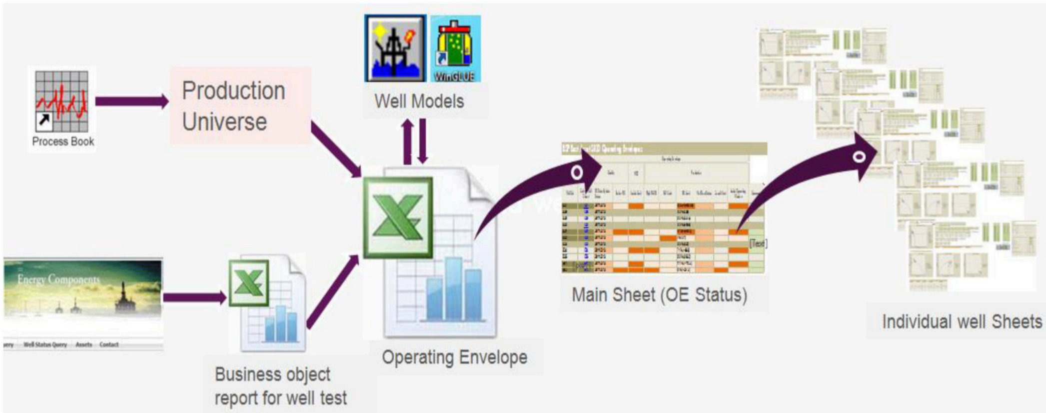
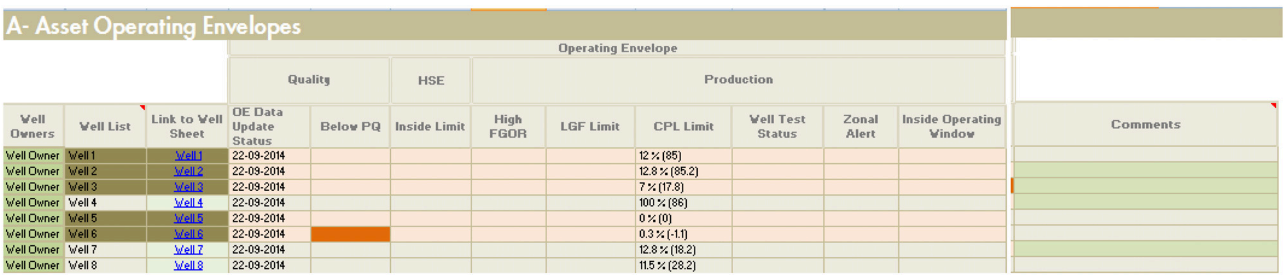


Figure 1—Data Flow Diagram from different Data sources into OE Tool



A- Asset Operating Envelopes

			Operating Envelope									
			Quality		HSE	Production						
Well Owners	Well List	Link to Well Sheet	OE Data Update Status	Below PQ	Inside Limit	High FGOR	LGF Limit	CPL Limit	Well Test Status	Zonal Alert	Inside Operating Window	Comments
Well Owner	Well 1	Well 1	22-09-2014					12 % (85)				
Well Owner	Well 2	Well 2	22-09-2014					12.8 % (85.2)				
Well Owner	Well 3	Well 3	22-09-2014					7 % (17.8)				
Well Owner	Well 4	Well 4	22-09-2014					100 % (86)				
Well Owner	Well 5	Well 5	22-09-2014					0 % (0)				
Well Owner	Well 6	Well 6	22-09-2014					0.3 % (-1.1)				
Well Owner	Well 7	Well 7	22-09-2014					12.8 % (18.2)				
Well Owner	Well 8	Well 8	22-09-2014					11.5 % (28.2)				

Figure 2—Operating Envelope Tool Main Sheet

Deriving the P-Q curve requires a WinGlue model in the database. A well model is constructed and calibrated in WinGlue. WinGlue export curve functionality is used to automatically generate the VLP IPR curves and import it to the OE tool. To generate the curve, user can provide the inputs in the cells provided in individual well sheets. Plotted data is also visible in form of table in individual well sheets.

Operating Envelope Tool for Producer Wells

Operating Envelope tool consists of two visualization sheets: Main Sheet with traffic light and Individual Well sheets (one sheet per well).

Main Sheet A screenshot of the main sheet is depicted in Figure 2.

Main sheet is a traffic light visualization to enable Exception Based Surveillance, primarily to monitor three aspects:

- Well data quality is measured with following two traffic lights:
  - Date time stamp of last time the data in the individual sheets was updated.
  - Flag to check if the real time well production estimates and tubing head pressure are below the well P-Q curve.
- Safety criteria is implemented by checking if the real-time production estimates from PU and FTHP are inside the user provided limits.
- Production checks are performed with following traffic lights:
  - Formation Gas Oil Ratio (FGOR): A check to see if real-time FGOR value is within the Maximum FGOR limit provided by the reservoir engineer.
  - Lift Gas Flow (LGF): A check to see if real-time LGF is within the operating limits.
  - Current Production Level (CPL): Current Production Level is the expected production volume from the well, which is typically used for allocation. This traffic light checks if the real-time

