Reservoir Surveillance And Production Optimization Workflow From Real Time Data Advantage At A Joint Venture Gas Project

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Abstract

With the advancement of computer science and information technology, the oil and gas industry has been well positioned in the data-driven business. All kinds of data, from every phase of production, are useful if they can be interpreted in a real-time manner to support optimization and development.

Reservoir surveillance, starting with the data acquisition from the well and the production network, is the driver for evaluating well and reservoir performance, then OGIP/reserves evaluation, and finally, the foundation development, on which development options are optimally selected and production optimization decisions can be made. This paper here presents the practice that a greenfield gas field adopted and many other aspects of reservoir characterization and production optimization. Focal point is to start with the permanent downhole pressure gauge (PDHG) and then, application of the real time wellhead data monitoring and recording system are the best use when putting together with the well-defined engineering methodology to support for decision making.

This is even more beneficial in the context of high operational cost and inherent high environmental risk of the high H_2S operating exposure, for the Joint Venture Gas Project in Sichuan.

Introduction

The green-field sour gas project is developed in Sichuan, China. The full field development schematic is shown in **Figure 1.** The project involves development of gas resources in Triassic carbonate reservoirs. The field of interest is made up of bedded dolostone and limestone facies of Early Triassic age.

The depositional environment is carbonate platform and ramp with oolitic shoals. Gas is trapped in thrust-related anticlinal structures and seals comprise tight limestones and anhydrites. The structure is normally large. Rock porosity ranges from 3 to 20%, and permeability ranges from 0.01 to 1,000 millidarcies (md). The reservoir fluid is dry gas, with H_2S and CO_2.

The unique challenges for this project are sour gas, rugged terrain, large operating area, and high population.

Therefore, optimizing production and maximizing the value for the field development is the primary goal for the field development plan.

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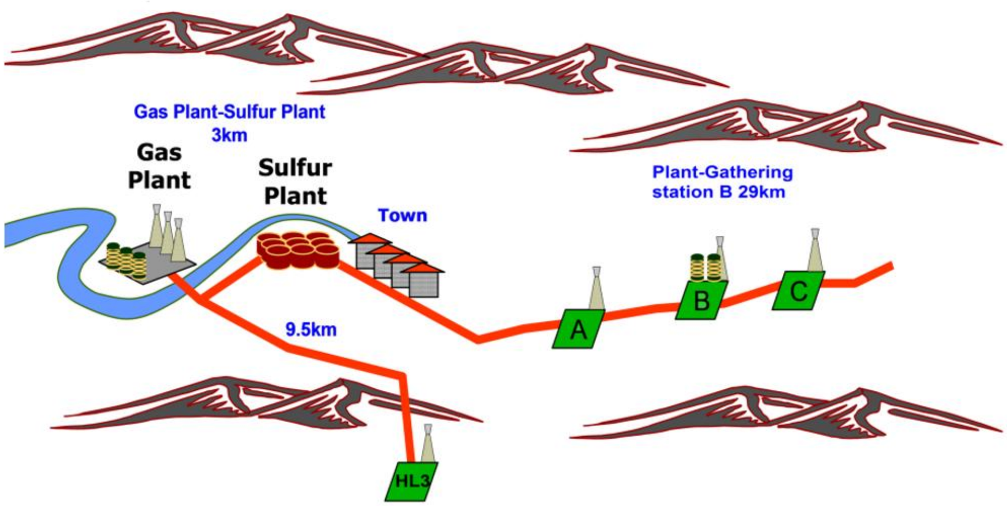


Figure 1—Sour gas development project.

Reservoir Surveillance Goal and Workflow

Reservoir surveillance, starting with the data acquisition from the wells and the production network, is to obtain data for evaluating well and reservoir performance, reserves evaluation and finally, the foundation development, on which development options are optimally selected and decisions are made.

The primary objectives of reservoir surveillance are to ensure gas availability meets all contractual agreements and timely promotion of resources to reserves. This is aligned well with the goals of the field development plan.

Contractual Production Demand. To achieve this goal, well and reservoir performance should be evaluated frequently to identify any signposts for upside / downside potentials. This is to:

- maintain predicted well deliverability;
- determine the optimal well-count and the preferred location / placement of wells; and
- support production accounting and allocation.