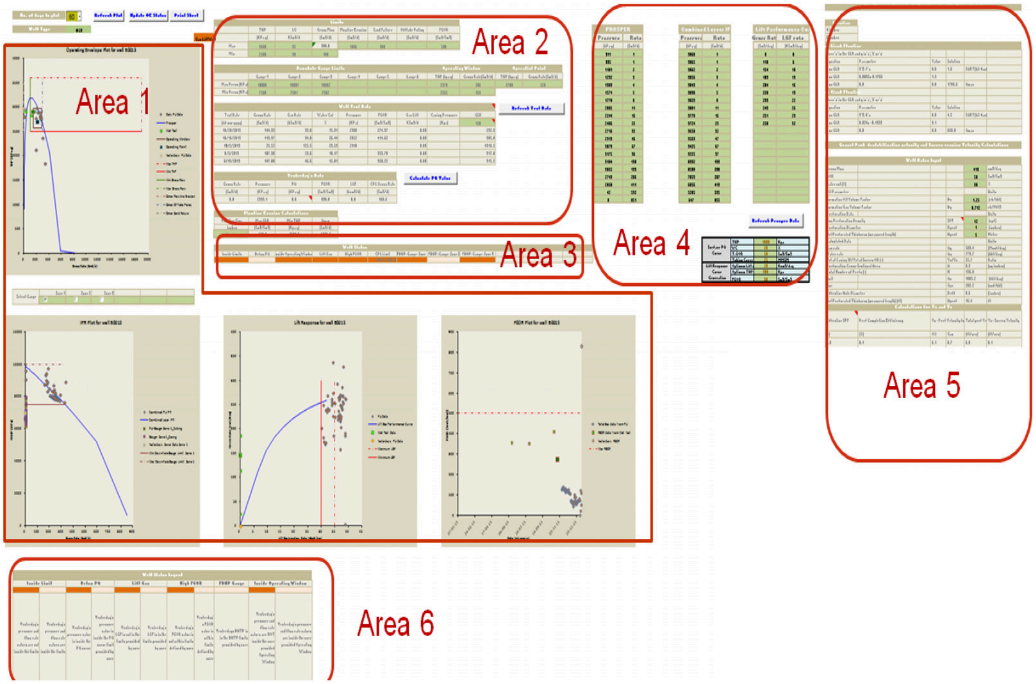


Figure 3—Individual Well Sheet Overview

PU estimate is within the range of the CPL for the well. Allowable tolerance in production is provided by the user.

- Well Testing: If the latest well test has been more than one month old then it is highlighted to user.
- Zonal Alert: Zonal bottom Hole Pressures are measured against the minimum and maximum pressure limits provided by the users. If any of the zonal pressure is outside the limit, it will be highlighted.
- Operating Window: To optimise production, a further smaller operating space is defined within the operating envelope. This range is the desired operating window. If real time data point is outside the Operating Window limits provided by the user, then it is highlighted.

Wells which are Closed-In are grayed out to avoid unnecessary traffic lights. Wells Closed in status is retrieved from PU to depict the current well conditions.

Individual Well Sheets The individual well sheet displays the OE limits and graphs for the well optimization and troubleshooting. A schematic of a typical individual well sheet is shown in Figure 3.

- Area 1: Displays the graphs like Surface P-Q curve, Inflow performance relationship, Lift response curve and FGOR vs. time.
- Area 2: User can input the limits for the operating envelope.
- Area 3: Based on the yesterday's data and user defined limits the status is displayed for different OE limits.
- Area 4: This includes the three input tables (Surface P-Q curve, lift response curve and IPR).
- Area 5: Displays the flowline erosion correlations and also Gravel Pack destabilization and sand screen erosion velocity calculations.
- Area 6: Legend for the data in the Area 3.

Individual well sheets have five major plots, which are shown in Area 1 in Figure 3.

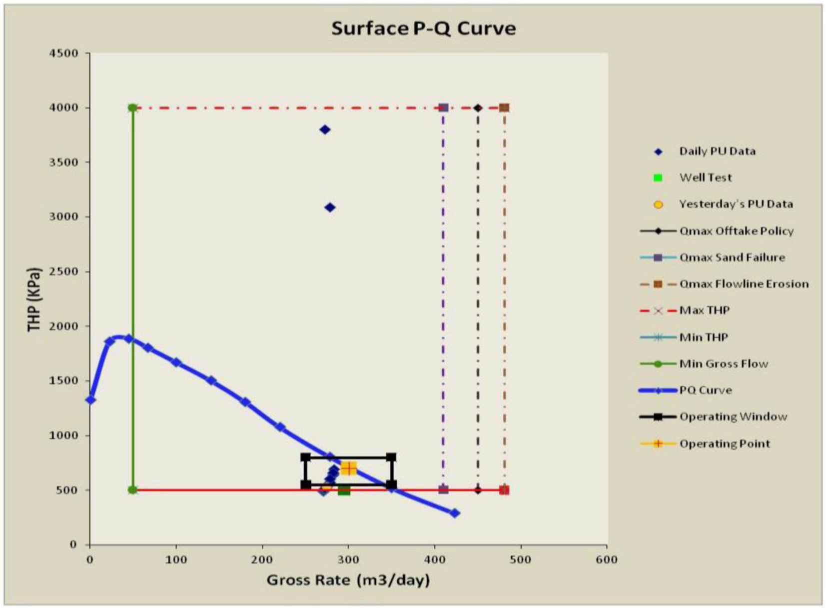


Figure 4—Operating Envelope Plot for Well

Operating Envelope Plot The range of possible operating points is constrained by a finite set of physical and commercial limits. The boundary defined by the overlay of all the limits is the operating envelope. The operating envelope thus represents the space for reliable operation. A sample plot is shown in Figure 4.

The parameters which define the Operating Envelopes in a well are the following:

- Real-time PU Data: This is represented as an amber circle in the plot. It is the real-time PU estimate of the Gross/Gas Flow at the current Tubing Head Pressure.
- P-Q Curve using Prosper: Well model must be constructed and calibrated in Prosper. P-Q curve is calculated in Prosper using Open Server interface and imported into the OE tool.
- P-Q Curve Using WinGlue: Deriving the P-Q curve requires a WinGlue model in the database. Well model is constructed and calibrated in WinGlue. P-Q curve is generated using the VLP and IPR intersections. Then polynomial interpolation is done to predict the P-Q curve for the gross production ranges. WinGlue export functionality is used to export the P-Q curve from WinGlue database into the OE tool.
- Operating Window: This range is the desired operating window for the system in question. If the operation is controlled within this operating window then compliance with the larger operating envelope is also demonstrated.
- Data from previous Well Tests: Latest five successful well tests data are visualized in the Operating Envelope plot, with latest test highlighted in dark green color.
- Minimum Flowing Tubing Head Pressure: The FTHP is governed by the reservoir pressure, flow rate, choke size and the flow line pressure (separator pressure + friction pressure drop). Minimum FTHP for the natural flowing wells and gas lifted wells can be derived by the following criteria.