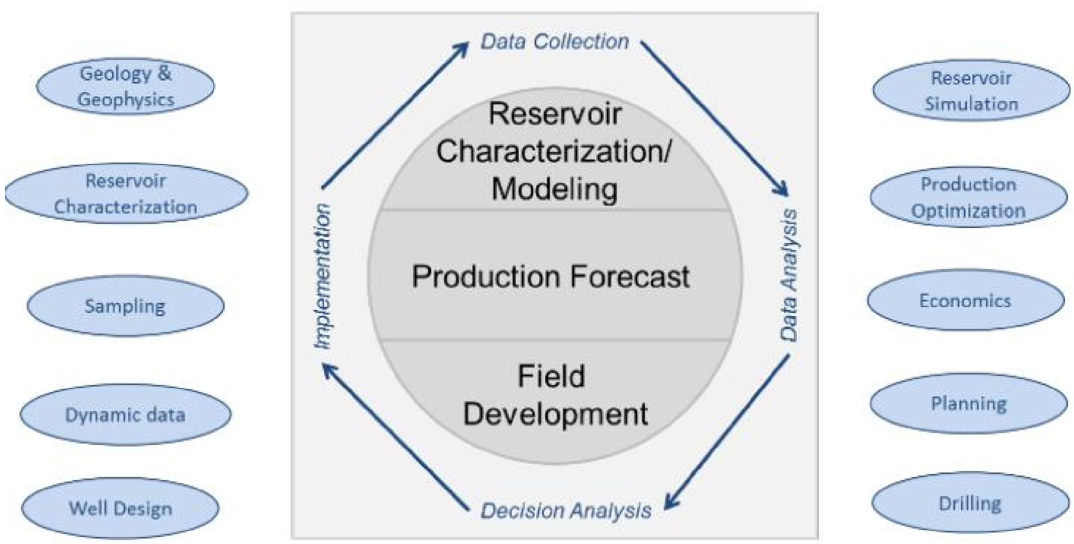


Figure 2—Rolling reservoir surveillance workflow.

Timely Promotion of Resources To Reserves. To effectively develop the field, timely execution of downside mitigation and upside capture strategies are needed. This requires the operator to:

- establish reservoir in-place gas volumes; and
- establish reservoir connectivity, both areally and vertically.

In brief, to achieve these goals, the team develops and follows the rolling reservoir surveillance workflow, conceptually described in **Figure 2**. The effectiveness of any decision will therefore dictate what data to collect and when to collect it (Satter et al. 1994).

Data Collection and Challenges

Typical gas field development will start from the wells, then connect to the gathering station(s), and finally to the processing system via pipeline. In this case study of the field development application, the gas field has been developed with six producing wells, of which one well is equipped with Permanent Downhole Gauge (PDHG), or Down Hole Pressure Gauge (DHPG). The schematics in **Figure 3** will provide a better picture how the system works.

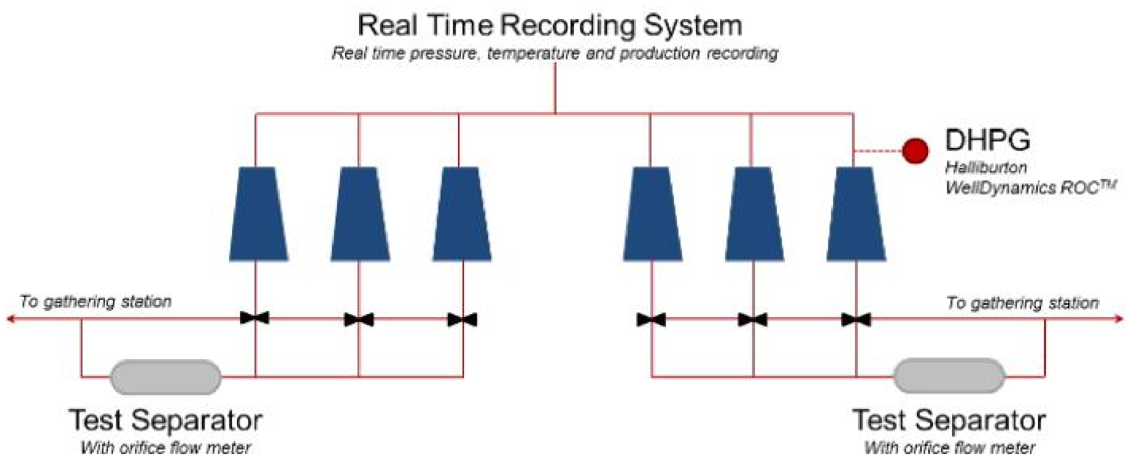


Figure 3—Real time recording system.