Naturally flowing oil / Gas producers The FTHP should ideally be equal to 1.8 times the flowline pressure in order to maintain a critical (sonic) flow and choke sizing done accordingly to maintain it. This helps stabilize production by isolating the well from downstream pressure effects. However, in case of wells producing from depleted reservoirs or with high water cut, this guideline may not hold and the choke size may be required to be increased to reduce the FTHP. In case of a well without a choke, the lowest attainable pressure is usually ~1.5 bar higher than the flow line pressure (this is a rule of thumb – high drop in pressures may occur due to multiple flow direction changes within a short distance). The minimum FTHP will correspond to the maximum allowable gross flow rate from the P-Q (Pressure-Flow) curve from the physical model (Prosper) [3].

Gas lifted oil wells The minimum FTHP should ideally be equal to the back pressure in the separator. For wells which flow to separators on other platforms, appropriate pressure drop should be taken into account. For exceptional cases where chokes are installed, the FTHP will be much higher. The 'choke calculation' in Prosper may be used for determining the FTHP. Like naturally flowing wells, the FTHP of gas lifted wells can also be derived from P-Q curve. For gas lifted wells, there will be multiple P-Q curves based on different gas lift rates. The P-Q curve based on optimal lift gas injection rate is used to define the limits. WinGlue model may be used to verify the same.

- Maximum Flowing Tubing Head Pressure: The maximum tubing head pressure that a well attains under normal condition is the closed-in tubing head pressure. Thus the expected closed in tubing head pressure may be calculated as follows:
  CITHP = Expected bottom hole pressure – (fluid gradient x fluid column length (True Vertical Depth))
  In case of gas lifted wells, the maximum CITHP would be equal to the higher of gas lift pressure or CITHP as calculated above.
- Minimum Gross Flow Rate: The minimum gross flow rate is defined as the rate below which the well will start to slug and there is a possibility of liquid loading. If the flow velocity and hence the flow rate is below the liquid loading rate, the flow may cease due to liquid loading. This phenomenon is of more importance in gas wells with high liquid content, but is also exhibited by low liquid rate gas lift wells in mist flow regime. In case of natural flowing or gas lifted oil wells which are flowing to separators located in distant locations, the minimum flow rate should be above the turn down flow rate for the flowline. The turn down rate is usually estimated by the facilities engineering group.
- Maximum Gross Flow Rate, which is minimum of:
  - Q_{MAX} Flowline Erosion: Depending on the velocity of the various phases and the flow regime flowing through the various well and surface components, as well as the presence of abrasive material such as sand fines, the metal components of the well can suffer from erosion which can lead to a failure (e.g. a leak).

  An erosional velocity limit is typically defined for BSP wells as 30 m/s for the total mixture flowing up the tubing. If this limit is not reached, the next component that defines an erosional risk is the surface flowline (including choke, elbows, etc). There is no cut off value defined for flowlines, but instead a calculation of the wall loss rate is used to determine the maximum allowable velocity for the current flow conditions defined by proportion of the various phases and total sand loading.
  The erosional velocity limit associated with flowline erosion is defined using [7]. The tool calculates sand erosion rates in the form of pipe wall penetration rate (thickness loss of pipe in mm/year) and pipe wall thickness loss per mass of sand (thickness loss of pipe divided by mass of sand in mm/kg) in several pipe geometries such as elbows, tees, straight pipe, direct impingement, sudden pipe expansion, and contractions. The computer program is also capable of computing threshold flow stream velocities or production rates. A quadratic equation is developed using this model for flowline erosion calculation. Based on the minimum FTHP and the maximum GLR, Q_{MAX} is calculated keeping the flow line erosion limits of 0.1mm/year.
  - Q_{MAX} Offtake Policy: Water coning or gas cusping may be an issue and the offtake from the

reservoir may need to be reduced to prevent these phenomena. These phenomena are usually modeled in reservoir simulators and maximum offtake limits derived thereof.

- Q_{MAX} Sand Failure: There are two possible failure modes in a sand control completion: screen erosion and gravel pack destabilization. The former failure occurs if there is high velocity through screen over very short interval which abrades the screen. The latter occurs if high velocities within the gravel pack dislodge the gravels to create low resistance flow paths. The formulation developed by Wong et al. [2] is used for calculating the sand screen erosional velocity limit, V_C and gravel pack destabilization velocity limit, V_S.

The only factors which affect the V_C are:

- Oil or gas rate.
- Formation volume factor.
- Net perforated thickness.
- Perforation diameter.

The V_S is a function of the V_C and the annular gap between the OD of the screen and ID of the casing.

V_C and V_S need to be checked if they exceed the threshold of V_S= 0.3 m/sec and V_C= 3 m/sec. This is a single phase tool. Since velocity is dependent on total flow (not just gas or oil) it is advisable to calculate and add the Vc_oil+Vc_gas and Vs_oil+Vs_gas.

For Open Hole Gravel Pack completions, no models have been developed to determine the maximum acceptable velocities. A possible but potentially too conservative approach used is to check the scenario wherein the gas velocity attains screen erosion velocity (Vs). This could potentially happen with continuous screen plugging due to e.g. fines or filter cake, leading to hotspotting. An example of the analysis to determine the anticipated screen plugging that would result in a velocity equal to Vs as shown in the graph below in Figure 5. Since it is difficult to measure area of screen plugged, an indirect method wherein the increase in skin due to plugging may be analyzed by carrying out pressure transient analysis in the well. Hence in these wells, surveillance is a key to monitor increase in drawdown or decrease in productivity index and subsequently go for a detailed pressure transient analysis to confirm the skin build up.

Inflow Performance Relationship (IPR) Plot for well A sample plot is shown in Figure 6.

- Combined Layer IPR: The relationship between the flow rate and the flowing bottom hole pressure is characterized by the Inflow Performance Relationship (IPR). IPR curve is calculated in Prosper using Open Server interface and imported into the OE tool. A maximum and a minimum flowing bottom hole pressure can be plotted on the IPR as part of the Operating Envelope.
- Combined PU IPR: Downhole annulus pressure for all the zones is averaged out, and plotted against the PU gross flow estimates for the well.
- Min Downhole Gauge limit: The minimum flowing bottom hole pressure limit for a reservoir zone may correspond to the maximum gross rate contribution allowed from that zone.
- Max Downhole Gauge limit: The reservoir pressure of the most depleted zone (translated to the gauge depth) can be used as maximum flowing bottom hole pressure, to ensure zonal contribution from all the layers. This limit ensures each zone is contributing in the gross production.

Lift Response Plot A sample plot is depicted in Figure 7.

Lift Performance Curve curve is calculated in Prosper using Open Server interface and imported into the OE tool. The gas lift response (Lift gas vs. Liquid flow – “gross”) curve is used to optimize the production from gas lifted wells.

Lift Performance Curve can also be exported from the WinGlue database.

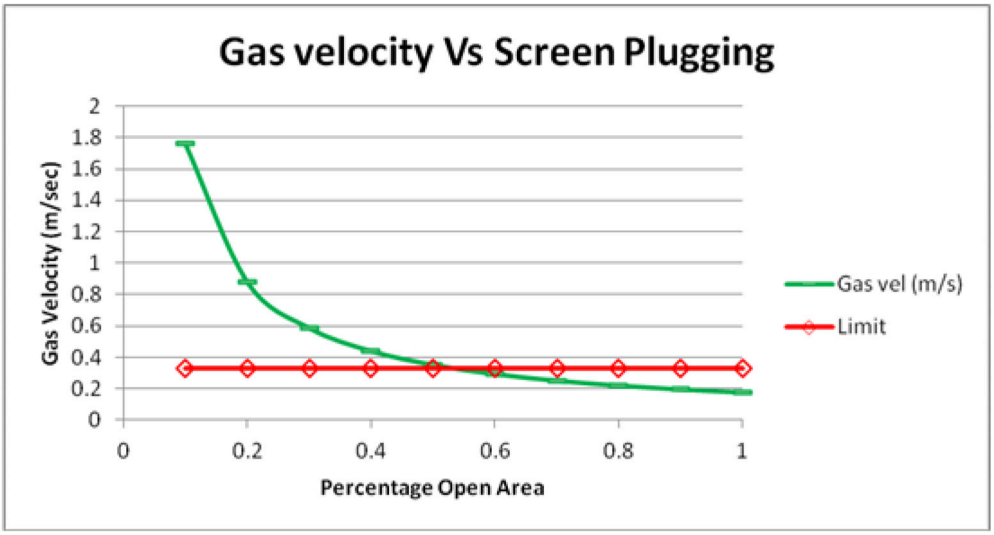


Figure 5—Example of Screen Plugging at Velocity close to V_S

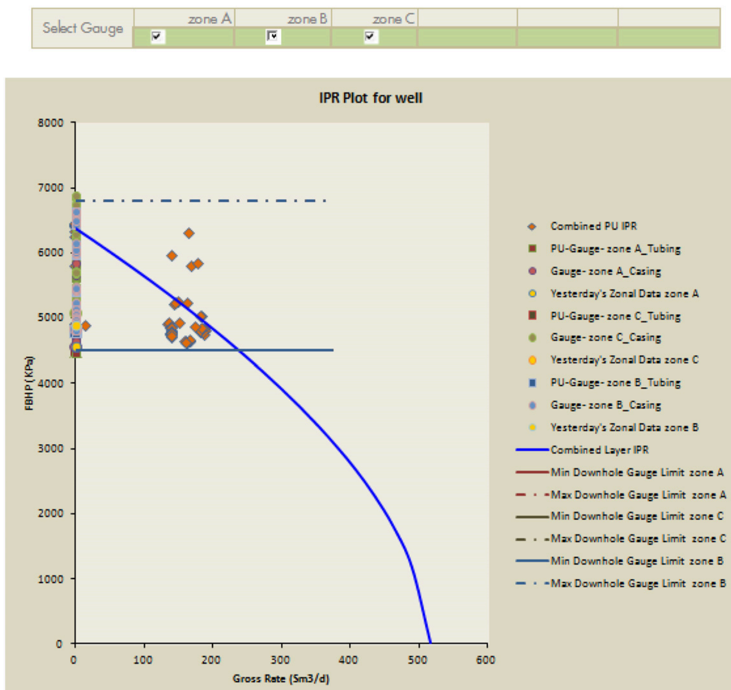


Figure 6—IPR Plot for Well

- Maximum LGF: If the well is not constrained by the lift gas supply then the maximum lift gas rate is defined as the maximum gas injection rate after which the well production starts to decrease or lesser benefit can be seen in the gross rate increment. If there is a lift gas constraint, this parameter should be constrained based on the overall optimum distribution for the field.
- Minimum LGF: The minimum gas lift injection rate can be defined as the injection rate below which the well production is considered as sub-optimum.
- PU Data: Lift Gas Flow estimates calculated by PU are fetched into the OE tool.
- Well Test: Latest five well tests data are visualized in the OE plot.

Formation Gas Oil ratio (FGOR) Plot A sample plot is depicted in Figure 8.