As seen in Figure 3, only one well was equipped with a PDHG in this field, whereas the other five wells have a wellhead data monitoring system in place. To ensure the reliability and the accuracy of the data recorded downhole, the operator selected a Halliburton WellDynamics ROC (Satter et al. 1994), which was the first of its application in China. The downhole reservoir pressure data is the most important reservoir surveillance measurement, and provides invaluable information about the reservoir behaviors at different production arrangements. Key surveillance data are thus composed of wellhead and bottom-hole-pressure and temperature, gas and water rate, and gas composition. Real time monitoring of well operating conditions will help collect the data from the wells to server.

Except for limited downhole data available, a challenge for any field development also is the high production requirement from the wells. Each well is therefore planned to produce at the high flow rate, ~85% – 95% of the well constraints (e.g., Pressure Safety Valve limit, flare limit, erosional limit). With a limited cushion of production, well intervention operations of any well will lead to a large production loss, associated with an execution risk of well intervention and also high operations cost.

Data Analysis

A question then follows of how to make the best use of available data to conduct reservoir surveillance to optimize production and to maximize the value for the entire life of field development.

Since limited bottom-hole data is available, if the wellhead data including pressure, flow rate and temperature from the real time recording system is used, it would be an advantage. Several well-recognized methodologies can successfully be used in the oil industry to convert the wellhead data into the bottom hole data, such as Cullender and Smith (1956), Beggs and Brill, Dukler Flannigan, Fancher Brown (William 2004). At this gas project, an internal petroleum engineering toolkit has been available to use, with more than 20 different correlations available.

The workflow is described below in **Figure 4**. Starting with the well where both surface and downhole pressure data are available, the Petroleum Engineering model has been built and it helps calculating the gas compressibility z factor under specific production condition (i.e., from gas composition, including H2S and CO2, and non-linear temperature profile along the wellbore). The uncertainty on fluid PVT (Pressure Temperature Volume) and tubing roughness can be eliminated as having a low impact. Appropriate correlations are loaded to convert the surface pressure data to downhole pressure data, and the results are compared with the actual PDHG data measured directly from the downhole gauge.

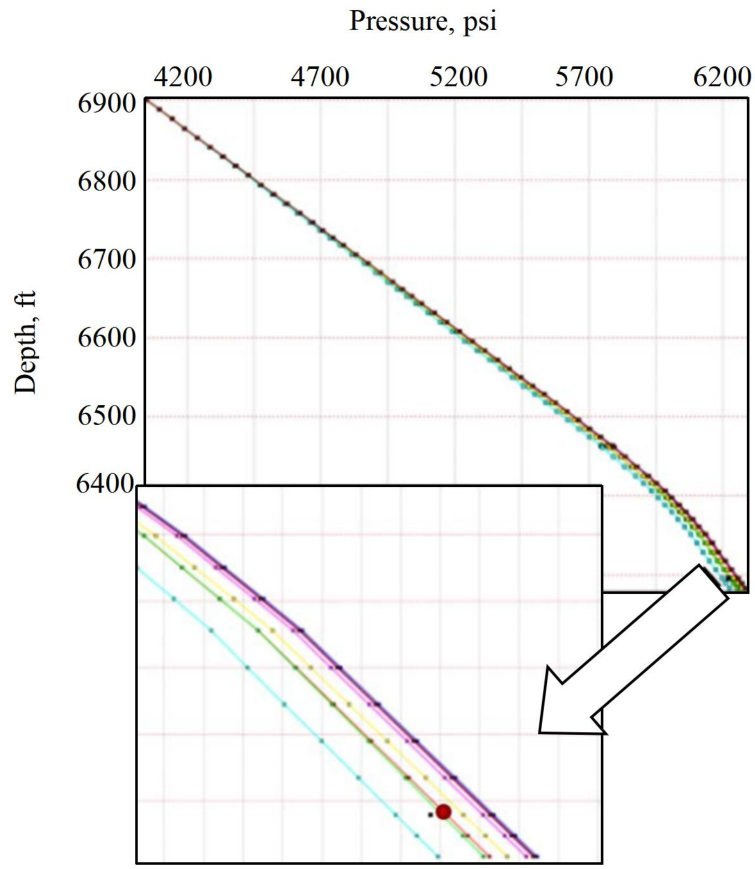


Figure 4—Using PDHG data for best fit correlation.

The correlation with a minimal gap is then selected and calibrated to match with the PDHG, by adjusting friction and gravity loss in tubing.

Since all six wells have similar structures in this project, this calibration exercise can be applicable to the other five wells without the PDHG, and all are with the good quality conversion. Once wellbore flowing data and bottom-hole data are determined with above method, the data can be further linked to selected Inflow Performance Relationship IPR model. By observing the change of intersection, we can monitor how the performance of the wells has changed with time. The work can be illustrated in **Figure 5**. In this plot, the results from all six wells, using the wellhead pressure data and the converted downhole pressure data to evaluate well performance and benchmark their potential to identify wells with formation damage.

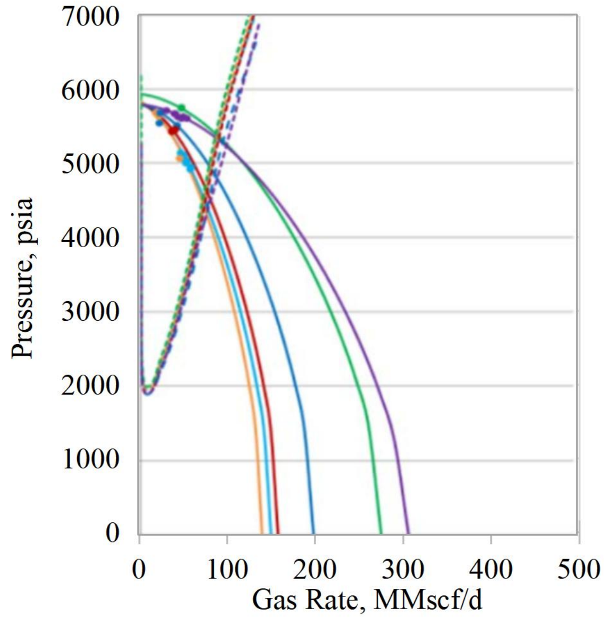


Figure 5—Use wellhead and downhole data for well performance update.

To maximize the value of this workflow with real-time data, an analytical model has been developed at this gas development project. The work started from PDHG data to select the best fit model and then, used that to convert all the wellhead data available in the other wells. The data is then used for formation damage estimate. The workflow is summarized as **Figure 6**.

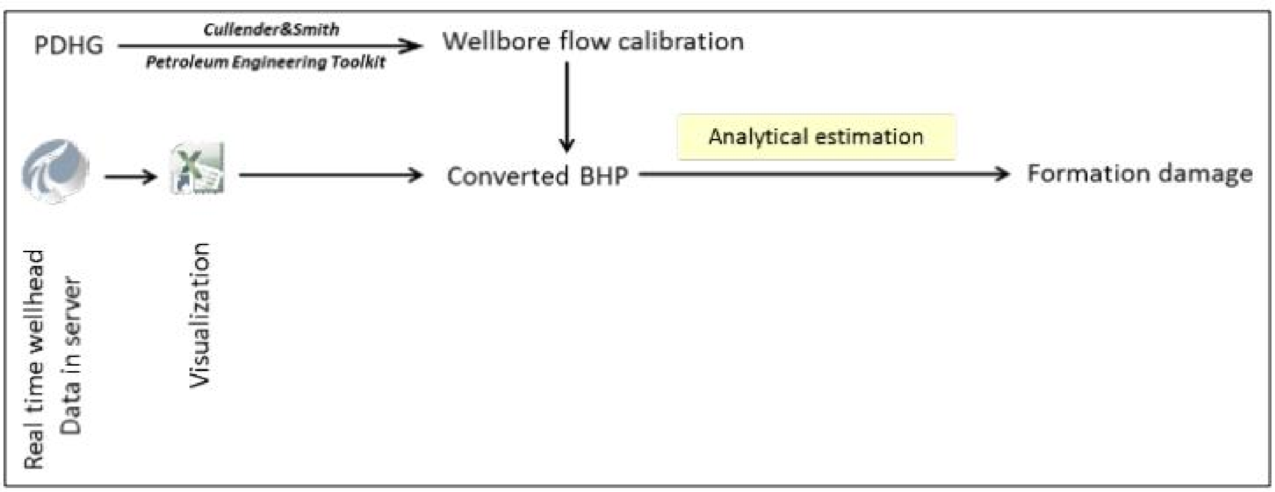


Figure 6—Data conversion and well performance evaluation model.