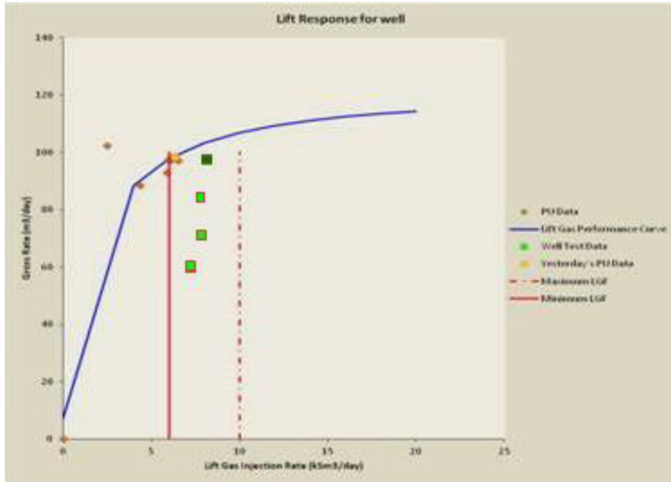


Figure 7—Lift Response Plot for Well

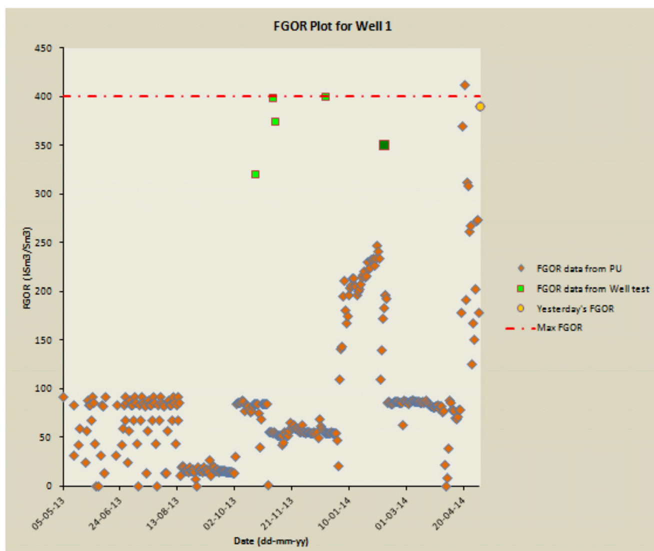


Figure 8—FGOR Plot for Well

The maximum FGOR may need to be capped with consultation with the Reservoir engineer to minimize offtake from the respective reservoir and hence reduce the depletion of the reservoir energy. The maximum GOR may also be limited by government regulatory requirements. FGOR estimates for last one year are plotted against maximum FGOR limit. Last five well tests are also plotted in for comparison with the real-time gas estimate.

SCSSSV Control Line Pressure Plot A sample plot is depicted in Figure 9.

The functionality to monitor real time SC-SSSV hydraulic line pressure for HP and HHP wells is useful where the reservoir pressure may change significantly. This may cause a reduction in THP which may lead to failure of the control line or pressure seals, if hydraulic line pressure is not reduced accordingly. Including it into the EBS system allows us to monitor the pressures regularly, hence reduce the chances of SC-SSSV failure.

Modifications in Operating Envelope Tool for Injector Wells

Most of the features in the Operating Envelope Tool for Injector wells are common to those for the Producer wells, which are described above. The major highlights of the differences are described below.

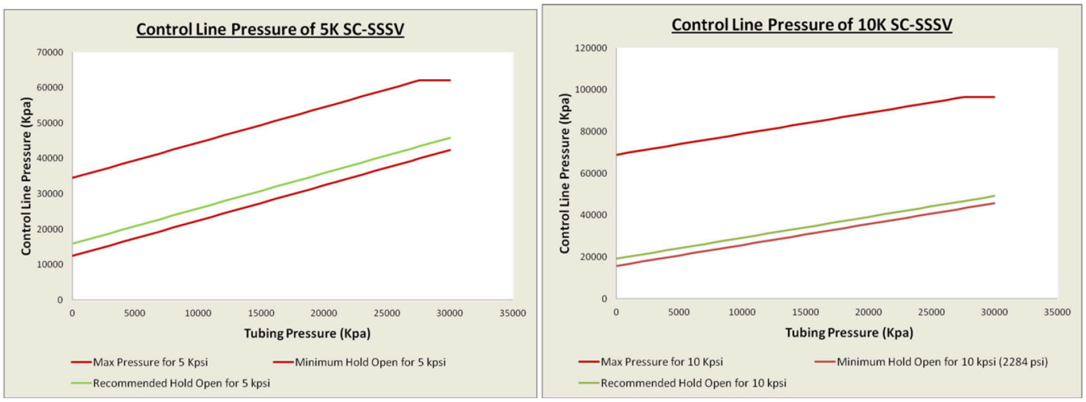


Figure 9—SSSV Control Line Pressure Plot for 5K and 10K SC-SSSV

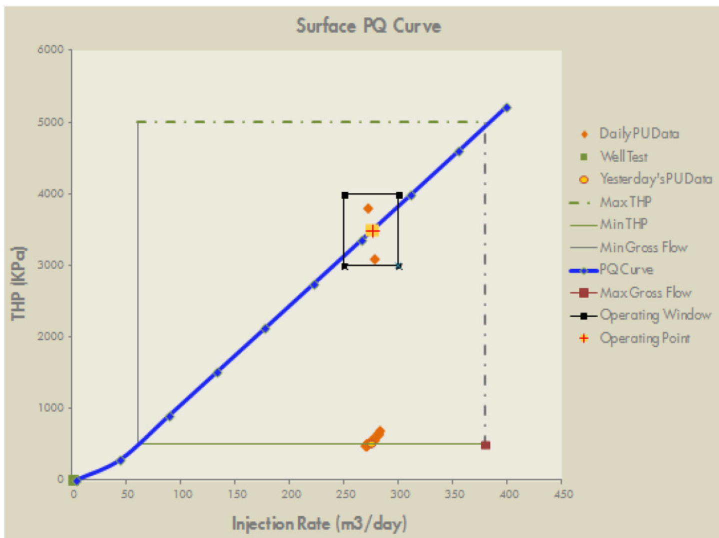


Figure 10—Operating Envelope Plot for Injector well

Performance Curve for Water Injectors Surface P-Q curve for injectors represents the relationship between the flowing tubing head pressure and gross injection rate. This curve can be used to optimize the injection rate by increasing or decreasing the injection pressure. A screenshot is attached in Figure 10.