Note that skin, as normally used in the oil and gas development, is defined as the level of formation damage; the higher the value of skin, the more the formation was damaged by drilling, completion, and production activities. More specifically, several wells in this field development were identified with formation damage, whereas the others showed gradual cleaning (skin is reaching zero or even negative). More benefits from the usage of this analytical model are shared below.

Decision Analysis

It is hard to overstate the importance of integrating reservoir surveillance together with performance forecast, production optimization and field development. Different engineering tools such as production optimization and reservoir simulation are also being used to help understanding the reservoir. Meanwhile, cross-functional teams such as operations, geophysics, economics and planning are also involved when making any decision of field development (Thakur 1990).

What we learned from reservoir surveillance, such as reservoir connection, formation damage, and OGIP/reserves of each well should be treated as input for any field development decision, such as infill drilling, stimulation, and expansion.

Implementation

Besides of reliably and economically executing an optimization project, Health, Safety and Environment (HSE) is always the top criteria in performing any development plan at this gas project. Therefore, any decision will be evaluated together with its value creation.

- When opportunities are identified, and evaluated, cross-functional team such as subsurface, facilities, operations, commercial and planning, economics should be involved.
- With clearly and transparently defined goals, several doable and practical alternatives can be evaluated. The project scope can be varied, as small as stimulating a well, or as big as project scope expansion. Reservoir surveillance always provides the first and invaluable information in selecting the best alternatives.
- After determining the preferred alternative, a detailed plan will be developed. At this phase, reservoir surveillance doesn't go alone. Simulation, geophysics, operation, HSE, etc. are involved to develop the detailed project plan.

After implementation, a lookback is normally conducted to see the performance and if there are any lessons learned or best practices. In terms of reservoir surveillance, input data quality and ensuring operations fully followed the procedure are the keys.

Case study: Benefits of Reservoir Surveillance and Production Optimization

Several key uncertainties were identified before First Gas from the project, mainly reservoir connectivity and other characteristics, and well deliverability. Real time data were collected before, during, and after first gas in an effort to narrow these uncertainties.

Interference Test for Compartmentalization. Recognition of compartmentalization is especially critical to help identify signposts of both low side and high side for the real-time optimization decision. Interference test between these wells provided relevant data for well connectivity and so, reservoir compartmentalization.

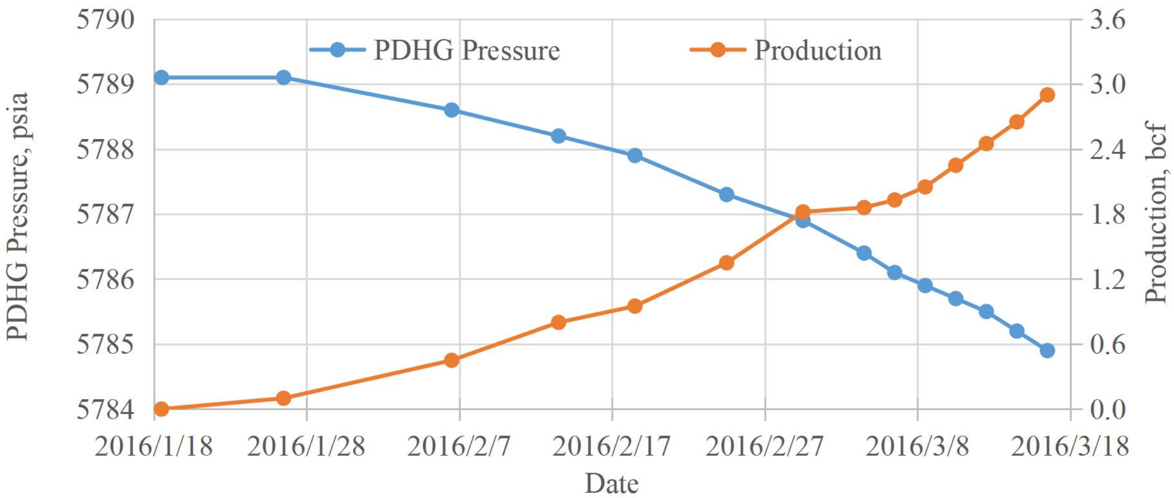


Figure 7—Pressure response on PDHG when the other well pad started production.

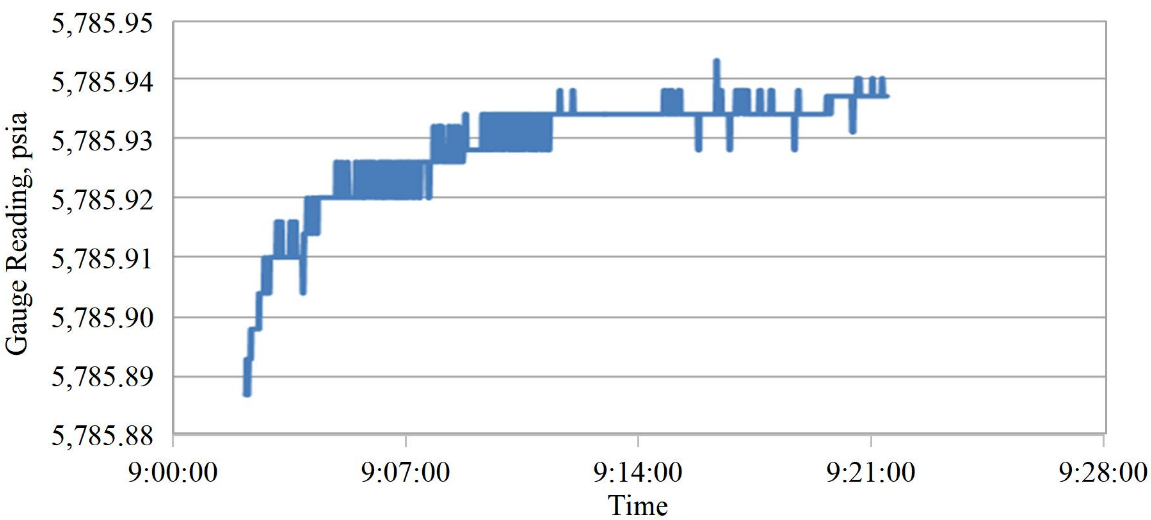
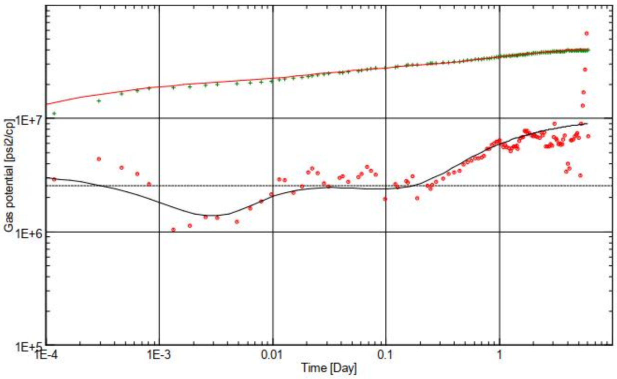


Figure 8—Pressure response on PDHG days after the other well pad stopped production.

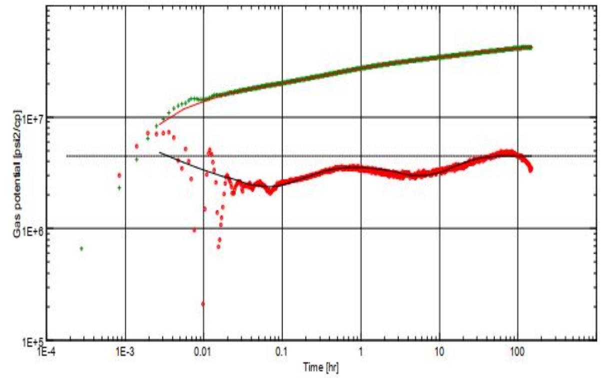
To support this test, production started from one well pad and gradually ramped up. Just days after that, pressure drop was observed from PDHG installed on the well at another well pad. Not only pressure drop, the lateral communication was also confirmed by plant shut down that PDHG reading increased accordingly. This is clearly shown in **Figures 7** and **8**.

Well Test Analysis for Formation Damage Evaluation. Understanding well skin damage is critical for estimating the well deliverability and making any intervention decision. After days of trial and calibration, the wellhead pressure can be consistently converted into downhole pressure with minimal error. In most cases with stable production, the gap between converted bottom-hole pressure and PDHG data is within 10 psi.

To understand more about the value of pressure conversion, a case study has been done at Well A where we have both the surface and downhole pressure data. **Figure 9a** shows the test interpretation using the pressure conversion data and **Figure 9b** from the PDHG data. Note that the data from surface gauges results in similar reservoir parameters such as skin and permeability. Also, with multiplewell tests done at different times, reservoir characteristics (e.g., fractures and no flow boundaries) can be characterized and understood.