The P-Q curve can be derived from a Prosper model. Other OE limits remain same as for Producer wells.

Hall plot The Hall plot is the method to evaluate the performance of the water injector wells through time [1]. Cumulative PU water flow estimates and cumulative THP is plotted on the Hall Plot. From Hall plot, we calculate the slope of the Hall Plot [f(x)] for small intervals of cumulative water injection volume [x]. To remove the noise, we filter out the outliers, and then make a reasonable running average taking only consistent points together. Then, we plot the derivative (df(x)/dx) on the same chart as the Hall Plot but on a different scale. It gives us the idea on the quality of injection as follows:

- if the derivative is horizontal, that means the Hall Plot is a straight line (stable injectivity).
- if the derivative deviates up, there is loss in injectivity.
- if the derivative deviates down, there is improvement in injectivity.

Hence, we can detect a loss of injectivity earlier through the Hall Plot, and also we can compare the average slope of the Hall Plot at different periods to compare injectivity. A screenshot is attached in Figure 11.

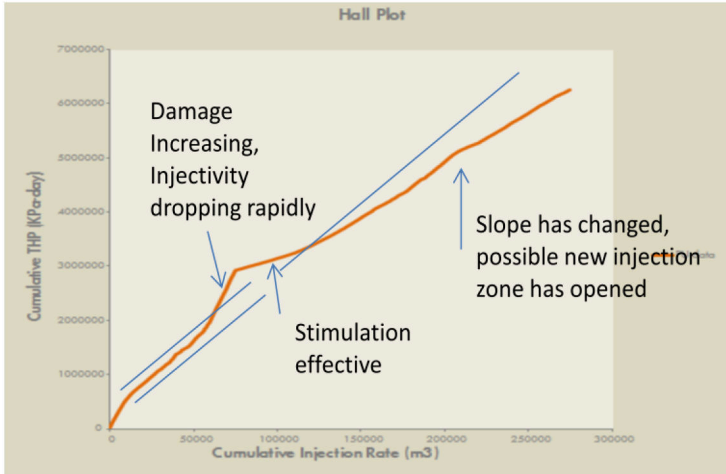


Figure 11—Hall Plot for Injector well

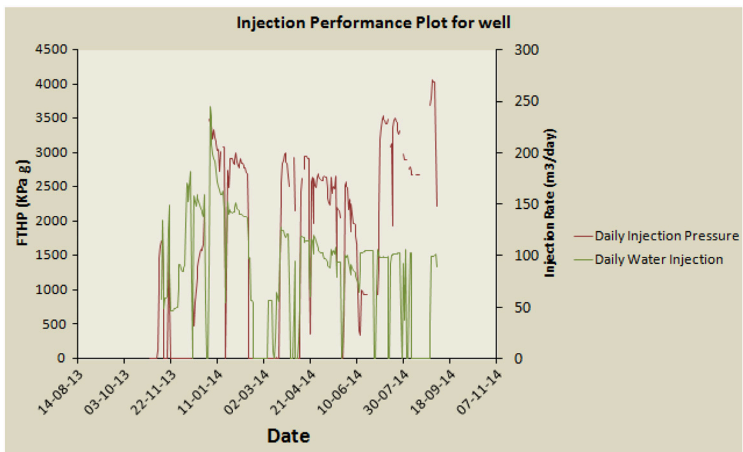


Figure 12—Injection Performance Plot for well

Injection Performance Plot Injection performance is measured by plotting Daily Average Tubing Head Pressure along with Daily Water Injection PU estimates for last one year. A screenshot is attached in Figure 12.

Case Studies

The implementation of well operating envelope tool has led to significant improvements in daily production monitoring from safety as well as production point of view. A few case studies are described hereby.

Production-Critical Improvements using the OE Tool

Improving Hydrocarbon Allocation Accuracy A gas-lifted well quit due to unstable gas lift injection. This was captured during the morning daily produc-

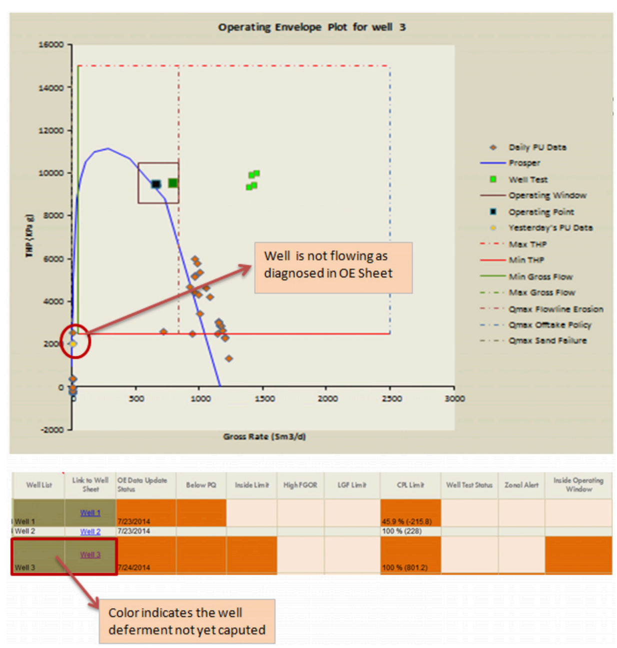


Figure 13—OE Tool assists in improving Hydrocarbon Allocation accuracy

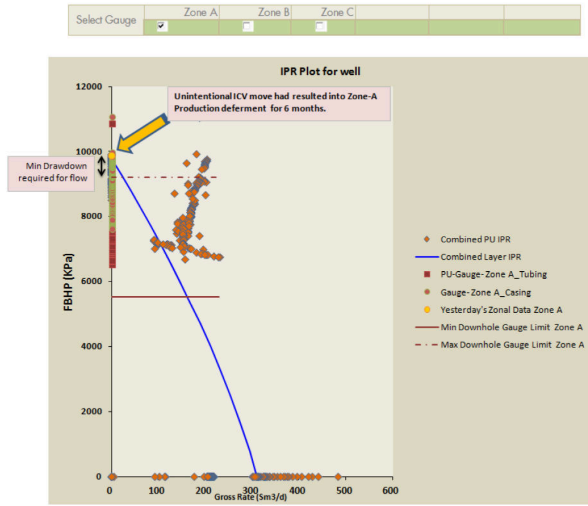


Figure 14—OE Tool assists in achieving Effective Surveillance on Downhole ICV Changes