(a)



(b)

Figure 9—Pressure transient analysis (PTA). (a)PTA with converted data. (b) PTA with PDHG data.

The biggest benefit from this pressure conversion work (from data surveillance) could be highlighted at Well B, when consistently poor performance indicated a large formation damage (i.e., skin factor greater than +30). The decision was made to acidize this well. From **Figure 10**, it can be seen that the deliverability improved after stimulation and the skin factor reduced sharply.

In brief, the timely evaluation of formation damage from real time data is used to help understand well performance change during liquid unloading and ramp-up period. This helps guide well intervention decisions to optimize field development.

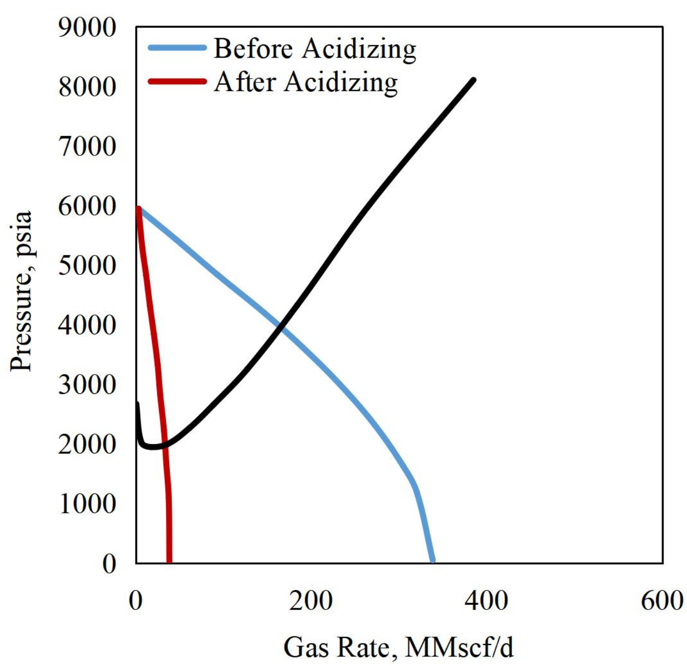


Figure 10—Well

Well Performance Monitoring and Update. With production, it is critical to monitor well performance changes. Since there is little spare capacity in the whole production system, one failed well will lead to production loss.

Wellhead and PDHG data are monitored real time to see if there are any changes. As we see in this field, most producers get better performance after ramp-up due to cleaning of the near wellbore area damage by continued big gas flow (**Figure 11**).

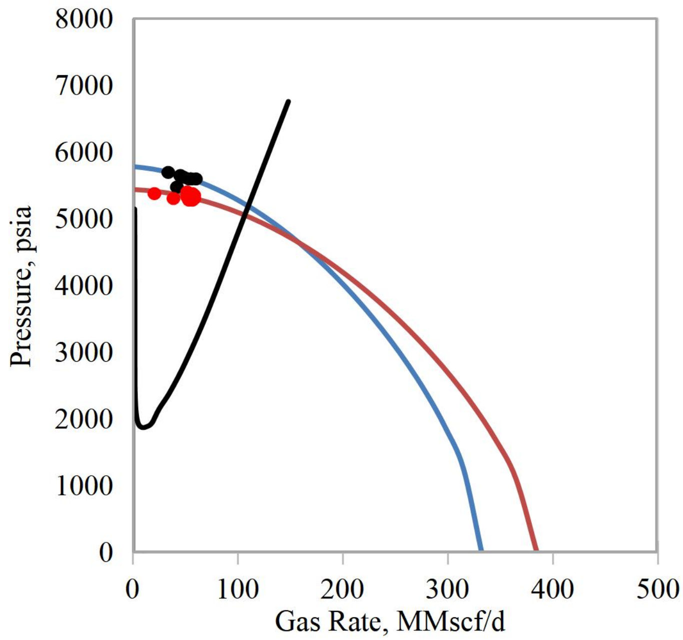


Figure 11—Well production improvement monitoring.

Tracking and plotting the well performance variance helps optimize production from each well. Production optimization aims to sustain production, manage reservoir depletion and extend plateau production by allocating production target to each well. To perform this, the 3-step process starts with real time data collection, then, frequent well tests with the orifice meters to validate flow rate and update gas compositions; and finally, update well performance curve with above petroleum engineering tool kit to determine an optimal production rate target for each well.

Reservoir Performance Monitoring and Update. Well performance monitoring is the first step for reservoir performance monitoring. OGIP cannot be changed by any artificial lift or stimulation. However, a recovery factor can be improved with good reservoir performance monitoring.

In this case, well shut-ins when appropriate provide invaluable information for the field development evaluation. Well shut-ins can be managed during planned maintenance such as turnaround and pigging to minimize production loss. By estimating the change of reservoir pressure, the speed of reservoir depletion and OGIP can be derived.

The ultimate goal of all above surveillance techniques is to maximize plateau of the gas field, optimize infill drilling time, and determine well location and well count. With the well performance, deep understanding of reservoir characteristics, and reservoir depletion estimate, the value of field development can be effectively maximized, illustrated in **Figure 12**.

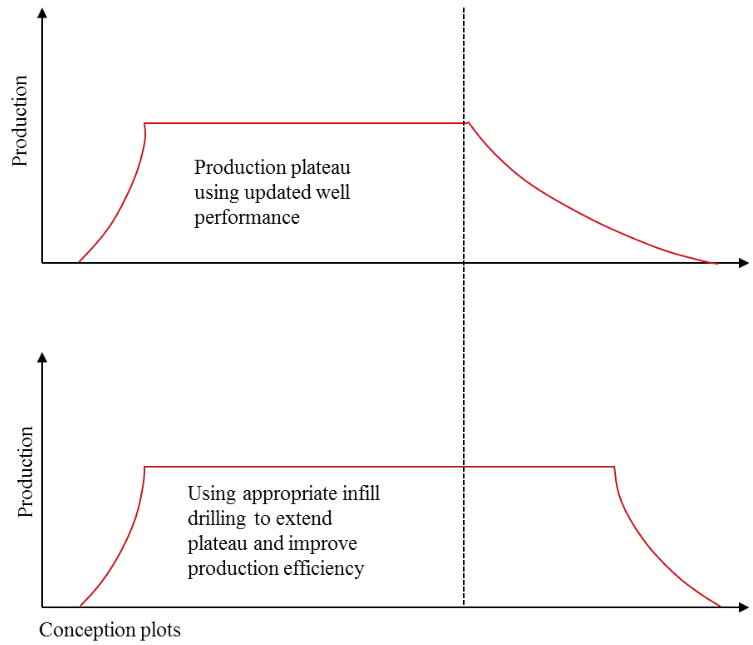


Figure 12—Timely decision of drilling for field development optimization.

Reservoir Surveillance in Long Run

Surveillance conducted after the plant has achieved full throughput is very important, particularly when all wells are producing near maximum capability and stabilized operating rates. If it can be managed properly, it will provide invaluable information to achieve the critical subsurface objectives.

- Surveillance data to achieve the above objectives are required as frequent as practical, and with the workflow and analytical model set up, routine well shut-in data can prove a very valuable sources of reservoir information.
- Well shut-in pressure data are critical to accurately estimate well OGIP, and therefore proven reserves by well. This in turn is the most reliable method to confirm the extent of reservoir compartmentalization, and, in severe instances of such, enables an assessment of undrilled resource which is critical for determining the feasibility of further development.
- Except for well shut-in, other common surveillance methods at gas field development include deliverability testing, transient pressure analysis and production logging, fluid sampling. Selecting the most appropriate surveillance methods to acquire the most valuable information at different phases of field development is important for all reservoir engineers when involved in development decision making.

Conclusions

Advancement of computer science and information technology is a key driver to support the oil and gas industry and makes the reservoir surveillance effort more effective and efficient. This paper detailed several examples of how real- time data, new technologies, and standardized processes could be used to support interpretation and analyses for decision making. Specific cases from well performance analysis (e.g., formation damage) to pressure transient analysis (e.g., interference test for reservoir connectivity and PTA for reservoir characteristics), and eventually, to OGIP and reserves evaluation are shared to demonstrate how the new information and techniques can be used to support production optimization and a long-term development value maximization.

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Conflicts of Interest

The author(s) declare that they have no conflicting interests.

Nomenclature

PDHG = Permanent Downhole Gauge

OGIP = Original Gas In Place

SITP = Shut In Tubing Pressure

H_2S = Hydrogen Sulphide

FDP = Field Development Plan

PVT = Pressure Temperature Volume

IPR = Inflow Performance Relationship

PTA = Pressure Transient Analysis

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