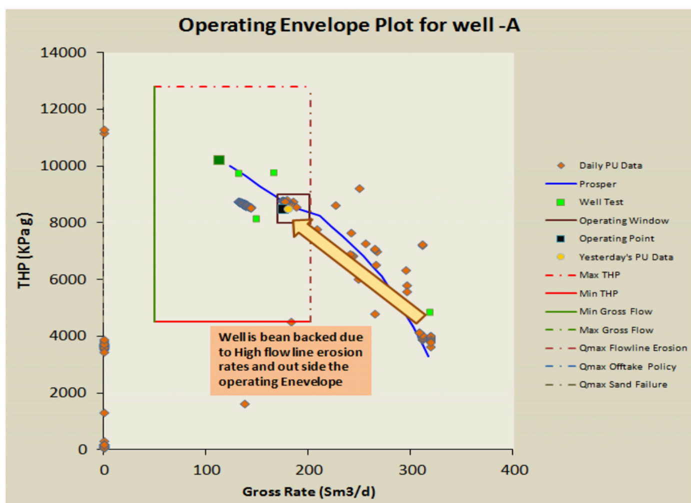


Figure 15—OE Tool assists in avoiding potential LOC

tion review as the OE sheet showed 100% production discrepancy with respect to current production level. The deferment was subsequently captured in Energy Components to improve the hydrocarbon allocation accuracy. In addition, remedial steps were agreed and carried out to bring the well back online. The example is depicted in Figure 13 below.

Achieving Effective Surveillance on Downhole Inflow Control Valve (ICV) Changes There are some wells present in BSP with smart completions to optimize the well and reservoir management through ICV changes. However, unintentional ICV moves may occur due to small leak in the hydraulic line or high pressure differential across the ICV. Historically, there have been examples of such cases, which were not noticed immediately as actively monitoring each Zonal ICV on all the wells is challenging. These cause significant unscheduled production deferments. Therefore, drawdown monitoring functionality was incorporated in the OE tool. As soon as the bottom hole pressure data comes closer to the reservoir pressure, this will generate a red signal based on the minimum drawdown limit in the OE tool which can be addressed in the daily production review. The example is depicted in Figure 14 below.

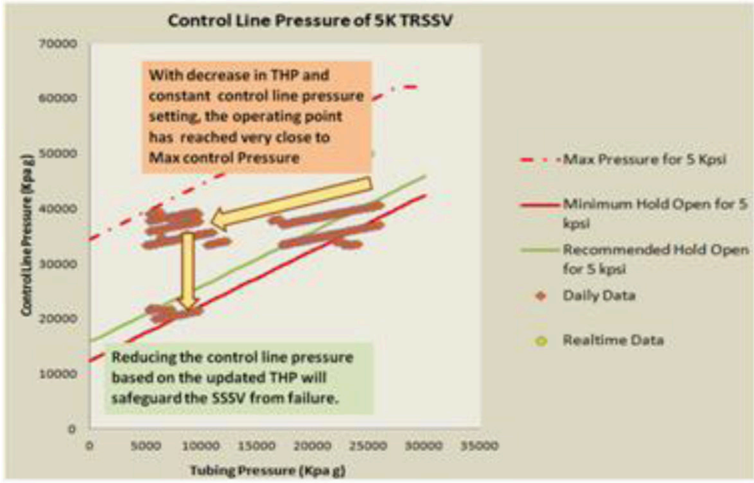


Figure 16—OE Tool assists in safeguarding SC-SSSV

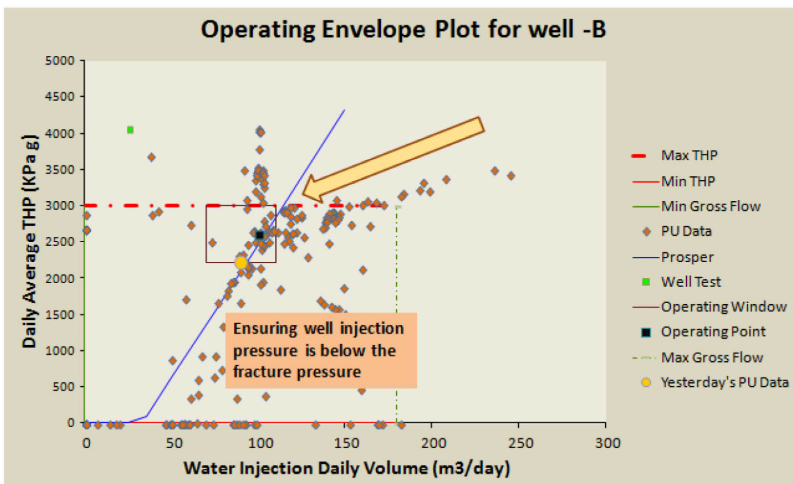


Figure 17—OE Tool Assists in ensuring Matrix Injection

Safety-Critical Improvements using the OE Tool

Proactive measures to avoid potential Flowline Loss of containment (LOC) A well was producing outside the maximum Flowline limit of the operating envelope. This limit is governed by the Tulsa flowline erosion model [7]. As a part of proactive measure to avoid LOC, the well was shut-in for investigation. To confirm the remaining flowline thickness, the Ultra sonic Thickness measurement (UT) was conducted on downstream and upstream of choke. Based on the analysis of this measurement, it was found that the expected remaining life of flowline is only 3 to 5 years. As a result of this risk assessment, the well was beaned back to operate within the safe operating limit till the time the flowline is replaced.

Operating envelope tool helped in taking the proactive measures to prevent the potential loss LOC due to excessive flowline erosion as depicted in Figure 15.

Safeguarding Sub-surface Safety valve A gas well was completed and tied up into the High Pressure (HHP) production system. Due to depletion drive, the reservoir pressure declined at a fast rate. This resulted in a drop in FTHP from 300 bars to 80 bars in 6 ~8 months time. However, the SSSV control line pressure setting was not updated due to lack of proactive monitoring; hence the operating pressure point

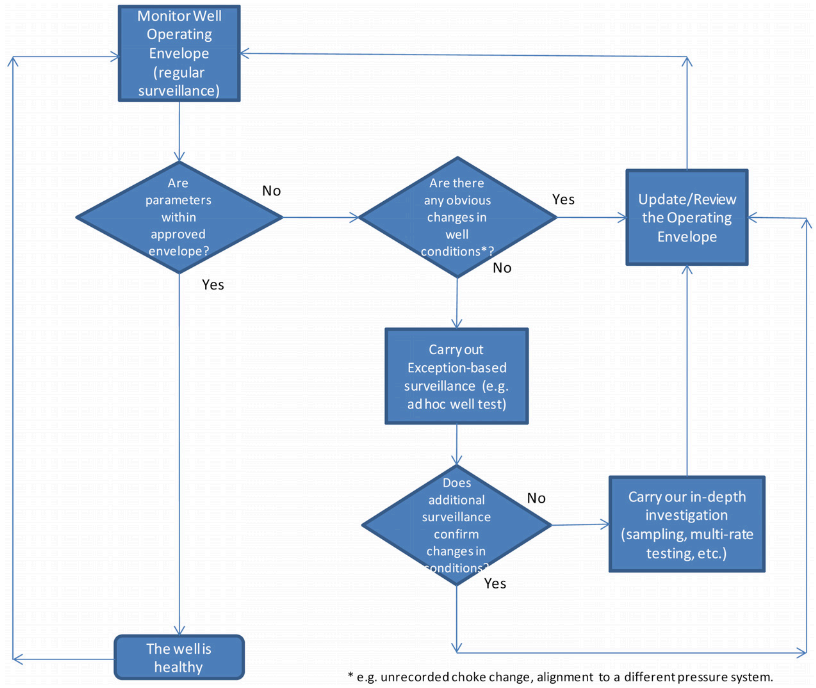


Figure 18—Workflow on updates in the Operating Envelope

reached very close to the maximum fail safe hydraulic line pressure, thereby causing leak in the SSSV hydraulic line of the well.

Operating envelope EBS system could have highlighted the red flag under this condition and safeguard the SSV from failure. This feature has been implemented in the OE tool as depicted in Figure 16.

Ensuring Matrix Injection In order to arrest the reservoir pressure decline, the water injector wells were drilled and matrix injection scheme was selected. This is because injection wells are quite shallow and injection pressure can break the cap rock seal. Hence, injection pressure control is quite critical for these wells. All the shallow injectors have the step rate test to determine the fracture injection pressure. These values have been used to monitor the injection pressure daily using the well operating envelope.

In the following example, the well was injecting above the fracture pressure and operating envelope EBS system showed this well as outside safety limit due to injecting outside the maximum THP limit. Proactive measure has been taken to reduce the injection pressure and ensuring the injection in the matrix condition. This is depicted in Figure 17.

Workflow on Updates in the Operating Envelope

The workflow below in Figure 18 focuses the period when Operating Envelope reviews or updates are done. The well operating envelope are reviewed or updated when any significant changes occur in the well condition, such as changes in the production system (e.g. choke changes), or changes to the well and reservoir system (e.g. the well "gases out").

Conclusions

The Operating Envelope Tool has significantly helped in improving the well surveillance and focussed on establishing the boundary conditions of various safety-critical parameters and optimized well performance. Visualization of information from multiple data sources into this real-time tool provides an effective and efficient monitoring to ensure optimal well production within safe limits on a day-to-day basis for well, reservoir and facility management. This tool is estimated to bring down the well surveillance time-saving by 1000 man-hours per year by production programmers.

A few examples of benefits derived from this tool have been discussed in the case studies in the previous section. In summary, following improvements have been observed with implementation of this tool:

- Traffic light and graphical representation enables quick well surveillance in identifying problematic wells and taking corrective measures.
- Monitoring of the daily PU estimated production vis-à-vis well tests, allocated production volumes and the physical well models will increase hydrocarbon accounting efficiency.
- Monitoring real-time parameters like THP, FBHP, SC-SSSV control line pressures and flow-rates allows the Petroleum Engineers and Operations to operate safely within defined boundaries.
- Monitoring of parameters like GOR, drawdown will enable adherence to reservoir management guidelines and reduce potential reserve losses.

There are still many more possibilities for the extension of the Operating Envelope Tool to address other gaps in the day-to-day management in oil and gas production operations. The additional work is in progress at BSP by the OE Implementation team, in conjunction with Production Technology and Production Operations teams.

Nomenclature

Terminology specific to this paper is given in the table below:

Abbreviation/Term	Meaning
BSP	Brunei Shell Petroleum Sdn. Bhd.
CITHP	Closed-in Tubing Head Pressure
CPL	Current Production Level
EBS	Exception Based Surveillance
FTHP	Flowing Tubing Head Pressure
GLR	Gas-to-Liquid Ratio
GOR, FGOR	Gas Oil Ratio, Formation Gas Oil Ratio
HP, HHP	High Pressure, High-High Pressure
IPR	Inflow Performance Relationship
LOC	Loss of Containment
OE	Operating Envelope
PDHG	Permanent Downhole Gauge
P-Q Curve	Production – Rate curve
PU	Production Universe
SC-SSSV	Surface Controlled Sub Surface Safety Valve
VLP	Vertical Lift Performance curve
VRR	Voidage Replacement Ratio
Vs, Vc	Sand screen erosional velocity, Gravel pack destabilization velocity
WRFM	Well, Reservoir and Facility Management

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